Public Health Applications in Remote Sensing

Initial Benchmark Report For Public Health

(February 2004-September 2005)

Agreement NNSO4AA19A

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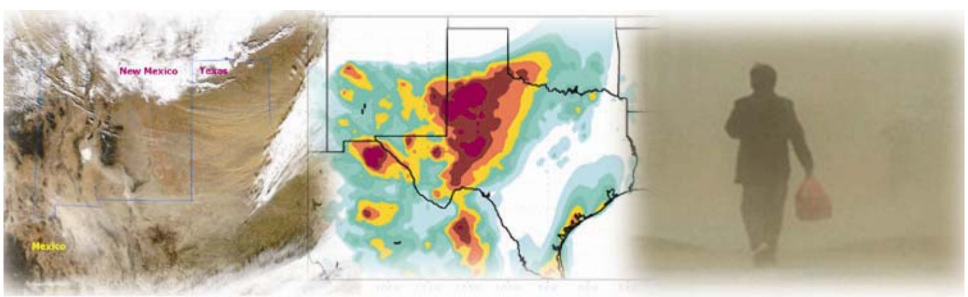

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Executive Summary

Many challenges in Earth system science require not only integrating complex physical processes into system models, but also coupling environmental biogeochemical and chemical phenomena. Human health responses are among the most important of these challenges. The challenge for the next generation of modelers will be to form teams that partner members from the biogeophysical realm with those from the medical realm to assess quickly changing and highly vulnerable situations.

The National Need

Coupling biogeochemical and dynamical processes that lift dust into the atmosphere with the ecology of airborne pathogens will allow epidemiologists to better understand the medical consequences of dust transport across regions and continents. Through Internet- and Intranet-accessible syndromic surveillance and reporting systems, medical professionals someday will better diagnose individual patient symptoms in a geospatial context for early warning of disease outbreaks and deteriorating environmental conditions that put populations at risk. The role dust storms play in human health is an important part of Earth system science that has fundamental socioeconomic and political importance.

The Public Health Applications in Remote Sensing (PHAiRS) project is a first step in this direction. This initial benchmark Report shows why this is so, and why guarded optimism for a significant contribution to public health services is warranted.

When the Operational National Weather Service forecast model is modified to accommodate a dust entrainment process (i.e., the Dust Regional Atmospheric Model (DREAM)), meteorological variables are well simulated and predicted, both before and after experimental satellite observations are assimilated.

The Project

PHAiRS is a 5-year project that began February 2, 2004 (NASA award NNS04AA19A). It is an element of NASA's Public Health Application initiative focused on atmospheric dust as an environmental factor affecting respiratory diseases. Its geographic focus is on populations living in the Southwest, and its importance is that it links the public health communities described in Section 1 of this benchmark with satellite observations of widespread airborne thoracic dust.

The project has three thrusts moving along a parallel front. The first thrust focuses on assimilating satellite observations from MODIS Terra and other sources into the Dust Regional Atmospheric Model (DREAM). DREAM, in turn, is driven by the National Centers for Environmental Prediction (NCEP)/Eta weather forecasting model. The aim of this effort is to: (a) verify that advanced satellite image data from current research sensors can replace model parameters from traditional non-satellite sources, or from earlier (coarser resolution) satellite sources; and, (b) validate that parameter replacements lead to more reliable model forecasts of dust episodes.

The second thrust focuses on optimizing DREAM model outputs by iterating model inputs with a variety of satellite products and assessing incremental improvements to the Rapid Syndrome Validation Project (RSVP). The questions of greatest interest to the research team are: (a) how well and with what degree of sensitivity can NCEP/Eta and DREAM forecast dust that will be lifted from a landscape? (b) how well can these models predict the speed and direction of moving dust clouds? (c) can medically sound evidence be generated that couples dust episodes to documented respiratory health responses at the population level? and, (d) can areas affected by dust clouds be forecast in a timely fashion to alert health officials and populations at risk?

The third thrust involves establishing collaborative relations with public health authorities to determine whether there are statistically valid relationships between dust episodes and increased respiratory complaints. This is a difficult effort in the United States because public health authorities are distributed throughout all levels of government (city, county, state, and federal), and because standardized record keeping is not mandatory for all types of records within or between these levels. Furthermore, because of patient confidentiality, it is impossible to know exactly the environmental circumstances or the geospatial coordinates behind any given record. These circumstances have led developers of RSVP to design a decision support system that encourages public health officials, air quality monitoring offices, doctors, and clinicians to coordinate their information electronically, and in appropriate ways to protect patient confidentiality. The system should also allow group attributes

to emerge in such a geospatially explicit way that populations at risk can be forewarned.

These three thrusts are interactive. For effective application of satellite observations to public health, physicians and clinicians need to be motivated to report non-confidential patient information in such a way that emerging spatial patterns at a broader scale can be recognized by public health and safety offices early in the development of an episode. For this to happen in a timely fashion, satellite-based dust forecast models must be recognized as a reliable source of information to issue medical alerts.

Ultimately, the goal of the project is to contribute to an improved public health decision support system that can evolve toward operational status for the next generation of space-based sensing. The National Polar-orbiting Environmental Satellite System (NPOESS) is scheduled for launch in the 2010 timeframe. It will consist of several platforms carrying operational versions of NASA's current experimental sensors. It is now time to build the scientific and technological underpinnings of these near-future capabilities, and to test them with appropriate public health user communities.

Results to Date

From comparisons of dust model results to measurements and comparison between model results before and after NASA data assimilation, the sea level pressure, 500 hPa potential height and temperature patterns of before and after NASA data model results matched the measurements well. The differences between the two sets of the model results occurred in sea level pressure fields, although they did not affect the overall pattern. Significantly, the upper-air fields were *not* affected by the MODIS land cover data input.

Comparisons also showed that modeled meteorological fields, both surface and 500 hPa level, were in agreement with measured observations. The modeled vertical profiles of wind speed, wind direction, temperature, and specific humidity matched the observed profiles. Statistical evaluation of the modeled and observed surface winds and temperatures showed the model performed reasonably well in reproducing the measured values.

For model evaluation, significant gains were accomplished with the addition of MOD12 data to the DREAM model. The peak hour correlation was least affected by the change. However major gains were made in modeling the magnitude and duration of near-surface high dust concentration. The enhanced model predicted accurately the order of magnitude of the dust storm event at almost all locations in the model domain. The dust episode in Lubbock, TX was also accurately modeled after assimilating NASA data. The improved model indicates no false alarms in either test case. This result begins to illustrate the potential use of the DREAM model as a tool for the medical community and local government to accurately predict unhealthy dust levels in the desert southwestern United States.

What remains to be demonstrated in the remaining years of this project is (a) the direct coupling of specific dust episodes with health response statistics; and (b) that there will be continued improvements in DREAM's model performance with each incremental replacement of its parameters with NASA-generated data sets.

Initial Benchmark

Given the promising results obtained from the DREAM baselining model runs and the MOD12 data set replacement runs, the PHAiRS project team is well satisfied that Earth science satellite observations can improve dust episode forecasting significantly in the southwestern U.S. The team and its public health partners are very encouraged that these improvements will lead to more timely forecasts that will enable public health officials issue early warning alerts to populations at risk based on coupled evidence from coincident syndromic surveillance.

From the PHAiRS team

Table 1 lists the performance statistics for modeled surface variables. The biggest differences between results from before and after MOD12 data assimilation are for 2m temperature. The agreement index after NASA data assimilation was 0.95, in comparison with 0.71 obtained using the original DREAM parameters. This is a significant model improvement.

Table 1. Performance statistics of modeled surface wind and temperature.

Metrics	Wind Speed	Wind Direction (degree)	Temp (K)
Agreement Index (DREAM only)	0.74	0.74	0.71
Agreement Index (DREAM + MOD12)	0.75	0.76	0.95

From RSVP/SYRIS developers

The new version of SYRIS in development contains extensive modeling and disease prediction tools, including the environmental disease. The latter is especially important in daily clinical practice (in both veterinary and human disease) as dust particulates (PM2.5), nitrous and sulfur oxides and ozone clearly increase the acute incidence of lung disease and respiratory symptoms in a given area. Distinguishing such environmental illness from infectious disease is a very difficult clinical challenge. Thus, atmospheric data combined with a dust model may be very useful for clinicians in their daily practices. Indeed, such predictive models may enable emergency rooms and clinics to prepare for an increase in patient visits or may enable public health officials and physicians to contact patients who may be advised to change medication or behavior in anticipation of an environmentally induced exacerbation of chronic lung or cardiac disease.

We anticipate that NASA's REASoN program will provide SYRIS with timely, extraordinarily useful environmental data that can be directly integrated into the SYRIS communications and analysis environment, and hope to have this important augmentation to SYRIS' capability implemented in 2006.

From public health users

Arizona Department of Health Services

As a syndromic surveillance epidemiologist, I am always searching for useful sources of data to track syndrome illnesses that I can add to my program. One of the problems with disease surveillance in general is that we do not know when and where events are going to take place and therefore we are reactive, not proactive. Another problem specific to syndromic surveillance is that with the non-traditional data sources commonly used in syndromic surveillance there is no common user interface. We must use many different programs and software to visualize and analyze the data. Based on the demo we at Arizona Department of Health Services were shown, the Dust Regional Atmospheric Model has the potential to add to existing data sources for syndromic surveillance. First, the dust storm model can help predict when and where respiratory illnesses are potentially going to increase, which is a much needed addition to disease surveillance tools. Being forewarned about the possibility of dust storm-related illnesses will help health officials better cope with the resulting illnesses. Second, the model seems simplistic enough to integrate into existing programs instead of requiring its own user interface and program. I understand that it will be possible to format this model to be added as an extra button/tab built into existing visualization systems. This aspect alone will increase the utility of the model for sydromic surveillance. If the DREAM program can help us prepare for events and be integrated into current program operations with such ease, it will be a very welcome and useful tool.

Pima County Arizona

The visualization of the data was an exciting way to see the numbers on a page come to life. It was especially intriguing to watch changes in the dust plume over time and from different perspectives. Our department is looking forward to continued coordination with the U of A and others to develop a method of forecasting airborne dust events to protect the many individuals who are at risk in our community. Wayne offered further comments: *The DREAM model visualization was quite interesting. It provided a virtual look at the formation of a dust event with indications of the originating area. I believe with some modifications it might prove useful in pinpointing sources of dust events which could prove useful in remediation. It would be more useful if the values for dust content, elevation, and wind speed could somehow be indicated in the visualization. Overall, I think it is a good beginning.*

From NOAA

Sprigg: *If you or other colleagues are interested, I would love to have your involvement in developing health impact statements related to dust issues that potentially could be delivered on the air by professional broadcast meteorologists and/or warning coordination meteorologists. I have been working with another public health group affiliated with Tufts University and University of Colorado focused on increasing physical activity according to weather. Looking forward to working together with you.*

From City of Lubbock Health Department

RSVP was the only active SBDSS available for comparison to the passive systems. RSVP1 defined six common syndromes worded in the daily parlance of medicine and public health, and further provided an electronic interface that operated on virtually any computer connected to the Internet. It

[1] Zelicoff A, Brillman J, Forslund DW, George JE, Zink S, Koenig S, et al. 2001. The Rapid Syndrome Validation Project (RSVP). Albuquerque, NM: Sandia National Laboratories;

also provided primitive, but useful geographic mapping tools.

Their experience with RSVP was generally positive. Physician compliance was high (contrary to the popular, but incorrect belief that physicians will not take time to enter cases) because the number of cases of seriously ill patients who fit into one of the syndrome categories was, on average, a case per month per physician (except during large epidemics). Further, RSVP provided information of immediate clinical importance to physicians thus increasing their cost-effectiveness in practice. Finally, on rare occasions, RSVP enabled public health officials to contact doctors within minutes of a case report when the data suggested unusually worrisome symptoms that might require immediate contact investigation. Thus, RSVP cut down the time from initiation of contact investigation from days to mere minutes.

Table of Contents

Public Health Applications in Remote Sensing Initial Benchmark Report

Challenges in Public Health

Respiratory diseases and syndromes are becoming more widely recognized as important indices of population health. Medical specialists, led by the American College of Allergy and Immunology, and the newly formed Society for Advanced Disease Surveillance are encouraging attention to the etiology of these diseases.

Surveillance

Every day in the public health community bulletins are posted on the World-Wide Web related to health issues and infectious diseases around the world. Mortalities from Hantavirus, avian flu, asthma, and a host of other infectious and chronic illnesses are reported. Most of the concern focuses on containment through quarantines of animals or people, the fear of rapid global epidemics if containment fails, or the ability of public health authorities to treat sudden onset of epidemic situations. One of the grand challenges of this century will be to develop highly reliable surveillance and monitoring systems that ensure detection and recording of individual cases even in remote parts of the world. Among these grand challenges are: (a) developing technologies that permit quantitative assessment of population health status, and (b) developing technologies that allow assessment of individuals for multiple conditions or pathogens at point-of-care (Varmus et al., 2003). The stimulus for these developments is compelling because emerging infectious diseases (EIDs) in the 21st Century are overwhelmingly centered on the densely populated temperate zones of the Northern Hemisphere. In earlier centuries, EIDs were associated with the equatorial zone, especially tropical humid regions (Binder et al., 1999; Fauci et al., 2005). The fact that EIDs today can spread at the speed of international airlines underscores the need for coordinated, global surveillance and reporting systems.

