ENGINEERING EARTH OBSERVING DATA FOR USE IN A PUBLIC HEALTH SURVEILLANCE SYSTEM

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ABSTRACT:

Public health concerns are growing as the Earth's environment is changing due to climate variability. Dust storms so large that they can be viewed from satellite imagery can be seen moving across Asia, over the Pacific Ocean, and into North America. Similarly, dust picked up by prevailing winds over North Africa is carried westward across the Atlantic toward the Caribbean. The fine particulate matter ($PM_{2.5}$) in these storms poses serious health threats for persons with respiratory diseases such as asthma. This is a global concern, one that has captured the attention of several international organizations including the World Health Organization (WHO), the International Society for Disease Surveillance (ISDS), and the Group on Earth Observations (GEO). While the medical community recognizes the adverse effects $PM_{2.5}$ can have in patients with respiratory conditions, they are lacking reliable information for forecasting dust storms so that public alerts can be issued. Respiratory diseases and syndromes typically are monitored by surveillance systems consisting of electronic databases in which data are entered and accessed by doctors and clinicians. But these systems do not provide enough information for issuing public warnings in advance of a storm. The University of New Mexico and the University of Arizona are partnering in a project via a cooperative agreement with NASA to enhance the decision-making capabilities of public health officials for issuing early alerts concerning potentially dangerous dust storms. The Public Health Applications in Remote Sensing (PHAiRS) project has four primary goals: (a) select an atmospheric dust model and baseline its use and forecasting performance in the Southwest United States; (b) assimilate satellite observations into the base-lined dust model and quantify the value added to this model by incorporating satellite observations products; (c) partner with health care scientists and public health authorities to verify and validate the Earth system science coupling mechanisms between environmental health and public health; and (d) benchmark quantitatively the scientific and societal benefits of this engineering effort. PHAiRS is using a dust forecast model (DREAM) developed at the University of Malta that has been adapted to conditions over the Southwest United States. Static parameters are being replaced with more dynamic parameters derived from Earth observation data to improve the model's output, and thereby the information needed to issue public warnings. Using web-mapping technologies, this information is presented to public health officials in a visual format so that they can "see" the extent and severity of an imminent event. These improvements are being verified and validated using data from a network of air monitoring ground stations. Results are documented and benchmarks are recorded for each step in the process. This paper describes the scope of the PHAiRS project, reports on its status, and demonstrates a prototype mapping client for visualizing and analyzing output from the DREAM dust forecasting model.

1. INTRODUCTION

Public health concerns are growing as the Earth's environment is changing due to climate variability and climate change. Dust storms so large that they can be viewed from satellite imagery can be seen moving across Asia, over the Pacific Ocean, and into North America. Similarly, dust picked up by prevailing winds over North Africa is carried westward across the Atlantic toward the Caribbean. Saharan dust also travels across the Mediterranean affecting large parts of Europe (Pérez, et al., 2006a). The fine particulate matter ($PM_{2.5}$) in these storms poses serious health threats for persons with respiratory diseases such as asthma. While the medical community recognizes the adverse effects $PM_{2.5}$ can have in patients with respiratory conditions, they are lacking reliable information for forecasting dust storms so that public alerts can be issued. Respiratory diseases and syndromes typically are monitored by surveillance systems consisting of electronic databases in which data are entered and accessed by doctors and clinicians. But these systems do not provide enough information for issuing public warnings in advance of a storm.

For environmentally induced medical emergencies such as dust storms and smoke plumes, global and regional Earth observation data offer a wealth of information that can benefit public health officials whose responsibility is to be on the alert for events that could adversely affect populations at risk. By marrying Earth science technology and modelling with medical knowledge and practice, a potentially powerful resource could be available to public health decision makers. There is growing interest in disease surveillance systems covering a wide array of chronic, infectious diseases and medical conditions that allow health care professionals to query databases for similar cases reported locally, regionally, and globally. None of these databases, however, have used Earth observation data or climate models to enhance the system.

The Universities of New Mexico and Arizona are partnering in a project via a cooperative agreement with NASA to enhance decision-making capabilities of public health officials by assimilating Earth observation data into a regional dust forecasting model. The model output, in turn, is used to provide visualizations and analytical data that can be incorporated into existing disease surveillance systems. This paper describes the methodology and initial results of the 5-year project, now in its third year.

2. PHAIRS

The Public Health Applications in Remote Sensing (PHAiRS) project has several primary goals. First, it has adapted the Dust Regional Atmospheric Model (DREAM) to conditions in the Southwest United States. Second, Earth observation data have been assimilated into the model to improve the model’s output. Third, improvements to the model have been verified and validated against *in-situ* air quality data. These improvements have been benchmarked through documentation. Fourth, a web-enabled mapping client has been developed to deliver information to existing decision support systems. Public health authorities in the Southwest are active participants in the project and, as the primary stakeholders, soon will beta-test the project’s products and help assess relationships between dust episodes and increased respiratory complaints. The importance of this project is that it links public health communities with Earth observations of thoracic and pulmonary dust.