Reporting

A recent article in Vaccine (Oxford et al., 2005) hypothesizes that the pandemic flu of 1918-19, which killed more than 50 million people worldwide, began at the end of WW-I in an overcrowded British base camp surrounded by livestock markets for pigs, horses, geese, ducks, and chickens. The flu virus probably jumped rapidly from avian forms to pigs and/or horses and thence to humans, and spread over the following 18 months, as millions of men returned home from the war. A related scenario has recurred in the chicken markets of Hong Kong as recently as the SARS event of 2003-4; and, many fear it is about to reoccur in Thailand, Campuchea, and Viet Nam. Detecting and reporting individual cases is essential to monitor and contain the virus, but in today's world, containment by quarantine only can be implemented by linking possible human carriers of the virus with airline passenger lists during the flight's duration. Clearly, there must be a rapid reporting system based on modern computing technology. At present, science and technology increasingly support the practice of medicine; but, appropriate technology for reporting health syndromes is only now emerging from the paper world of the 20th Century. According to Zelicoff and Bellomo (2005, page 168ff.), public health reporting systems are "exquisitely designed for failure" because they rely on doctors filling out tedious paper forms and/or relying on the instant availability of public health officials by telephone. Neither of these means of communication helps a doctor learn whether there are similar syndromes being reported nearby or whether his/her patient is in a life-threatening situation. Electronic reporting systems only have been prototyped in the past 2 to 3 years (see Centers for Disease Control and Prevention, 2005).

Environmental Forecasting

Environmental health and public health often are linked in the scientific and popular literature even though they require different scientific skill sets, technologies, and models for their study. Environmental health includes not only the health and sustainability of natural ecosystems, but the environments of built landscapes, home and building environments, and of the Earth system processes that promote or retard environmental change (Morain and Budge, 2005). To study them, one needs education in atmospheric physics and chemistry, water chemistry, geophysics, and biology. Public health is related in large measure to environmental parameters suffering degradation induced by modern economic, social, and human pressures on landscapes. To study public health, one needs medical training and an appreciation of those processes that impact environments and that, in turn, may influence populations whose health might be at risk. Using satellite-acquired data and imagery to study environmental health has many immediate attractions; however, the extension of these studies for better understanding public health patterns and outcomes lags far behind, and does not yet embrace medical communities. As the PHAiRS project has shown, it requires forging new scientific partnerships between the environmental and medical professions.

Articles appear frequently in the popular press that link space technology to environmental and public health issues. A recent example by Wright (2005) lists several human activities that cause increases in atmospheric dust episodes and the ability of dust to carry viruses, bacteria, radioactive isotopes, and pesticides that are deleterious to human health. While such articles add to the public's general appreciation of Earth system processes, they often imply higher than true levels of scientific understanding of these processes; and in some cases the authors draw premature conclusions about cause and effect relationships. Behind these popular press contributions is a body of national and international literature citing the perils of doing "business as usual" at the expense of environmental and public health. Among the noteworthy in this category is Woerden (1999).

The first principle to emerge from the 1992 United Nations Conference on Environment and Development (UN, 1992) is an early link between environmental health with public health. It states that "Human beings are at the center of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature." Ten years later at the 2002 World Summit on Sustainable Development, the Johannesburg Plan of Implementation was adopted (UN, 2004). In this Plan, paragraphs 53-57 refer specifically to human health issues. It is stated (p. 31) that "there is an urgent need to address the causes of ill health, including environmental causes, and their impact on development, and to reduce environmental health threats."

People and Pixels (Liverman et al., 1998) was among the early publications to draw humankind into the arena of satellite remote sensing. Earlier scientific literature focused on physical and natural applications in agriculture, forestry, rangeland, hydrology, and mineral exploration. After People and Pixels was published, interest migrated to people-oriented issues like food security, environmental health, public health, disasters and hazards, and to security and antiterrorism. Because of their immense humanitarian and policy implications, remote sensing and geospatial programs are moving quickly to address the consequences of global environmental changes on human health.

Many challenges in Earth system science require not only integrating complex physical processes into system models, but also coupling environmental biogeochemical and chemical phenomena that trigger human health responses. The challenge for the next generation of modelers will be to form teams that partner members from the biogeophysical realm with those from the medical realm to assess highly dangerous situations that evolve quickly.

Decision Support Systems

"The heart of the public health system [in the United States] is comprised of over 3,000 Local Health Departments. Almost 96 percent are in small cities, towns, and rural areas that serve fewer than 25,000 people. It is here that public health decisions are most likely to affect the public's health (Parsons, 1997)." These circumstances represent a powerful motivation for health departments to transition to better, faster, and cheaper ways of making decisions. At the local level, which is where all public health decisions are made, departments are always under-staffed and under-funded. Nevertheless they deliver essential public health services through surveillance, health education, and prevention (Anon, 1997). Furthermore, electronic syndromic reporting systems must serve many purposes because of the widespread nature of some health issues (like asthma or valley fever) on one hand, and the quite restricted localities for others (e.g. bubonic plague) on the other. The challenge is to develop a syndromic reporting system that starts with a few well-known syndromes that includes local, regional, and national geospatial content for tracking the frequency and distribution of cases; and that can expand its range of services to include not only zoonotic and chronic respiratory diseases, but other health conditions as well, especially those that might be delivered through bioterrorism.

Bioterrorism

Bioterrorism capitalizes on maximizing disruptions by introducing massive amounts of foreign material in disguised ways, at a single point in time, to over-power an ecosystem's ability to respond. Among the major categories of bio-threats are: (a) airborne and vector-borne contagious, or infectious, diseases; (b) threats to the safety of commercial food supplies as plants and animals are imported and exported; and (c) threats caused by hazardous or toxic materials in transport that, if released, could represent horrific means for massive and extensive biological damage.

Human health is a top concern for bio-threat reduction. Preventing or mitigating infectious diseases by creating an infrastructure for better vaccines and research laboratories, as described by Binder et al. (1999), clearly is necessary; but, meeting some of the “grand challenges” defined for human health by Varmus (2003) also will require better means for environmental information sharing, especially in rural states like New Mexico where people are concentrated into cities, towns, and villages isolated by essentially empty countryside. Among the current concerns are: (a) a pandemic influenza, especially one spread deliberately; (b) introduction of spores like anthrax into a regional dust cloud; and, (c) early detection of widespread acute respiratory disorders. To greater or lesser extent, these are all observable and addressable through a variety of surveillance technologies that provide environmental information between population centers.

Remote surveillance cannot yet track individual microorganisms, plants, or animals with any degree of resolution or sensitivity. The best means for reducing bio-threats from these life forms is to understand their ecology and physiology, and to monitor the environments through which they pass. If anthrax spores cannot be “seen” by remote sensors, one can at least observe and track the dust and aerosol clouds into which they could be introduced; and, from these observations, estimate human and animal populations at risk.

PHAiRS Description

Public Health Applications in Remote Sensing (PHAiRS) is a 5-year project that began February 2, 2004 (NASA award NNS04AA19A). It is an element of NASA’s Public Health Application initiative focused on atmospheric dust as an environmental factor affecting respiratory diseases. The geographic focus is on populations living in the Southwest. The importance of this project is that it links the public health communities described in Section 1 of this benchmark with satellite observations of thoracic dust. Table 2 summarizes the scope of the PHAiRS project.

Table 2. Scope of PHAiRS aims and goals.

Intends to Address	Does Not Intend to Address
Quality of life	Lives saved
Public health	Individual health
Forecasting airborne dust episodes that could affect populations at risk	Forecasting public health per se
Syndromic surveillance (pre-diagnostis)	Disease diagnosis

Approaches to Health Reporting

At least two approaches to medical information management are being developed. One is based on medical reporting by doctors, clinicians, nurse practitioners, school nurses, first responders and others; the other is based on electronic information gathering through data mining and statistical analyses from historical reports and current medial record databases. Both approaches rely on “syndromic surveillance,” the ability to detect outbreaks of illness earlier than disease-specific reporting systems and with sensitivities to detect outbreaks that might otherwise be missed (Hadler et al., 2005).

Each approach has its advantages and disadvantages, as expressed by the friendly exchange between Dr. Alan Zelicoff and Dr. David Forslund[2] (Appendix 1). The project reported in this initial benchmark is based on a clinician-driven approach for the three reasons articulated below by a public health coordinator in Texas[3]. Specifically, the emphasis here is on the Rapid Syndrome Validation Project (RSVP) developed by Sandia National Labs, and its subsequent intended commercial successor, the Syndrome Reporting Information System (SYRIS).

1. Human resource issues: “Any syndromic system used must be timely, cost-effective, and have few false-positives. Locals simply do not have a cadre of statisticians and epidemiologists to analyze the plethora of data from data-mining syndromic systems. Such systems may be useful in academic settings or better-staffed/funded, large metropolitan centers. A clinician reporting his/her

[2] The Zelicoff/Forslund exchange occurred June 1-2, 2005 via the RAMBO List Serve. Dr. Morain has edited the material for spelling and grammar.
[3] T. Ward. City of Lubbock, TX Health Department in an email to the RAMBO List Serve dated June 2, 2005.

timely observations for their population is more pertinent to us than the analysis of a distant summary report. In short, not a lot of us out here, and we want the most bang for our buck."

2. Timeliness and accuracy: "A clinician reporting to local public health at the time of patient visit has a low error rate. Data-miners are not timely, [and] may be days to weeks after the patient visit. Data are entered by non-clinicians who may not be local. For example, a data-entry staff [member] of a data miner based in Georgia reported a case of Congo Hemorrhagic Fever, 6 weeks after the event. The alleged case was in West Texas. When reviewed by local public health [officials], the Congo Hemorrhagic Fever was correctly identified as Congestive Heart Failure. NO CLINICIAN would have made that kind of data entry error. Such errors are time-wasters to an already-strapped public health system."

3. Cost-effectiveness: "While many local public health departments are benefited by the infusion of [bio-threat reduction] funding, again, getting the most value for the dollar is key. I can't fathom spending the public's money on systems that cannot directly impact the daily activities of local public health. Clinician-driven systems meet the challenge."

Focus on Dust-related Illnesses

Airborne thoracic particles range in size from 10ųm to 0.01ųm, which includes pollen, bacteria, viruses, and molecules (Figure 1). Only the coarse particle fraction ($PM_{2.5}$-PM_{10}) is being addressed in this project, but these particles can carry potentially lethal concentrations of finer biological material.

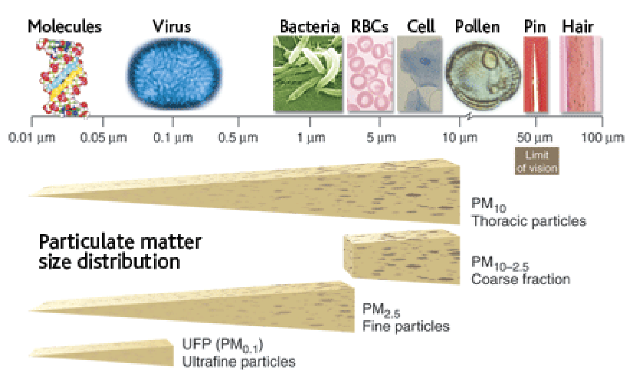

Figure 1. Medically relevant size distribution of atmospheric particulates. Source: *Science* 307:1859.

Relevance of Earth Observations

In PHAiRS, the framework for coupling atmospheric dust processes with human health responses begins with experimental NASA Earth science satellite products and modifies them for assimilation into the Dust Regional Atmospheric Model (DREAM). The output from DREAM is input to RSVP. This support system is queried by doctors and clinicians who desire additional corroborating information about similar cases being reported by their local or regional colleagues. The ultimate goal is to have the output from RSVP delivered to public health decision makers for announcing appropriate health alerts.

People immediately question how satellite-based Earth observations can detect "illnesses in people." Clearly this is not possible with today's technology; but, forecasting potential environmental impacts on a population's health is widely accepted. Once airborne, a dust cloud can affect human health in a variety of ways, some of which are lethal while others contribute to chronic respiratory conditions. The first clinical evidence of a relationship between air quality and lung development in 10-18 year olds is given in Gauderman et al., (2004). The results suggest that extending satellite observations to public health authorities could permit forecasts of deleterious health episodes and issuance of health alerts.

Numerous studies have confirmed that direct satellite observations of moderate to severe dust events can be detected, and that dust can be traced in the atmosphere across continents and oceans (e.g. Lee, 1989; King et al., 1999; Prospero, 1999; Kaufman et al., 2000; Chu et al., 2003; Grousset et al., 2003; Gu et al., 2003; Miller, 2003; Kaya et al., 2004; Stefanov et al., 2003). Likewise weather forecasting models, augmented with regional dust forecasting capabilities, show promise for better predicting the onset and tracking of dust events. Lastly, it is well known that naturally dusty environments have long-term human health impacts (e.g., Policard and Collet, 1952; Bar-Ziv and Goldberg, 1974; Norboo et al., 1991; Goudie and Middleton, 2001; Xu et al., 1993; Mathur and Choudhary, 1997; Wiggs et al., 2003; Wright, 2005). Whereas lifetime exposures to dusty environments may lead to desert lung (silicosis), or other deleterious medical conditions (pneumoconiosis) in high altitude or desert-dwelling populations, asthma is a global chronic respiratory disease triggered by numerous indoor and outdoor attributes. What remains to be demonstrated by

PHAiRS is: 1) a direct coupling of specific dust episodes with health response statistics; 2) that populations respond to individual dust events in numbers high enough to warrant public health alerts; and 3) that such events can be forecasted and tracked in time to issue effective alerts.

Asthma typifies concerns of the American College of Allergy and Immunology. It is one of the most common chronic diseases in the United States and is the most prevalent chronic disease in children. For poorly understood reasons, the rate of asthma among children in the northern mid-latitudes has more than doubled in the last 20 years. Nationwide, more than 9 million children struggle for breath. According to the National Center for Health Statistics, asthma causes more missed school days than any other chronic condition, and is the leading cause of hospitalization for children under 15. Asthma is the most common reason that children younger than five go to the emergency room. Based on outpatient visits, the prevalence of asthma has increased by 50 percent over the last decade. During this time asthma fatalities have increased more than 80 percent. Currently, more than 5,000 children die from asthma every year. This increase in asthma morbidity and mortality has not been uniform throughout the country. Certain urban settings and minority groups have experienced higher rates of increase, but much about the disease is unknown, particularly in regard to incidence and prevalence in rural areas where access to care is limited and exposure to organic and inorganic dusts is inescapable.

PHAiRS Goals and Project Design

The project has four primary goals: (a) select an atmospheric dust model and baseline its use and forecasting performance in the Southwest; (b) assimilate satellite observations into the baselined 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.

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Ultimately, the goal of the project is to contribute to an improved public health decision support system that can evolve toward operational status for the next generation of space-based sensing. The National Polar-orbiting Environmental Satellite System (NPOESS) is scheduled for launch in the 2010 timeframe. It will consist of several platforms carrying operational versions of NASA's current experimental sensors. It is now time to build the scientific and technological underpinnings of these near-future capabilities, and to test them with appropriate public health user communities.

Baselining DREAM

DREAM (Nickovic et al., 2001) is the basis for modeling dust events. Since it was originally developed for use in Europe and North Africa, it had to be adapted and regionalized for use in the southwestern United States, and its performance had to be tested and validated using observed weather patterns and dust events. Only after this baselining effort was finished would it be possible to assimilate NASA sensor data and be confident in the measured improvements to the model's performance. This process took 12 months of project time and will be continued throughout the PHAiRS project as incremental improvements are made.

Model and model setup

DREAM is an online desert dust cycle modeling system developed under the NCEP/Eta model framework (Janjic, 1984; Mesinger et al., 1988; Janjic, 1994). It consists of two major parts. One component simulates the atmosphere; the other models the dust cycle.

The dust cycle module simulates dust production, dust advection and turbulent diffusion, and dry and wet deposition (Nickovic et al., 2001; Shao et al., 1993; Georgi, 1986). The desert dust sources are based on land cover types. The physical properties of the dust particles from these dust source areas are associated with clay, silt, and sand components of the soil texture types. Dust particles are modeled in dust bins 0-3.4μm, 3.4-12μm, 12-28μm, and over 28μm.

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. With the Eta vertical coordinate, which generates quasi-horizontal model levels, topography is represented by step-like elements. Physical parameterization in the model includes land surface processes, turbulent mixing, convection, large-scale precipitation, lateral diffusion and radiation.

The model has been run for the southwestern U.S. for two dust storm events. One storm occurred on December 8 through 10, 2003 (hereafter, Case 1); the other occurred on December 15 through 17, 2003 (hereafter, Case 2).

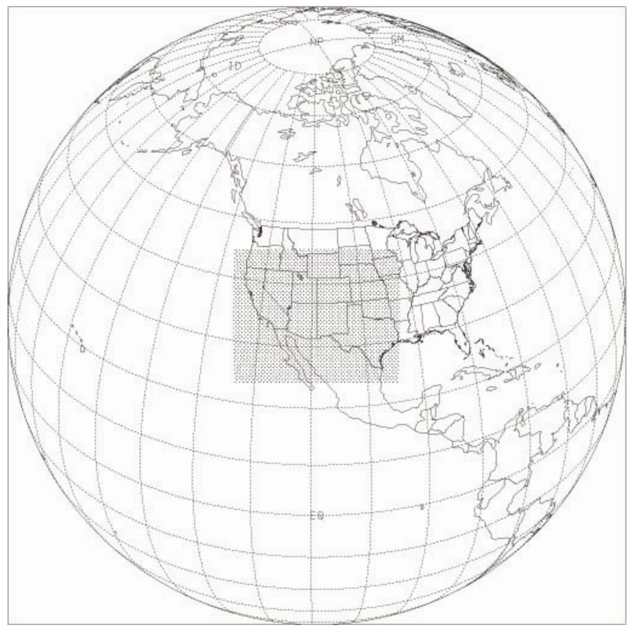


Figure 2. Dust model domain.

In Figure 2, the stippled area is the modeling domain. This domain is large enough to encompass the southwestern U.S. It is centered on 109°W, 35°N.

Horizontally, the model uses a semi-staggered Arakawa E grid (Arakawa and Lamb, 1977). Before using MODIS land cover, the E grid spacing between neighboring mass (h) and wind (v) points is 1/3 degree. This spacing is reduced to 1/9 degree to take advantage of the high spatial resolution of the MODIS land cover data. Vertically, the model uses the Eta coordinate with step-mountain representation (Mesinger et al., 1988). The Eta surfaces are quasi-horizontal in both mountain and non-mountain areas. From sea level to 100 hPa, there are 24 half-Eta levels.

Data from the European Center for Medium-Range Weather Forecast (ECMWF) were used to generate initial and boundary conditions in the model, although the NCEP data could have been applied also. Climatological values of sea surface temperatures were used (Yin et al., 2005).

DREAM is based on a Eulerian modeling approach. Its dust concentration module consists of three static surface parameters: soil types converted into texture classes at 2x2 minute resolution; 10 minute resolution vegetation cover; and 1x1km resolution topography. One hundred thirty four (134) categories of soil data[4] were used for the basic soil texture parameter. In model preprocessing, these were aggregated into nine (9) Zobler soil categories (Zobler, 1986), and then converted into Cosby soil categories (Cosby et al., 1984). The clay/sand/silt compositions of soil texture categories, which determine the physical properties of the wind-blown dust, were assigned according to Cosby soil categories. The Olson World Ecosystems (OWE) land cover classification scheme contains 59 land cover categories with a 10 minute spatial resolution.

Assimilating Data into DREAM

Table 3 is an initial list of products prepared for assimilation into DREAM. These are intended to replace equivalent surface parameters in the baseline version to achieve finer landscape resolution and more dynamic temporal resolution. These products include MODIS (MODs 12, 13, 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 most difficult parameter to engineer as a replacement has been “z_o”, the length associated with surface roughness. 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.

Table 3. Initial products for testing improvements of input parameters for DREAM.

Name	Sensor/ Origin	Original Format	Time Period
Leaf area index, (LAI), FPAR	MOD15	HDF	Dec 03
Land cover – LC	MOD12	HDF	Dec 03
Enhanced vegetation indices – EM	MOD13	HDF	Dec 03
gclayh – max clay content	STATSGO	Coverage	
gclayl – min clay contnet	STATSGO	Coverage	
gsurflex – USDA surface texture	STATSGO	Coverage	
gweg – wind erodibility	STATSGO	Coverage	
Shuttle Radar Topography Mission	Space Shuttle	DTED	Feb 00

[4] Obtained from the Food and Agriculture Organization (FAO)/ United Nations Education, Scientific and Cultural Organization (UNESCO)

Data assimilation is a multifaceted process hampered by the general absence of metadata. One must first compare the attributes of existing model inputs and of possible replacements using satellite observations. Like DREAM, many models currently used for Earth system science were designed without benefit of data sets acquired remotely. Data compatibility issues therefore must be considered, including: (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. Table 2 includes inputs that are direct replacements for baseline data sets, assuming the data are compatible in the model. If yes, then the next steps are to iterate the process with different kinds of products and resolutions, and to measure the incremental improvements in model outputs.

In Figure 3, four replacement data sets are visualized. These are: (a) 17 classes of 1x1km land cover (MOD12) and (b) 1x1km leaf area index (MOD15), both from MODIS Terra; (c) 10m elevation data from SRTM; and, (d) surface soil texture from STATSGO (NRCS).

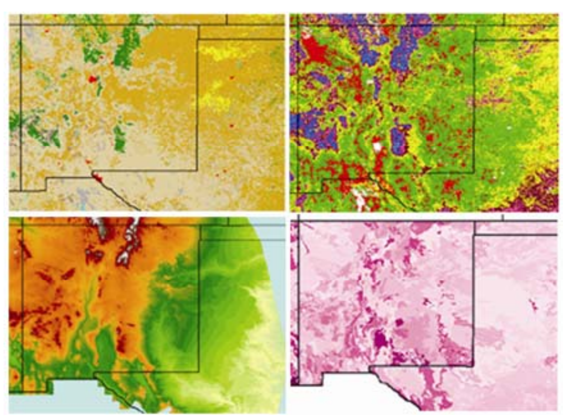


Figure 3. Visualizations of four data sets to replace the baseline DREAM surface data sets.

Assessing Health Data Inputs[5]

Health data are being assembled in two ways: (a) a review of the literature on windborne contaminants and health; and (b) a review and analysis of retrospective health data from the panhandle of West Texas. The aim of the literature survey is to validate that atmospheric dust is coupled to human health in scientifically measurable ways. The review addresses five categories of concern:

- The physical properties of dust storms from a geophysics perspective;
- Aerobiology – how far organisms and chemical compounds are transported on the wind;
- Fungi (including indoor molds and outdoor mycoses) with particular reference to natural histoplasmosis, coccidioidomycosis, and blastomycosis;
- Bacteria, and their ability to be carrid by dust; and,
- Chemicals (including human-made, fungal, and bacterial toxicants).

Search results have been narrowed to about 950 primary references focused on anthropogenic factors relevant to West Texas and Eastern New Mexico. This region is sparsely populated, which means that land disturbances caused by overgrazing, the addition of fertilizers and pesticides, and other management practices lead to industrial and agricultural surface emissions like cotton gin dust and aerosolized cattle feed-lot waste that are triggered by periods of drought.

Dust from Eastern New Mexico is such a perennial problem in West Texas that validating its medical impacts on populations at risk is a core goal of this project. Records have been kept in West Texas for the past two decades. Over 100,000 records of respiratory illnesses have been drawn from a variety of sources and aggregated to the census block level. These records include detail on asthma, influenza, mortality, behavioral- and risk-factor surveys, clinic files, and hospital discharges. Companion research also is underway in West Texas on the implications of cotton gin dust, cattle feedlot dust, and crop pesticide spraying on human health. Results from all of these should augment understanding of the coupling between atmospheric dust contaminants and human health.

[5] This assessment is not a NASA-funded element of the project. It has been performed through the generosity of faculty and staff at Texas Tech Health Sciences Center in Lubbock Texas as a collaborative effort to several of their other funded projects.

RSVP Decision Support

RSVP was is a novel prototype among only a few decision support systems aimed at modernizing health care reporting. It is an Internet-based syndromic surveillance system designed to facilitate rapid communication between epidemiologists (public health officials in local jurisdictions) and health care providers (physicians, physician assistants, and nurse practitioners). It is a reporting and discovery system for primary care physicians and clinicians who want to determine if their patient's syndrome has been reported by others in the local or surrounding area. It provides medical and environmental information in a geospatially explicit architecture in three modules: (a) a syndromic information collection module whereby doctors can submit an inquiry, (b) a communication module whereby a public health official can respond to an inquiry; and, (c) a data visualization module that permits both parties to review collective inputs in the medical and geographic domains.

The prototype system has been successfully beta-tested for six syndromes in several states in the U.S.A. and internationally (Singapore), and had, until recently, on-going testing on respiratory syndromes in Texas. Beta testers have expressed a universal desire for more visualization tools, especially those of a geospatially explicit kind. In response, this project is partnering with developers of RSVP to insert an imagery and geospatial module into which outputs from DREAM can be placed and made available via the Internet. Future design elements include analytical tools like data mining, 3-D visualizations, and disease analysis algorithms; and expanding the range of data types to Internet-based sources for prescriptions, patient complaints, and lab results (all on a patient confidential basis).

SYRIS

The Syndrome Reporting Information System (SYRIS) is an advanced version of RSVP designed for commercial applications. RSVP was well accepted by physicians and public health officials, but suffered from lack of multi-community surveillance. SYRIS represents a fully operational, highly-secure system for syndrome-based disease reporting that offers high-fidelity information with minimal false positives and at least two dramatic successes in ruling out a bioterrorism threat and in early detection of influenza.

SYRIS is focused on capturing the clinical and professional judgments of professionals in the following communities:

- Physicians
- Veterinarians
- Nurses (especially school nurses)
- Coroners and medical investigators
- Emergency medical response teams and ambulance services
- Animal control
- Environmental health
- Clinical laboratory chemists, microbiologists, and immunologists
- Wildlife rehabilitators

When clinicians see a seriously ill patient with presumed infectious disease (national studies suggest this is less than 0.1percent of all clinical encounters in human medicine and perhaps slightly greater in veterinary practice), it takes less than 20 seconds to report that case via SYRIS. In addition, SYRIS contains summaries and analysis from local public health officials (thus focusing on diseases of importance in a particular geographic area relevant to those clinicians) that can be accessed with a single click of the mouse.

Our experience with properly designed active, clinician-driven surveillance systems demonstrates that physicians and other busy health professionals will report cases of suspected infectious disease if the system is fast (less than 15 – 30 seconds), provides immediate feedback to clinicians on local infectious disease outbreaks, permits selective interaction between public health officials and clinicians on a real-time basis as warranted, and which is inexpensive. SYRIS meets all of these criteria. In addition, unlike the “passive” or “data-mining” approaches, SYRIS has a low false-positive rate (thus mitigating the investigation of a large number of false alarms) while at the same time facilitating enhanced relationships between local public health officials and all health care providers.