2.1 Dust Atmospheric Regional Model

DREAM is an online desert dust cycle modelling system designed to simulate and/or predict the atmospheric cycle of mineral dust aerosol (Nickovic et al., 2001). It was developed under the National Centers for Environmental Prediction (NCEP)/Eta model framework (Janjic, 1984; Mesinger et al., 1988; Janjic, 1994). Based on an Eulerian modelling approach, it consists of two major parts: one that simulates the atmosphere and another that models the dust cycle. The climatological data driving DREAM require a model domain larger than the Southwest United States project domain. Figure 1 shows the extent of the model domain (yellow box) and the project area (red box).

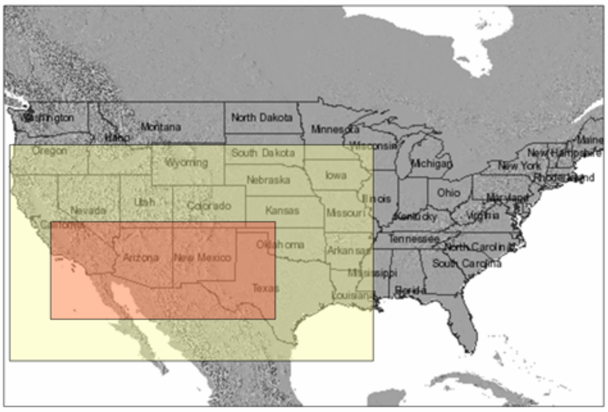

Figure 1. Extent of modelling domain and project area.

2.1.1 Atmospheric Modelling System: The atmospheric modelling system is the SKIRON forecasting system, based on the 1997 version of the NCEP/Eta regional atmospheric model. It has 32 model layers extending from the Earth’s surface to 100 hPa in the vertical. The atmospheric component is based on large-scale numerical solutions controlled by conservation of integral properties. It uses a non-linear horizontal advection numerical scheme that preserves energy and squared vorticity and controls non-linear energy cascade (Morain and Sprigg, 2005). With the Eta vertical coordinate, which generates quasi-horizontal model levels, topography is represented by step-like elements (Mesinger et al., 1988). Horizontally, the model uses a semi-staggered Arakawa E grid (Arakawa and Lamb, 1977).

2.1.2 Dust Concentration Module: The second module introduces several improvements to DREAM. First, a new scheme for dust production is applied on the basis of a more sophisticated parameterization of the dust mobilization process. Second, a four-particle bin instead of one-particle size scheme has been implemented to simulate more accurately the size-dependent processes. Third, it uses a higher resolution topography, soil, and vegetation-type data than those used in the original NCEP/Eta model. Fourth, a new parameterization scheme for dry deposition has been applied. The dust cycle module simulates dust production, dust advection and turbulent diffusion, lateral diffusion, and dry and wet deposition (Nickovic et al., 2001; Shao et al., 1993; Georgi, 1986). Initial and boundary conditions were generated using data from the European Center for Medium-Range Weather Forecast (ECMWF) and climatological values of sea surface temperature (Yin et al., 2005).

These modules include effects of the particle size distribution on aerosol dispersion. Desert dust sources are based on land cover types. Physical properties of dust particles from these dust source areas are associated with clay, silt, and sand components of the soil texture types. These dust particles are modelled in four bins with particle size radii of 0-3.4μm, 3.4-12μm, 12-28μm, and over 28μm (Pérez et al., 2006b). A critical element of the dust model is the treatment of sourcing terms in the dust concentration continuity equation which simulates all major processes of the atmospheric dust cycle. Failure to adequately simulate/predict the production phase of the dust cycle results in incorrect representation of all other dust processes in the model.

2.1.3 Surface Parameters: DREAM employs three high resolution static surface parameters, including, soil types converted into texture classes, vegetation cover, and elevation with spatial resolutions of 2x2 minutes, 10 minutes, and 1x1 km, respectively. One hundred thirty-four (134) categories of soil data obtained from the Food and Agriculture Organization (FAO)/United Nations Education, Scientific and Cultural Organization (UNESCO) were used for the basic soil texture parameter. The clay/sand/silt compositions of soil texture categories, which determine the physical properties of the wind-blown dust, were aggregated into nine (9) Zobler soil categories (Zobler, 1986), and then converted into Cosby soil categories (Cosby et al., 1984). The vegetation parameter uses the Olson World Ecosystems (OWE) land cover classification scheme which contains fifty-nine (59) land cover categories. The global data set GTOPO-30 is used for the elevation parameter in DREAM.