SYRIS represents a fully operational, highly secure system for syndrome-based disease reporting. It offers high-fidelity information with minimal false positives. SYRIS captures the clinical and professional judgments of experts such as physicians, veterinarians, nurses (particularly school nurses), coroners and medical investigators, emergency medical response teams and ambulances, animal control officials, environmental health experts, clinical laboratory chemists, and wildlife rehabilitators. Geospatial mapping tools provide an additional ability to perform rapid hypothesis testing and statistical analysis.

RSVP / SYRIS and DREAM

While DREAM performs well predicting meteorological patterns, it has mixed performance predicting the extent of dust events. The team hopes to improve this performance by deriving a better estimate of aerodynamic surface roughness length (z_0) through remote sensing. Understanding and measuring this parameter is crucial for understanding surface friction and the ability of wind to lift dust from a surface.

The project team is convinced from early results that there is ample room for improving the model with better resolution Earth science satellite observations for surface parameters. Future reports will document the incremental improvements to DREAM and RSVP. Hopefully, these reports also will document the medical impacts of atmospheric dust events.

Results to Date

In the following two subsections, model results are given with no NASA sensor data assimilated, followed by results *after* MODIS land cover data were assimilated.

Dust Storm Modeling

An obvious test of the dust model forecasts for Cases 1 and 2 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: (1) 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; and, (2) 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?

The DREAM-modeled 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 modeled dust field patterns and dust concentrations were compared with satellite images, measured visibility distributions, and the surface $PM_{2.5}$ and PM_{10} (particulate matter with aerodynamic diameter less than 2.5 and 10 micrometer) 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.

Because of the wealth of public health data available from West Texas, emphasis in this section is on Case 2 results. Case 1 results are used primarily to validate model performance. The Case 2 dust storm was triggered by a Pacific cold front that swept through the region bringing gale force winds and dry conditions, and causing one of the worst dust storms in recent years. Since it was installed in 2001, one of the Continuous Air Monitoring Stations (CAMS) in Lubbock measured its highest $PM_{2.5}$ one-hour average (485.6 μg/m^3) between 1300-1400 hrs Central Standard Time. It also measured a daily average $PM_{2.5}$ of 76.7 μg/m^3. The PM_{10} daily average concentration of 384 μg/m^3 was estimated to be five times higher, than is considered “healthy” by the U.S./EPA.

Results without NASA inputs

Model comparisons showed that modeled meteorological fields, both surface and 500 hPa level, were in agreement with measured observations. The modeled vertical profiles of wind speed, wind direction, temperature, and specific humidity matched the observed profiles. Statistical evaluation of the modeled and observed surface winds and temperatures showed that the model performed reasonably well in simulating the measured values.

Comparison of surface patterns

For Case 1 (Figures 4a and 4b), note that the 12-hour simulated forecast of the high pressure location over northern Utah matches well with the observed location. Atmospheric pressure differences between the model (Figure 4a) and the measured fields (Figure 4b) of less than a few millibars are also quite good. The dust model 12-hour forecasts of precipitation along the northern California and southern Oregon coasts match observations. Most important, for the Lubbock, Texas forecast verification, the location and intensity of the low pressure area, the location and timing of frontal passages, and centers of precipitation were predicted quite well; but, the dust model spread precipitation more generously across central Colorado and western Nebraska than the observations show. Since pressure patterns reveal something about wind direction and speed, it can be inferred also from these data that wind forecasts were realistic. The model saw this storm coming at least twelve hours in advance.

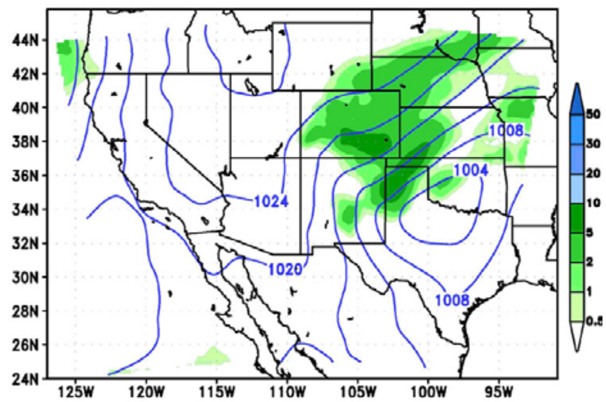


Figure 4a. Model-generated precipitation/pressure.

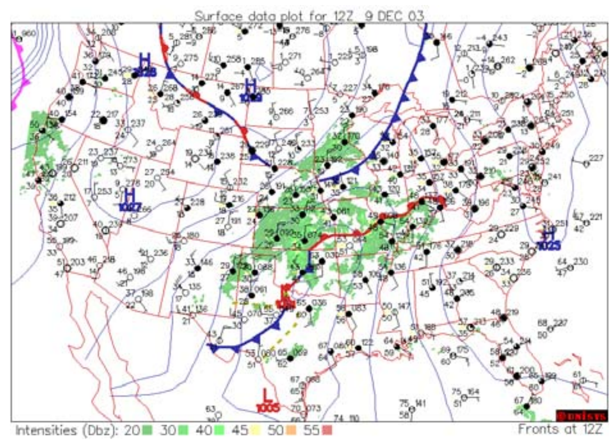


Figure 4b. Observed weather pattern.

The Case 2 storm also was well predicted (Figures 5a and 5b). The model surface pattern (Figure 5a) locates the Utah high pressure center at 12Z on 16 December 2003 slightly north of the observed position (Figure 5b), and is lower in pressure by perhaps five millibars. The forecasted precipitation pattern is slightly south of that observed, but the frontal passage and pressure (correlated with wind) patterns are reasonably ‘forecasted’ twelve hours in advance.

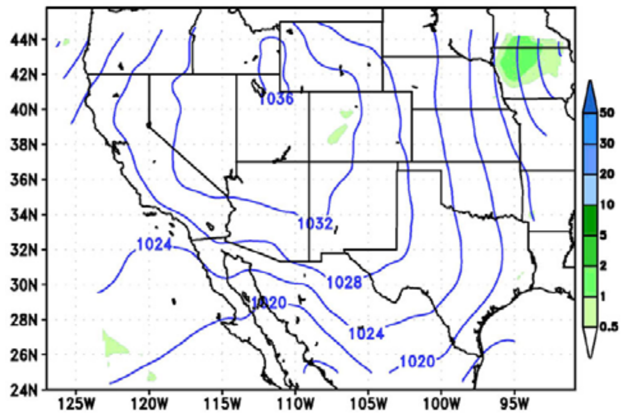


Figure 5a. Model-generated precipitation / pressure.

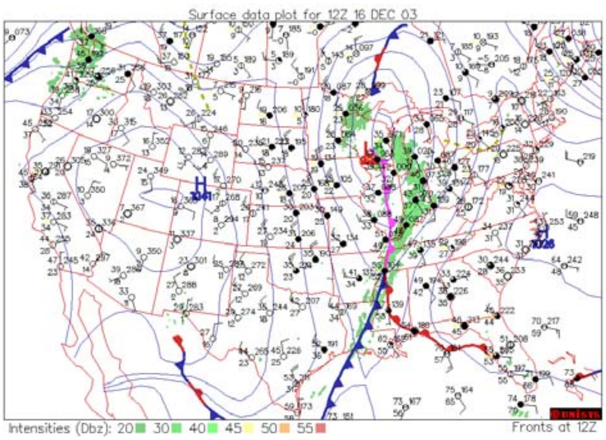


Figure 5b. Observed weather pattern.

Comparison of upper air patterns

Figures 6a and 7a show the modeled upper-air geopotential height and temperature patterns for both Case 1 and Case 2. Figures 6b and 6c and Figures 8b and 8c show the measured conditions. For Case 1 (Figure 6b) the cold air intrusion with a low trough centered in northern Texas, and the general temperature and height patterns (Figure 6c), compare reasonably well with the simulated 12-hour forecast with the (after-the-fact) observations.

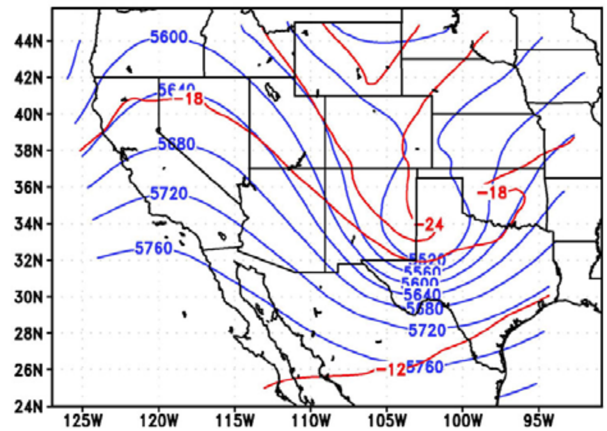


Figure 6a. Model simulation, 12Z 09 Dec 03 (Case 1).

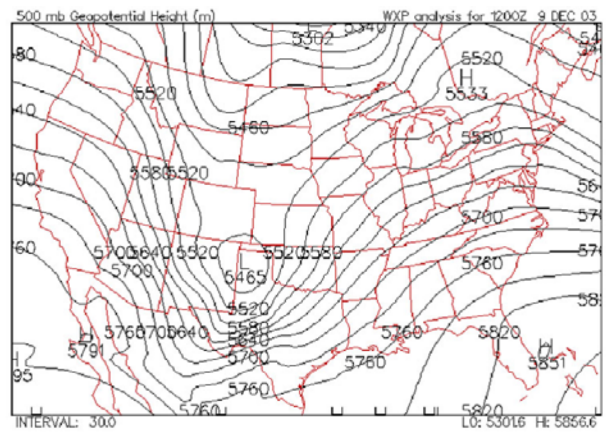


Figure 6b. Observed geopotential height, Case 1.

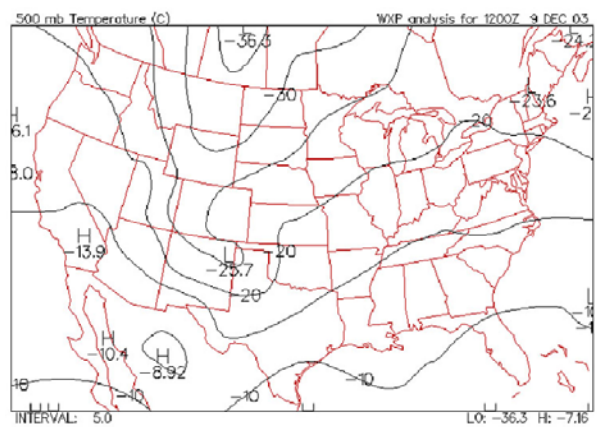


Figure 6c. Observed temperature, Case 1.

Comparing the same meteorological fields for Case 2, the upper-level trough depicted in geopotential height appears in both the modeled and measured patterns (Figure 7a compared to 7b). The observed temperature field (Figure 7c) shows fine agreement with the model simulation.

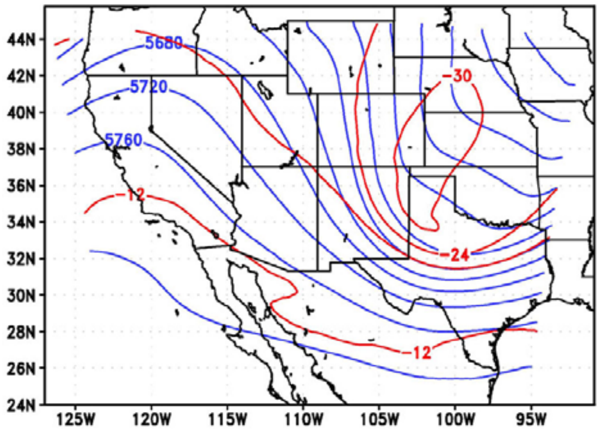


Figure 7a. Model simulation, 12Z 16 Dec 03, (Case 2).

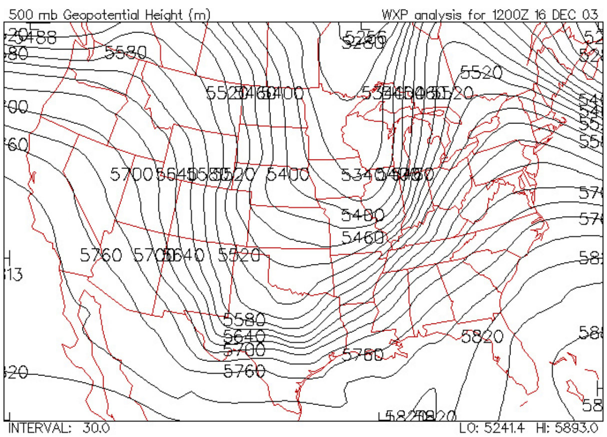


Figure 7b. Observed geopotential height, Case 2.

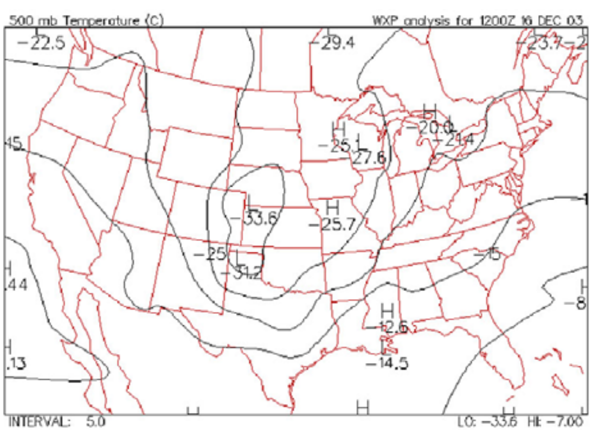


Figure 7c. Observed temperature, Case 2.

Profiles through the atmosphere

The dust forecast model is three dimensional. Dust concentrations can be calculated for any point, at any height, at any time. Thus, it is important to know if meteorological variables in three-dimensions, including vertical profiles, are being simulated correctly. Figure 8 shows how closely the forecast simulations match the observed variables.

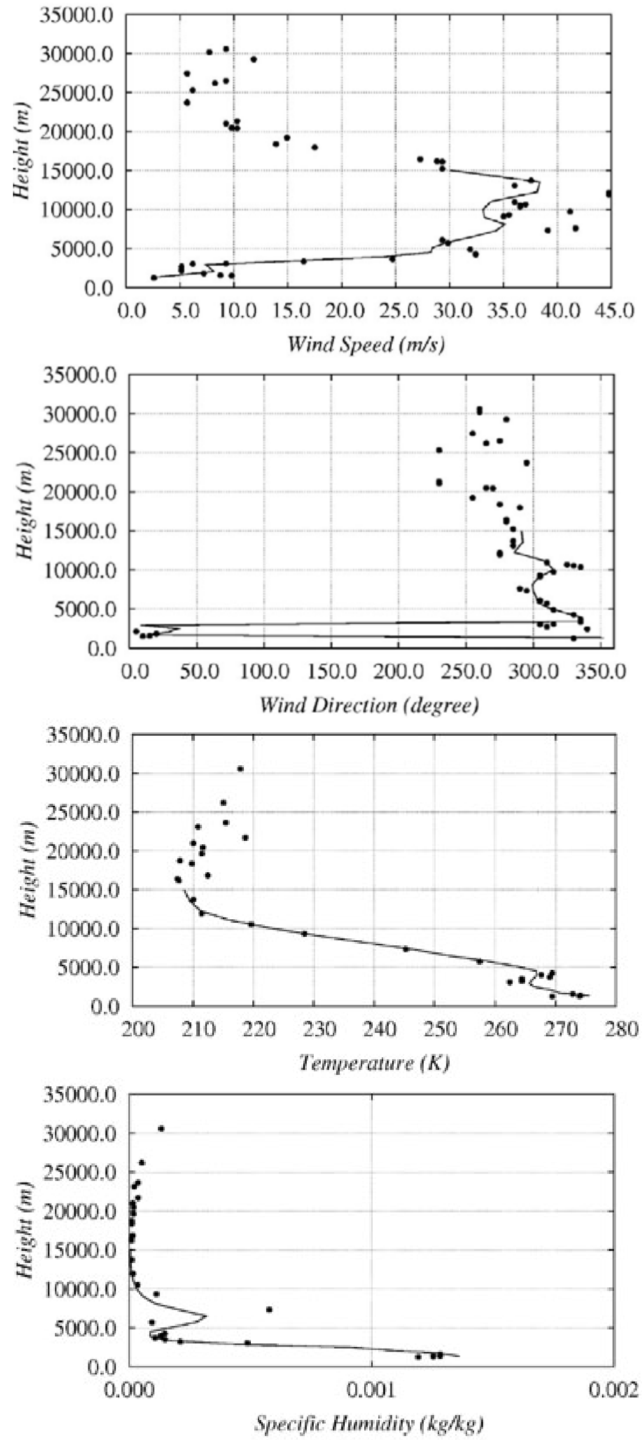


Figure 8. Modeled and observed vertical profiles at Santa Teresa, NM for 12Z 16 Dec 03. Dots = observed values; lines = modeled values.

Surface temperature and wind

Wind and temperature at a given location will change over time as weather systems pass over. If the model cannot simulate or forecast these changes, it is unlikely the dust forecast will be correct. Table 4 lists the performance statistics of modeled surface meteorological variables for Case 2. These statistics were calculated using modeled data and hourly measurements from 95 surface synoptic stations and 633 surface METAR stations in the modeling domain. In addition to other statistics, the agreement of indices for wind speed, wind direction, and temperature all exceed 0.7. These performance statistics show that the model simulates surface wind and temperature fairly well.

Table 4. Performance statistics of modeled surface wind and temperature.

Metrics	Wind Speed	Wind Direction (degree)	Temp (K)	Definition M=modeled O=observed
Mean observed	5.53	231.40	276.74	$\frac{1}{N}\sum_{i=1}^{N} O_i$
Mean Modeled	4.65	226.60	275.56	$\frac{1}{N}\sum_{i=1}^{N} M_i$
Mean Bias	-0.88	-4.80	-1.20	$\frac{1}{N}\sum_{i=1}^{N}(M_i - O_i)$
Mean Error	1.97	51.76	4.09	$\frac{1}{N}\sum_{i=1}^{N}\lvert M_i - O_i\rvert$
Agreement Index	0.74	0.74	0.71	$1-\frac{\sum_{i=1}^{N}(M_i - O_i)^2}{\sum_{i=1}^{N}\left(\lvert M_i-\overline{O}\rvert+\lvert O_i-\overline{O}\rvert\right)^2}$

<u>*Modeled & storm-generated dust cloud*</u>

The modeled dust distributions were comparable with the satellite-observed dust clouds and the reduced visibility patterns. However, there are discrepancies between the details of the modeled and observed dust cloud distributions. The highest dust concentration areas did not coincide with the most reduced visibility areas.

Figure 9 shows the dust cloud for Case 1 observed by the MODIS sensor on Terra. Such high concentrations of airborne dust particles cause severely reduced visibility at the surface. Figure 10 shows the observed visibility distribution in the imaged region for 20Z December 15, 2003. Prevailing visibilities from METAR observations were used. A Cressman objective analysis (Cressman, 1959) was performed to generate the distribution. An impact radius of 1 degree was applied to ensure that the gridded data maintain good representation of the site data. White areas in the plot indicate that no measurement data exist. Unfortunately, there are not enough measurement data from Mexico to allow credible comparison with the modeled results in Mexico. Thus, looking only at New Mexico and Texas, the most reduced visibility areas are the Texas Panhandle, specifically the Lubbock area, and El Paso region, which correspond well to the locations of dust observed by MODIS.

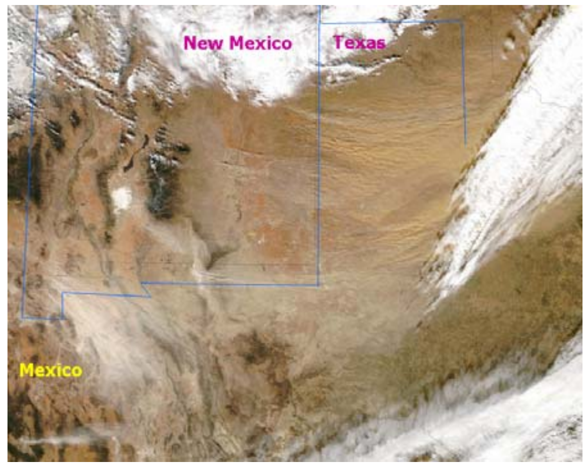


Figure 9. Terra MODIS image, 15 Dec 03 (Case 2). The bright circular spot at left-center is White Sands National Monument. siliceous, calcareous, and ferric dusts all are visible in the cloud-free area.

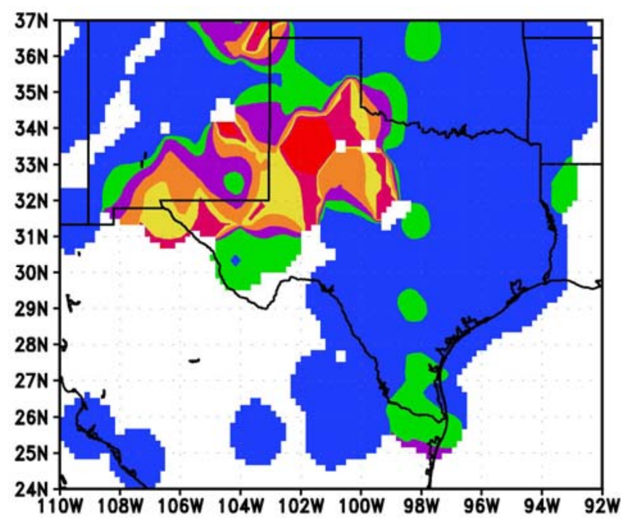


Figure 10. METAR prevailing visibility in miles for 20Z 15 Dec 03.

Output from the DREAM model (Figure 11) also shows that the dust cloud stretched across southern and southeastern New Mexico to eastern Texas. Although the model captured the general areas of dust, there is apparent bias between modeled and observed dust and reduced visibility.

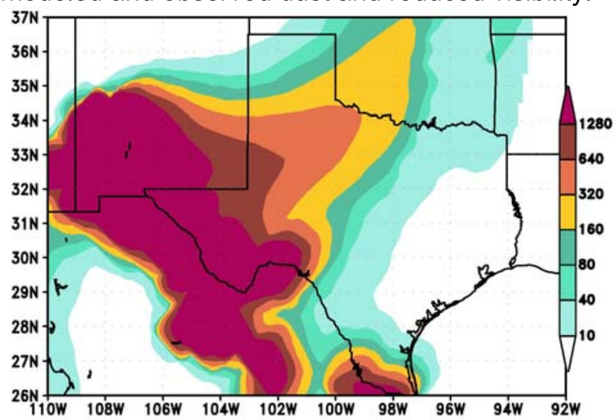


Figure 11. DREAM modeled dust concentration distribution for 20Z, 15 Dec 03.

Point by point comparison

The observed $PM_{2.5}$ data from 40 ambient air monitoring stations in New Mexico and Texas that were affected directly by the dust episodes are used in this model performance comparison. Figure 12 locates some of the sites. The measurement data were obtained from the US EPA's AQS[6] and Texas Commission on Environmental Quality. They are real time, hourly measurements from Tapered-Element Oscillation Microbalance (TEOM) samplers. The overall question to be answered is: how well does the DREAM model predict the timing, magnitude, and duration of a dust storm event at these air monitoring stations? In other words, do the model outputs correlate with actual, measured, *in-situ* data (do patterns in one set correspond to patterns in the other set)?

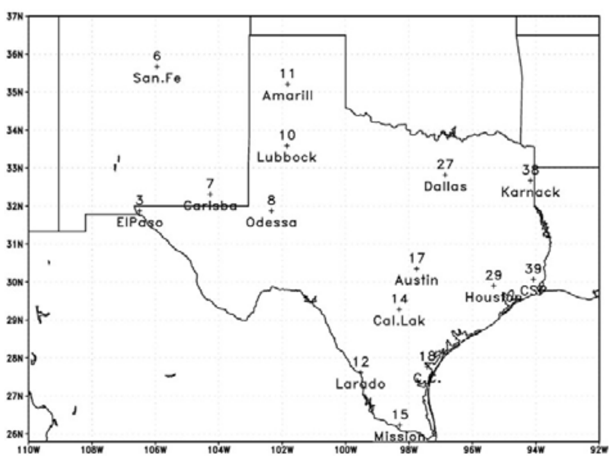


Figure 12. Locations of surface PM2.5 sites.

[6] Details about AQS data can be found on http://www.epa.gov/ttn/airs/airsaqs/index.htm.

$PM_{2.5}$ peak hours

The timing of the event is defined as the peak hour – the hour of day the maximum $PM_{2.5}$ value occurred at each site. There is reasonable correlation (R^2 = 0.77, Case 1; R^2 = 0.76, Case 2) between model and *in-situ* timing in both cases when all data (n = 40 sites) are considered collectively (Figure 13). Excellent correlation (R^2=0.96) is observed also in central and east Texas (n = 27) on December 16, 2003. Multiple sites represent the same metropolitan areas (Dallas, TX; Houston, TX) and no weighting factor is considered here. Two outlier sites (Mission, TX; Laredo, TX) do not follow the trend with the other sites and this may be due to their extreme southerly location in the model domain.

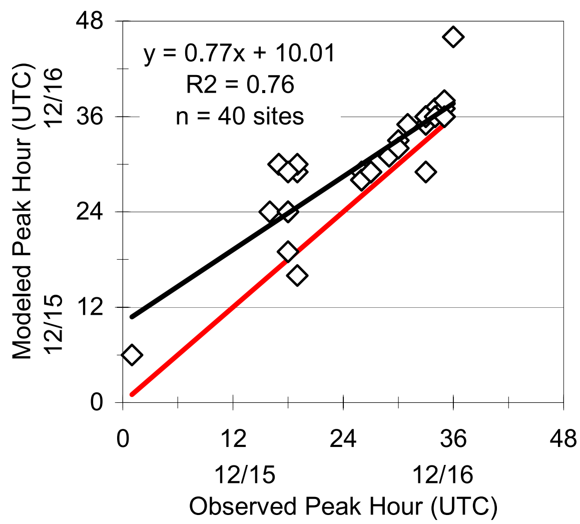


Figure 13. Correlation between modeled and observed peak hours for 15-16 Dec 03. Perfect correlation line (R2=1.0) in red.