The entire dust modelling system is easily configurable and adaptable to any location on the Earth, spanning domains of almost any size. Its horizontal resolution can vary from 100 km to approximately 4 km. Performance of the system has been tested for different dust storm episodes in various places around the world and at several resolutions using gridded analysis or forecasting fields from ECMWF and NCEP. The system has been in operational use during the last two years, providing 72 hour forecasts for the Mediterranean region. Results are available on the Internet (http://www.icod.org.mt and http://forecast.uoa,gr).

2.2 Assimilating Earth Observation Data

A key element of the PHAiRS project is to assess improvements of DREAM’s performance by replacing several parameters with high-resolution Earth observation (EO) data. These replacement data are “assimilated” into DREAM; that is their digital pixel values are replacing selected static parameters so that the EO data become part of the model without changing its intended purpose. DREAM, like many Earth system models, was developed without consideration for using remotely sensed data as input parameters. This presents data compatibility issues for modellers who assimilate such data into these models. Some of these issues are: (a) measurement units, (b) x,y,z resolution, (c) temporal frequency, (d) map projection and ease of re-projection to fit model requirements, (e) file formats, (f) error and error propagation, and (g) validity of the replacement data in terms of enhancing or improving model outputs (Morain, 2006a). Attributes of existing model inputs first must be compared to possible EO replacements to determine compatibility. Then the process is iterated with different data and resolutions to measure improvements in DREAM’s output (Morain, 2006b).

2.3 Verification and Validation

An obvious test of the dust model forecasts is to see how well critical meteorological variables were predicted. There are two fundamental reasons for making this comparison between the observed and model-generated patterns. First, if the high resolution dust model, embedded in the operational initial field analyses and employing the basic weather forecast model of the National Weather Service, accurately predicts the meteorology, then project scientists have some confidence that the dust component of the forecast is also realistic. Second, if the dust forecasts do not match the available dust measurements, it may be possible to diagnose the reasons why. Does the fault lie within the model meteorology, or within the model treatment of dust entrainment and dispersal processes?

Verification and validation of DREAM’s performance is measured against *in-situ* data collected by a network of air quality ground stations throughout west Texas and New Mexico. For a dust event in December 2003, the DREAM-modelled meteorological fields were evaluated against measurements and analysis products from 95 surface synoptic sites, 663 surface Meteorological Aerodrome Report (METAR) sites, and 77 upper-air radiosonde sites. The modelled dust field patterns and dust concentrations were compared with satellite images, measured visibility distributions, and the surface $PM_{2.5}$ and PM_{10} observations obtained by the Texas Commission on Environmental Quality and the U.S. Environmental Protection Agency (EPA) Air Quality System (AQS). Graphical measures, such as pattern comparison, site against site time series, vertical profile comparison, and statistical metrics, were used (Morain and Sprigg, 2005).

2.4 Initial Results

Model comparisons before EO data were assimilated showed that modelled meteorological fields, both surface and 500 hPa level, were in agreement with measured observations (Morain and Sprigg, 2005). The modelled vertical profiles of wind speed, wind direction, temperature, and specific humidity matched the observed profiles. Statistical evaluation of the modelled and observed surface winds and temperatures showed that the model performed reasonably well in simulating the measured values. The modelled dust distributions were comparable with the satellite-observed dust clouds and the reduced visibility patterns. However, there are discrepancies between the details of the modelled and observed dust cloud distributions. The highest dust concentration areas did not coincide with the most reduced visibility areas. For more information on these initial results see the paper by Morain, (2006b) in these proceedings.

3. WEB-BASED MAPPING CLIENT

The third component of the PHAiRS project is a web-based mapping client that brings information, products, and analysis capabilities to desk top decision support systems (DSS) of public health officials. This user community must make decisions regarding health risks to persons with respiratory ailments based on the best available data. Many of these decision makers are beginning to use electronic disease surveillance systems that provide information from a network of databases. Very few of these systems provide information in a web-mapping environment that has visualization and analysis capabilities.

The PHAiRS project has developed a client user interface using a variety of programming languages and standards that provides users with a simple, easy-to-navigate tool set (Budge et al., 2006). Figure 2 illustrates the home screen of the interface. Tools include: (1) geographic extent; (2) layer selection and legend interface; (3) date and time selections for time-sensitive layers; and (4) active analytical tools.

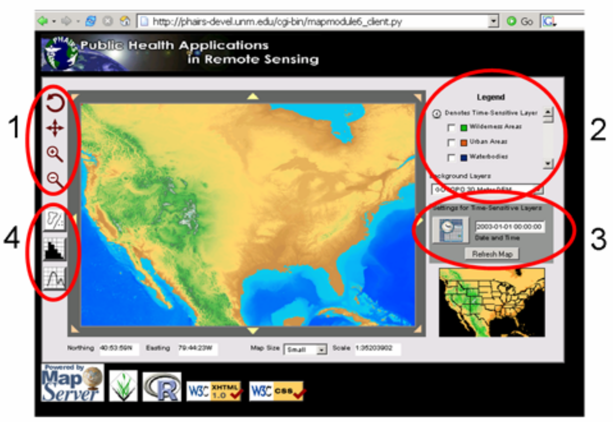

Figure 2. User client interface tools.

One of the features of the client interface is a time series animation which is a web-based viewer representing a specific date range of data (Figure 3.). On the left is a regional map and on the right is the point-specific time-series plot. As the animation progresses on the image the red bar in the plot marks the corresponding data. The screen can be frozen and captured as a portable document format (pdf) file.

The analytical function permits users to select, onscreen, a geographic extent represented by an irregular polygon, such as a political boundary. The user may request a density plot of a dust storm for that polygon. The underlying software performs a geostatistical analysis and presents the results as a graph on the screen (Figure 4).

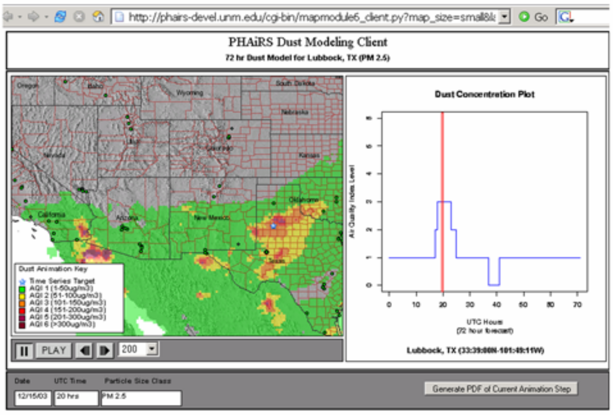

Figure 3. Animation viewer screen.

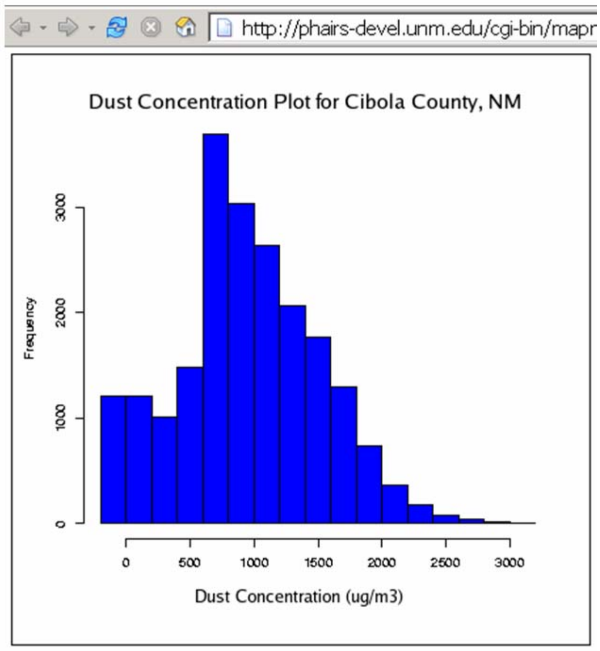

Figure 4. Density plot of dust concentration.

The increased capacity of the underlying programs facilitates delivering high-end capabilities to public health DSS applications without developers writing the often complex code necessary to generate the returned products. Users may link directly to the client interface service or integrate the service into their DSSs.

4. ENGAGING THE USER COMMUNITY

A key element of the PHAiRS project is active participation by public health decision makers in Arizona, New Mexico, and Texas. These stakeholders provide input and feedback in each of the project’s stages, helping to guide development of the tools and output products that are most useful to them. They attend regular project meetings and are an integral part of the process of designing a dust forecast module that will enhance their existing DSSs. These partners will be the beta-testers for PHAiRS’ prototype products and toolsets. Users outside of the medical community also find promise for the dust forecasting potential of DREAM’s output. The National Oceanic and Atmospheric Administration (NOAA), for example, is interested in developing health impact statements related to dust issues that potentially could be delivered on television by professional broadcast meteorologists. They see the capabilities and output from DREAM as a step toward this goal.

5. CONCLUSIONS

The goals and objectives of PHAiRS described are exciting because they represent a new frontier for both the developers and modellers of PHAiRS and public health decision makers. The research is innovative in that it assimilates Earth observation data from satellite platforms into established atmospheric models to improve model performance and output. Also innovative is application of the output products to existing public health decision support systems via an interactive web-mapping system. While the technologies employed in this project are not necessarily new, it is the way in which they are used that makes this project unique.

6. REFERENCES

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