$PM_{2.5}$ peak concentrations

The model overestimates the fine-particle aerosol mass generated in source regions during the onset of dust events in both test cases. Modeled peak concentrations have a much wider range (1 – 1185 ug/m^3) than *in-situ* values (11-168 ug/m^3) in Case 2. In both cases, the model appears to underestimate background levels. In one test case, the model overestimates the amount of fine-particle aerosol transported to eastern Texas; in the other test case, the model underestimates the amount to the same region. Figure 14 shows that there is almost no correlation between the two data sets on December 15 during the dust-generating stage of the model, and only a weak correlation on December 16 during the transport and deposition stages of the model.

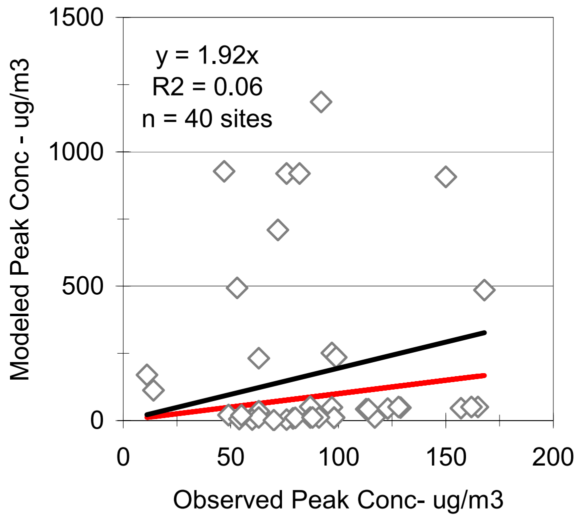


Figure 14. Modeled and observed peak PM2.5 concentrations for 15-16 Dec 03.

Dust episode duration

The duration of the episode is defined as the period of time where measurements at one or more of the *in-situ* monitoring stations exceed the US EPA National Ambient Air Quality Standards (NAAQS). In general, the duration of an episode is a function of the amount of dust generated. The duration of the event was exaggerated by the model at most sites in both test cases.

Of more interest are the periods of time that indicated an exceedance of the primary fine-particle ambient air standard (24-hr average of 65 ug/m^3 or more). EPA primary standards set limits to protect public health, particularly the health of "sensitive" populations such as asthmatics, children, and the elderly. Only one site was found for the two test cases that exceeded the primary fine-particulate standard (Lubbock, TX 12/15/03; 78 ug/m^3). However the model predicted eight exceedances in eastern New Mexico and western Texas during the same time period. This effect is related to the overestimated magnitude of the event throughout the model domain.

Model results using NASA MOD12 data

To date, the replacement inputs into DREAM are from the MODIS sensor on board the Terra and Aqua platforms. MODIS provides high temporal and spatial resolution compared to the OWE data. Data products obtained from MODIS include Land Cover, Leaf Area Index, Fraction of Photosynthetically Active Radiation and Enhanced Vegetation Index. The Land Cover product has been processed into an ASCII GRID format for easy input into DREAM.

Along with MODIS, NASA Shuttle Radar Topography Mission (SRTM) data were obtained for a high-resolution elevation model. Level 2 data that have been processed to remove various artifacts was purchased for the project area. A later revision to DREAM's domain extended the project area. Level 1 SRTM data, were downloaded to cover the model's entire domain (see Figure 2). GTOPO30 data were used to fill in the larger areas where data were otherwise incomplete. Additionally, a targeted 5x5 neighborhood filter was applied to the small "salt and pepper" noise without affecting the rest of the dataset.

For surface roughness length, a program that generates roughness length values (z_0) using a look up table and MOD12 land cover was created at Stennis Space Center. As with the other datasets, this product was processed to ASCII GRID format. Links to all data products have been placed on the PHAiRS web portal.

If one compares model results before and after MOD12 data were assimilation, it appears that surface weather patterns (sea level pressure, 500 hPa potential height, and temperature) match well with the observed weather patterns. This suggests that the MOD12 land cover product had little noticeable affect in improving model performance. The primary difference between the two sets of model results is seen in sea level pressure fields, although these differences did not affect the overall pattern. Significantly, the upper-air fields were *not* affected by the model data set replacements.

Among the vertical profiles for wind, temperature, and specific humidity, only slight differences were seen after data assimilation, except for differences in the near-ground wind speed. This seems reasonable since the OWE land cover data used for the “before” model run had much coarser spatial resolution (10x10 min) than the run after employing MOD12 data (1x1km). Even though both data sets resulted in fairly good model performance, one expects vegetation height and density to add incrementally to topography’s influence on surface wind speeds; and, in turn, to influence surface roughness length, soil moisture status, and the ability of wind to entrain dust.

The performance statistics of the modeled surface meteorological variables using MOD12 land cover showed that model performance in 2m (height above surface) temperature improved by comparison to OWE results. The model performance for 10m wind speed and direction showed slight improvement using assimilated data.

Surface patterns

Figures 15 and 16 are the modeled sea level pressure and 12-hour precipitation for 12Z for Cases 1 and 2, respectively. Compared with Figures 4a and 5a, the modeled sea level pressure contours are not as smooth as in the baseline model runs. However, the sea level pressure and precipitation patterns are very similar before and after MOD12 data assimilation for both cases. These patterns match the measured patterns.

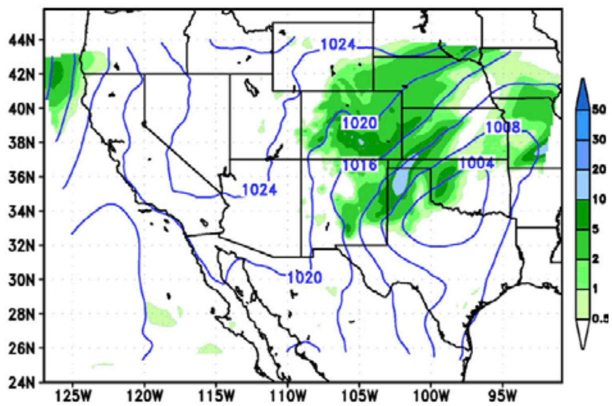


Figure 15. Modeled sea level pressure and precipitation for 12Z (Case 1).

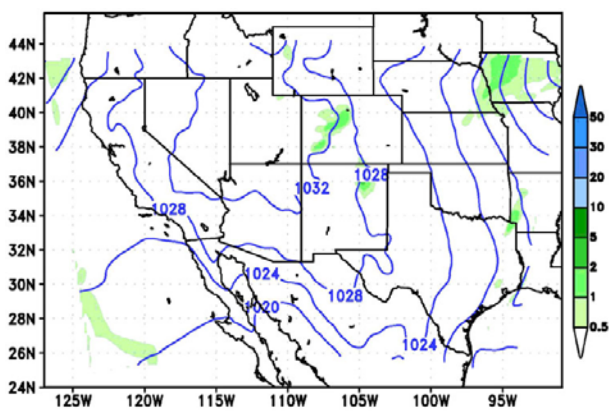


Figure 16. Modeled sea level pressure and precipitation for 12Z (Case 2).

Upper air patterns

Figures 17 and 18 are modeled 500 hPa geopotential height and temperature fields for Cases 1 and 2. Compared with Figures 6 and 7, the modeled geopotential height and temperature fields before and after MOD12 data are identical. Again, the upper air fields were not affected.

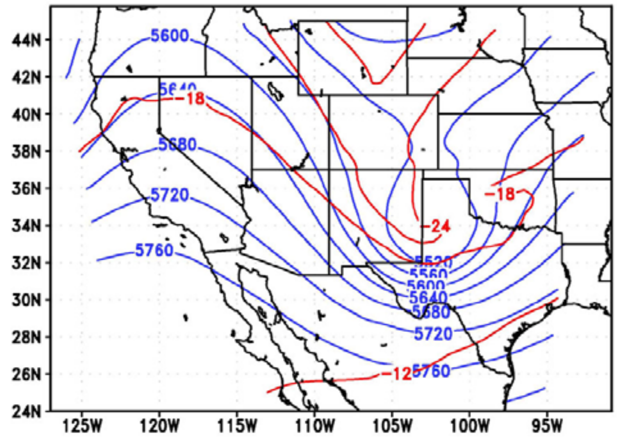


Figure 17. Modeled 500 hPa geopotential height and temperature field for 12Z (Case 1).

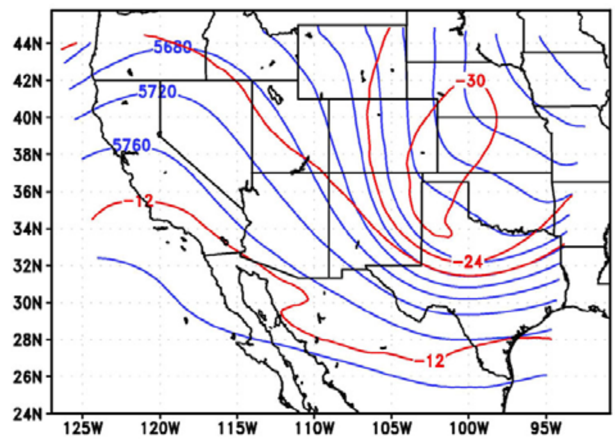
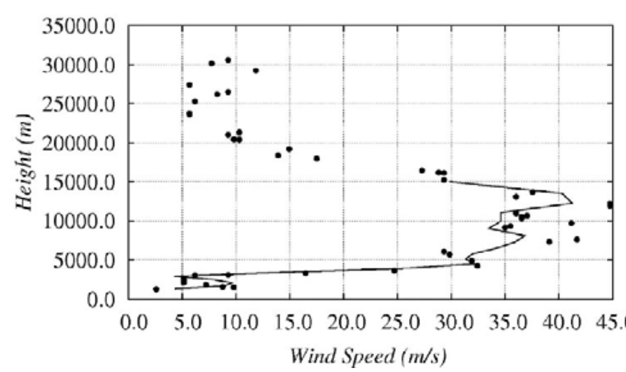


Figure 18. Modeled 500 hPa geopotential height and temperature field for 12Z (Case 2).

Profiles through the atmosphere

Visually, the modeled variables in Figure 19 match quite well with the observed values. Compared with Figure 8, the modeled wind direction, temperature, and specific humidity profiles are almost identical to the baseline DREAM results; however, as indicated earlier, there are slight differences in near-surface wind speeds.



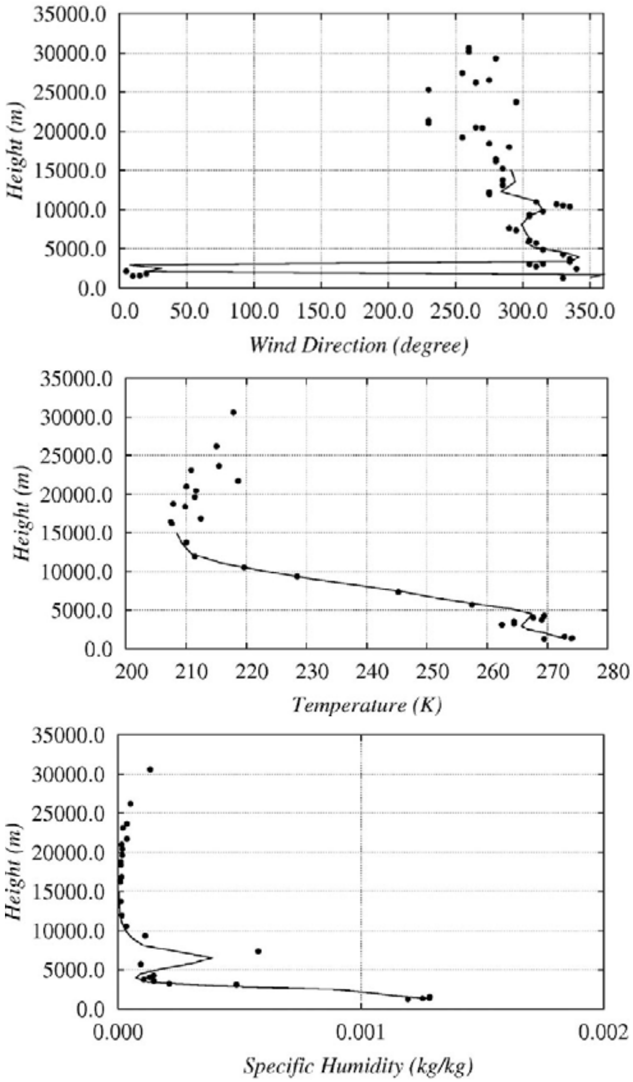


Figure 19. Modeled and observed vertical profiles at Santa Teresa, NM for 12Z 16 Dec 03. Dots = observed values; lines = modeled values.

Surface temperature and wind

Table 5 lists the performance statistics for these modeled surface variables. The biggest differences between results from before and after MOD12 data assimilation are for 2m temperature. The agreement index after NASA data assimilation was 0.95, in comparison with 0.71 obtained using the original DREAM parameters This is a significant model improvement. The mean bias and mean error after parameter replacement are less than those for the baseline parameters.

The agreement index for 10m wind direction and speed was slightly better after MOD12 data set replacement, but the mean bias and mean error were actually slightly higher than those obtained using the original DREAM parameters.

Table 5. Performance statistics of modeled surface wind and temperature.

Metrics	Wind Speed	Wind Direction (degree)	Temp (K)	Definition M=modeled O=observed
Mean observed	5.53	231.40	276.74	$\frac{1}{N}\sum_{i=1}^{N}O_i$
Mean modeled	4.37	230.38	277.48	$\frac{1}{N}\sum_{i=1}^{N}M_i$
Mean bias	-1.16	-1.02	-0.72	$\frac{1}{N}\sum_{i=1}^{N}(M_i-O_i)$
Mean error	2.03	47.85	2.67	$\frac{1}{N}\sum_{i=1}^{N}\lvert M_i-O_i\rvert$
Agreement index	0.75	0.76	0.95	$1-\frac{\sum_{i=1}^{N}(M_i-O_i)^2}{\sum_{i=1}^{N}\left(\lvert M_i-\bar{O}\rvert+\lvert O_i-\bar{O}\rvert\right)^2}$

Modeled & storm-generated dust cloud

MOD12 land cover data had a much larger influence on modeled dust concentrations than on meteorological fields. The near ground dust concentration distribution using the MOD12 product matched better to the satellite observed dust clouds and reduced visibility distribution than did the results derived from the OWE data set.

Figure 20 shows the modeled dust distribution after replacing OWE with the MOD12 product (Compare with Figures 10 and 12). The coverage and locations are much better defined than are the modeled results from OWE. The modeled high dust concentration areas also correspond better to the visibility impaired area.

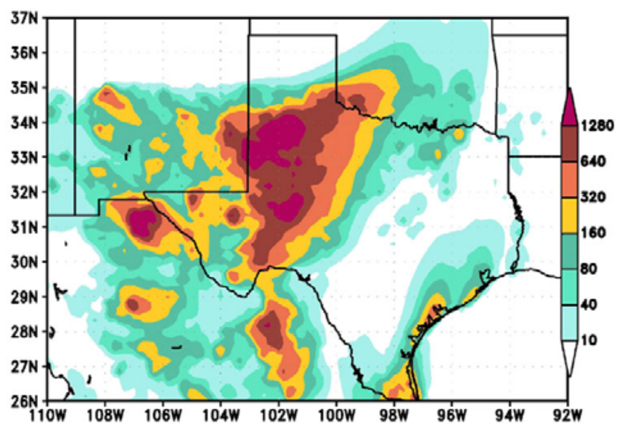


Figure 20. DREAM modeled dust concentration distribution for 20Z (Case 2) after replacing original DREAM surface parameters with assimilated data.

Point-by-point comparison

As described earlier, DREAM's enhanced model performance is evaluated by correlating specific parameters ($PM_{2.5}$ peak hour; $PM_{2.5}$ peak concentration, and duration) of the model output with observed (*in-situ*) data from forty sites in TX and NM.

For model evaluation, significant gains were accomplished with the addition of NASA MOD12 data to the DREAM model. The peak hour correlation was least affected by the change. However major gains were made in the magnitude comparison. The enhanced model predicted accurately the order of magnitude of the dust storm event at almost all locations in the model domain. The dust episode in Lubbock, TX was also accurately modeled after assimilating MOD12 data. The improved model indicates no false alarms in either test case. This result begins to illustrate the potential use of the DREAM model as a tool for the medical community and local government to accurately predict unhealthy dust levels in the desert southwestern United States.

$PM_{2.5}$ peak hour

There was reasonable correlation (R^2 = 0.63 for Case1; R^2 =0.71 for Case 2) between model and observed timing when all sample sites are considered (Figure 21). The enhanced model results appear slightly more scattered than results from the original model surface parameters, but the difference between the two outputs is within a reasonable margin of error.

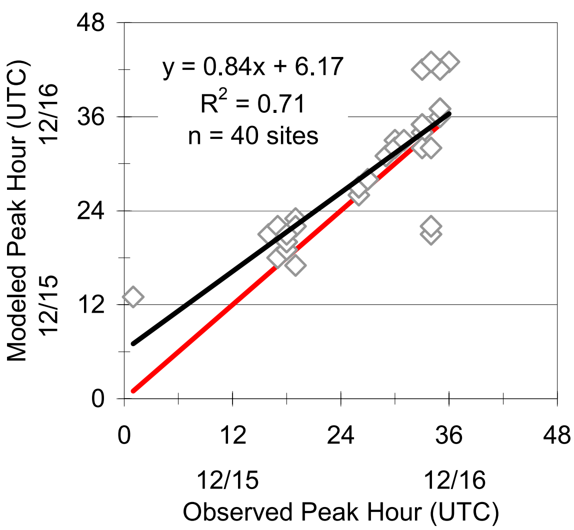


Figure 21. NASA enhanced DREAM model and observed PM2.5 peak hour correlation, Case 2.

$PM_{2.5}$ peak concentrations

Significant improvement in R values occur for the $PM_{2.5}$ peak concentrations and the MOD12-enhanced DREAM model output. The range of modeled values is now in good agreement with *in-situ* values (14-168 ug/m^3) in both case studies. In the baseline model runs there was almost no correlation between the two data sets (Figure 13). Although the correlation is better, there is much room for improvement (Figure 22).

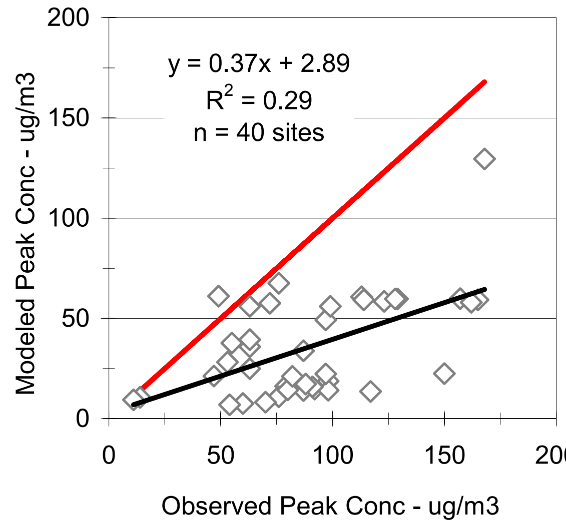


Figure 22. MOD12-enhanced DREAM model and observed PM2.5 peak concentrations, Case 2.

Dust episode duration

Significant improvements for duration of dust episodes were achieved in the enhanced model results for both Case 1 and 2 dust events. The MOD12-enhanced model predicted accurately the only time the primary fine-particle ambient air standard observed in Lubbock, TX was exceeded on 15 December 2003. The (baseline) model runs yielded exceedances eight times in western NM and east TX during for these two case studies. The improved model made no 'false alarm' predictions. This may be the most obvious and promising gain made with the new version of the DREAM model.

MODIS aerosol mapping

An attempt was made to map the horizontal extent of dust plumes over the Southwest using images from MODIS products.

MODIS was chosen because an aerosol optical depth product is readily available, and the aerosol models have been validated in the literature (Kaufman and Tanre, 1998; Ichoku et al., 2005; Remer, 2005). The MISR sensor was considered, but not included because the aerosol models and aerosol optical thickness product have been neither presented nor discussed in the peer-reviewed literature.

Candidate dust events were located first in the NASA Earth Observatory archive of natural hazard smoke and dust events. Eight dust storms in the desert southwest were clearly observed in the associated visible imagery. Appropriate MODIS L2 data were examined for all of these cases. Second, a university library data base (Lexis Nexis) of newspaper articles revealed 38 local and regional dust storms over the last four years, most of which caused fatal pileups on major highways. MODIS L2 data were examined for 26 of these dates. If high winds were reported for a series of days surrounding a dust event, data were ordered for days preceding and following these events, in the hopes that the dust storm evolution could be observed and/or tested against the DREAM model.

Over land, aerosol optical thickness (AOT) is derived using the dark target approach but limited to the moist parts of the continents (Kaufman and Tanre, 1998). A dynamical aerosol model was selected to describe the aerosol size distribution, refractive index, single scattering albedo, and the effect of nonsphericity. Models are derived from analysis of ground based remote sensing of the ambient column aerosol size distribution and in situ measurements. Measured radiance from the satellite is converted into aerosol optical thickness, volume/mass concentration, and spectral radiative forcing.

The expected result was that the AOT product would show well-defined areas of elevated dust concentration in the vicinity of the dust event. However, this did not occur. Horizontal distributions of dust in the regions of dust storms were ill defined by the MODIS AOT product. However, AOT data did show dust over some parts of the reported dust event. Furthermore, AOT products for the desert SW appear geographically incoherent in most cases. The AOT data seem to be interspersed with many pixels of no data.

Future Data Set Assessment

For future data assimilation the team has compiled a list of relevant imagery products. Currently these products are documented in a wide variety of hardcopy books and manuals as well as on many websites. Since they are so dispersed, it is difficult to view them simultaneously for comparison purposes. The EOS Data Products Handbooks, Volumes 2 (GSFC, 2003) and 1 (GSFC, 2000), were reviewed for all relevant sensor products. These were then put into an Access Database, resulting in roughly 120 data products that might be of interest to the project. The satellites of most immediate interest are Aqua, Terra, TRMM, and Acrimsat. A wide variety of sensors are carried by these platforms including: MODIS, MISR, CERES, ASTER, MOPITT, AMSU-A, AMSR-E, AIRS, HSB, Acrimsat III, TMI, VIRS, PR, and TRMM. From these two volumes, several attributes were retrieved for each sensor. These included, among others: sensor name, data product, process level, data format, and. resolution. Once these items were entered, columns were also added for website and product ID code. The websites will be explored for other parameters that will aid in evaluating which product codes might be appropriate for use in this project. Examples of assimilation assessment for MOD15 and AMSR-E soil moisture are provided below.

MOD15 FPAR

To pinpoint dust source areas, the team has looked at LAI (Leaf Area Index), EVI (Enhanced Vegetation Index), and FPAR (Fraction of Photosynthetically Active Radiation). The MOD15 FPAR product may be the most useful since there is an FPAR "class" (value 253) labeled "barren, desert, or very sparsely vegetated." In the FPAR algorithm this value, among others for water, urban, and permanent snow and ice, is known as a "fill" class. Since the FPAR algorithm requires MOD12 as an input, it may be possible to use fill class 253 to seasonally update MOD12 in the DREAM model. The team has tested this possibility using the White Sands National Monument in New Mexico. The idea was that wherever FPAR value 253 existed they could be substituted for equivalent MOD12 pixels. Results indicate however that MOD12 missed several areas of dunes while catching some more transitional areas. The FPAR fill value recognized the slightly vegetated transitional areas and only classified the barren areas as "desert". Obviously, the relationship is much more complicated and must be further assessed. Another complicating issue in the data set will be the effect of winter snow. In an assessment of FPAR value 253 over New Mexico for December 2003 and July 2005 (seasonal opposites), it is not clear that fill values are updated along with non-fill classes.

Visual comparisons of the MOD12 and MOD15 products to commercial 1m resolution satellite imagery for sites ranging from California to west Texas suggest that MOD12 over-estimates and MOD15 under-estimates the area of possible dust generation. Moreover the MOD12 product seems to identify small (~1km) dust source areas where there may be none, especially in eastern New Mexico and western Texas. Both products seem to show credible patterns, especially in the larger dust source areas as shown in Figure 23. Another advantage to considering MOD15 instead of MOD12 is its higher temporal resolution (every 8 days) if the fill values are also updated. The data set used for the comparison in Figure 23 is from June 2005; MOD12 was last updated in 2001.

(a) (b) (c)

Figure 23. (a) Digital Globe image at the head of the Sea of Cortez (CA, AZ, Mex.) copyright DigitalGlobe; (b) MOD12 – MODIS Land Cover IGBP Class 16 – “Barren or Sparsely Vegetated”; (c) MOD15 – FPAR fill class 253 – “Barren, desert, or very sparsely vegetated”.

AMSR-E soil moisture

The AMSR-E soil moisture product may be useful as a DREAM input, despite a few major issues. First, the data footprint is around 70km, which could be a problem for DREAM outputs aiming toward higher resolution. Second, there is an absence of data under snow-covered and densely-vegetated areas. As vegetation cover (leaf area index) increases, measurement error increases. Retrieval is not possible under dense vegetation. Third, under many conditions, soil moisture can be retrieved only from the surface centimeter (actual sampling depth varies with the amount of surface moisture present). Soil moisture below ~1cm, therefore, may not be sensed. These are all potential sources of error in the data set, but they do not affect data processing. Moreover, one could argue that recent rains falling on bare or sparsely vegetated surfaces in arid and semi-arid areas would provide enough soil moisture to retard the entrainment of dust for a day or two depending on soil/air boundary temperatures, surface wind speeds, and duration of wind. In DREAM, there is a module called the land surface model (LSM) that treats interactions among soil, vegetation, and atmosphere. LSM simulates soil moisture and soil temperature variations based on water and heat exchanges on the interface between land and atmosphere, including snow and vegetated areas. When precipitation occurs below zero degrees Celsius, the model counts the precipitation as snow and simulates sublimation and melting processes based on water and heat exchanges at the air/land boundary. In terms of assimilating AMSR-E sensor soil moisture data, there may be several alternatives. Ultimately the decision will be based on data availability and the quality of those data. The project’s strategy is to retrieve the best data available and to develop ways to augment with other data sources in areas where there are no good measurements; expand with additional satellites and data products; and, as modeling improvements continue, assimilate and evaluate the most promising products for improved model performance.

Mapping Services Module

New technology development for the project consists of two components: 1) development of modularized visualization tools that integrate model outputs, statistical methods and additional geospatial reference information; and, 2) development of automated data acquisition, processing, and integration technologies that streamline assimilation of NASA data and other model outputs into the DREAM model. A combination of Open Source technologies is being used to meet the requirements of both components.

The visualization component integrates MapServer (an Internet mapping application), R (a mathematical programming and statistical analysis package), and GRASS (a GIS application) through custom Python scripts to present to the user a combination of mapping and analysis tools via a web interface. The web interface provides a standards-compliant (validated against the W3C HTML 4.01 Standard) user interface that may be run on a variety of computer platforms through any standards-compliant browser. The extensive use of server-side processing and scripting also produces a very lightweight client that may be accessed over a wide range of network bandwidths, including dial-up.

The use of MapServer as the internet mapping server application will greatly facilitate the deployment of OGC Web Services (initially WMS, with WFS and WCS if needed), through its integrated support for these service architectures. The integration of R and GRASS into the mapping module permit using the wide range of statistical and geoprocessing functions provided by these applications. All three software environments have been successfully integrated into a client interface and the interface is currently undergoing testing and evaluation.

Data acquisition and processing automation has been accomplished through a combination of Python and Bash shell scripts. Shell scripts process MODIS land products, acquired as multiple HDF files, into mosaiced ArcASCII Grids for ingestion into DREAM, GRASS rasters for analysis, and GeoTIFF's for data download. Python scripts have been developed that may automatically acquire current NCEP/Eta forecast data via OPeNDAP and reprocess these data into GeoTIFF and ArcASCII grids, both for use as DREAM inputs and as data available for analysis and visualization within the user interface. These scripts will provide the foundation for automated acquisition and processing of NASA and other data sets assimilated into the DREAM model when it is installed for routine operation on the project server at the Earth Data Analysis Center, University of New Mexico.

In total, these technology developments facilitate timely acquisition of data and provide the tools and interfaces needed to improve public health decision-making using RSVP/SYRIS.

Review of Health Literature

Complications arising from Hurricane Katrina obviated this analysis. It will be revisited in later benchmarks.

Initial Benchmark

Given the promising results obtained from the DREAM baselining model runs and the MOD12 data set replacement runs, the PHAiRS project team is well satisfied that Earth science satellite observations can improve dust episode forecasting significantly in the southwestern U.S. The team and its partners are encouraged that these improvements will lead to more timely forecasts that will enable public health authorities to issue early warning alerts based on evidence from coincident syndromic surveillance decision support systems.

Improvements to DREAM

Previous sections have shown that assimilating NASA data (specifically MOD12 land cover data) into DREAM, improves model simulations of two dust storms that swept over parts of New Mexico, Texas, and Mexico in December 2003. In consultation with Arizona and New Mexico health and air quality offices, medical experts in epidemiology and the effects of airborne particles on human respiratory systems, and developers of public health decision support systems, the project team has focused on model output improvements that are most important to these stakeholder communities. Accurate, reliable, and understandable predictions and simulations of variables such as (a) time of arrival and duration of elevated levels of airborne dust, (b) expected concentrations, (c) particle size discrimination, especially $PM_{2.5}$, and (d) the time-dependent spatial extent of dust plumes, are needed.

In summary, using MOD12 land cover data (30-second spatial resolution) instead of the OWE (10 minute spatial resolution) improved “forecasts” of: the magnitude and duration of major dust events. Model results were compared to point measurements for “a” and “b” as given above, and to visibility measurements and satellite observations as given for “c” above.

Table 6 lists the performance statistics for modeled surface variables. The biggest differences between results from before and after MOD12 data assimilation are for 2m temperature. The agreement index after NASA data assimilation was 0.95, in comparison with 0.71 obtained using the original DREAM parameters. This is a significant model improvement.

Table 6. Performance statistics of modeled surface wind and temperature.

Metrics	Wind Speed	Wind Direction (degree)	Temp (K)
Agreement Index (DREAM only)	0.74	0.74	0.71
Agreement Index (DREAM + MOD12)	0.75	0.76	0.95

The project team has tested also the use of animated 2-D and 3-D visualization of model outputs to improve user/stakeholder understanding of model capability and to identify types of model output most useful for user applications. This has generated several suggestions from users. The voluntary assistance of the University of Arizona Computing Center staff is appreciated.

Improvements to RSVP

Dr. Alan Zelicoff, developer of RSVP and of its successor SYRIS, is excited by the dust forecasting capabilities that are produced by the DREAM output. The improvement to these surveillance tools that is offered by the model's output facilitates quicker analysis of disease outbreaks by public health officials. Products such as a simple histogram representing the elevation of Cibola County, New Mexico coupled with the observance of flu-like symptoms provides invaluable information for timely analysis of a disease such as hantavirus.

"The new version of SYRIS (in development) contains extensive modeling and disease prediction tools, including the environmental disease. The latter is especially important in daily clinical practice (in both veterinary and human disease) as dust particulates ($PM_{2.5}$), nitrous and sulfur oxides and ozone clearly increase the acute incidence of lung disease and respiratory symptoms in a given area. Distinguishing such environmental illness from infectious disease is a very difficult clinical challenge. Thus, atmospheric data combined with a dust model may be very useful for clinicians in their daily practices. Indeed, such predictive models may enable emergency rooms and clinics to prepare for an increase in patient visits or may enable public health officials and physicians to contact patients who may be advised to change medication or behavior in anticipation of an environmentally induced exacerbation of chronic lung or cardiac disease.

"We anticipate that NASA's REASoN program will provide SYRIS with timely, extraordinarily useful environmental data that can be directly integrated into the SYRIS communications and analysis environment, and hope to have this important augmentation to SYRIS' capability implemented in 2006."

System Improvements

The project team actively engages stakeholders in Arizona, New Mexico, and Texas to help develop a dust forecasting module that enhances their syndromic surveillance systems. Representatives from health and air quality offices in these states are excited about the projected outcomes that will improve their toolset and decision-making capabilities.

<u>*Arizona Department of Health Services*</u>

The Office Public Health Emergency Preparedness and Response at the Arizona Department of Health Services detects and responds to natural or intentional disease events. Funded by the Centers for Disease Control and Prevention (CDC), the Office is composed of several program areas, one of which is Electronic Disease Surveillance. Under this program, the Office is developing a web-based application to enhance disease surveillance and to detect bioterrorism events in Arizona. Known as the Medical Electronic Disease Surveillance and Intelligence System (MEDSIS), this tool is one of Governor Janet Napolitano's action items in [the state's] Homeland Security Strategic Plan. After a visit by the PHAiRS project team, Dr. Ken Komatsu, the Surveillance Project Coordinator, and Dr. Lea Trujillo, a Surveillance Epidemiologist, became very interested in using outputs from DREAM to enhance their surveillance tool. Dr. Trujillo offered these comments: "*As a syndromic surveillance epidemiologist, I am always searching for useful sources of data to track syndrome illnesses that I can add to my program. One of the problems with disease surveillance in general is that we do not know when and where events are going to take place and therefore we are reactive, not proactive. Another problem specific to syndromic surveillance is that with the non-traditional data sources commonly used in syndromic surveillance there is no common user interface. We must use many different programs and software to visualize and analyze the data. Based on the demo we at Arizona Department of Health Services were shown, the Dust Regional Atmospheric Model has the potential to add to existing data sources for* *syndromic surveillance. First, the dust storm model can help predict when and where respiratory illnesses are potentially going to increase, which is a much needed addition to disease surveillance tools. Being forewarned about the possibility of dust storm-related illnesses will help health officials better cope with the resulting illnesses. Second, the model seems simplistic enough to integrate into existing programs instead of requiring its own user interface and program. I understand that it will be possible to format this model to be added as an extra button/tab built into existing visualization systems. This aspect alone will increase the utility of the model for sydromic surveillance. If the DREAM program can help us prepare for events and be integrated into current program operations with such ease, it will be a very welcome and useful tool."*

Pima County AZ

The Pima County Department of Environmental Quality (PDEQ) is interested in improvements for forecasting airborne dust events that affect human health. Visualization techniques for presenting this information, captured the attention of Beth Gorman and Wayne Byrd from PDEQ. After experiencing a prototype virtual reality 3-D visualization of DREAM output, Beth commented: "*The visualization of the data was an exciting way to see the numbers on a page come to life. It was especially intriguing to watch changes in the dust plume over time and from different perspectives. Our department is looking forward to continued coordination with the U of A and others to develop a method of forecasting airborne dust events to protect the many individuals who are at risk in our community.* Wayne offered further comments: *The DREAM model visualization was quite interesting. It provided a virtual look at the formation of a dust event with indications of the originating area. I believe with some modifications it might prove useful in pinpointing sources of dust events which could prove useful in remediation. It would be more useful if the values for dust content, elevation, and wind speed could somehow be indicated in the visualization. Overall, I think it is a good beginning."*

Users outside of the medical community also find promise for the dust forecasting potential of DREAM's output. Margaret Fowke from NOAA wrote in an email message to Dr. Sprigg: "*If you or other colleagues are interested, I would love to have your involvement in developing health impact statements related to dust issues that potentially could be delivered on the air by professional broadcast meteorologists and/or warning coordination meteorologists. I have been working with another public health group affiliated with Tufts University and University of Colorado focused on increasing physical activity according to weather. Looking forward to working together with you."*

City of Lubbock Health Department

Since early 1999, the City of Lubbock Department of Health has evaluated "syndrome-based" disease surveillance systems (SBDSS). That office has provided a preliminary summary (Appendix 3) of its assessment of SBDSS, including RSVP, in meeting the following needs of public health services. The key points of their assessment are itemized below:

In theory, SBDSS's by virtue of their timeliness and volume of information flows could assist in meeting these central public health responsibilities. In practice however, the specific designs, and underlying technical features and scientific approach and ease-of-use is dramatically different across the dozens of SBDSS's currently in existence, some of which have been implemented only in narrowly defined demographic settings or which have other limiting features. The promise is often not met in real-world use.

It is also important to note that the overwhelming majority of SBDSS data gathering focuses solely on human patients, despite the fact that in all significant outbreaks of novel diseases over the past decade or more in North America, animals were the primary source of the diseases. In particular, very large or economically significant disease outbreaks among humans had animal sources.

We found that all of the "automated" SBDSS systems (that is, data mining systems as opposed to active syndromic surveillance systems were problematic in several key areas, timeliness and accuracy. Of importance to PHAiRS was that Information was almost always reported in tabular or textual format without mapping (geographic information system) tools for analysis.

RSVP was the only active SBDSS available for comparison to the passive systems. RSVP7 defined six common syndromes worded in the daily

[7] Zelicoff A, Brillman J, Forslund DW, George JE, Zink S, Koenig S, et al. 2001. The Rapid Syndrome Validation Project (RSVP). Albuquerque, NM: Sandia National Laboratories;

parlance of medicine and public health, and further provided an electronic interface that operated on virtually any computer connected to the Internet. It also provided primitive, but useful, geographic mapping tools.

Their experience with RSVP was generally positive. Physician compliance was high (contrary to the popular, but incorrect belief that physicians will not take time to enter cases) because the number of cases of seriously ill patients who fit into one of the syndrome categories was, on average, a case per month per physician (except during large epidemics). Further, RSVP provided information of immediate clinical importance to physicians thus increasing their cost-effectiveness in practice. Finally, on rare occasions, RSVP enabled public health officials to contact doctors within minutes of a case report when the data suggested unusually worrisome symptoms that might require immediate contact investigation. Thus, RSVP cut down the time from initiation of contact investigation from days to mere minutes.

In summary, RSVP™ was a useful and highly successful “alpha” product., The City Health Department completed its beta testing and has since adopted SYRIS™.

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Appendix 1

Email Dialog Between Public Health Decision Support System Experts

Zelicoff – ARES Corporation, Albuquerque

“ESSENCE is a "data-mining" system and, as such generates enormous amounts of data that have no sensitivity to clinically significant events. It has been tested (along with RODS, Redhat and [other] data-mining systems in Texas -- which is why they have chosen SYRIS. [I] don't want to get into a big discussion about this, rather just to point out the distinction with a difference that is data-mining vs clinician-driven surveillance. A short paper from the Lubbock DOH is available if you'd like to see it. In the end, the market of public health folks will determine what is useful and what simply generates more data-without-insight.

“It should be noted that RSVP (the predecessor to SYRIS) kept the Butler[8] event from turning into a bioterrorism scare. According to Lubbock public health officials, the syndrome surveillance system enabled them to keep the situation under complete control and not a penny of either public health or medical diagnostic funds were [spent] trying to "rule out" plague. This episode was in direct contra-distinction to the anthrax scares in NYC and Washington DC where literally millions of dollars were [spent] trying to "prove a negative," because of the complete absence of any clinical context into which to put the information

“I certainly agree that the underlying "statistic" determines the utility of the [information] system. In most diseases of public health importance, and in ALL of the diseases of bioterrorism importance (especially, but not limited to smallpox), th[e] underlying statistic is N= 1. That is what SYRIS is designed to have high fidelity for. That's also very problematic for data-mining systems that collect information like ER "chief complaints," which are almost always 2 or 3 word descriptors of the chief complaint, e.g."skin rash." How many of those occur in a typical busy ER every week? (answer: many dozens to hundreds). How many are of clinical public health importance (answer: usually zero). So, if one is looking at distributions for underlying statistics (say a standard deviation or two in a time series), data-mining systems are exquisitely designed to fail in terms of timeliness where hours matters. Perhaps this explains part of the reason that people were "scared" despite having ESSENCE or RODS.

“Put another way, there is a practical difference between lots of data (like numbers in a phone book) and the piece of data that is true knowledge (e.g. the phone number you want). SYRIS isn't "perfect" in this regard (nothing ever will be), but it is a big advance over what currently exists.”

Forslund – Los Alamos National Labs

“I'm not keen on most of the medical surveillance systems being deployed including ESSENCE or RODS, but ESSENCE and RODS do get syndromic data in large quantities [that are] useful for [assessing] anthrax outbreaks (as well as others). There are a number of excellent papers in the literature on the sensitivity and selectivity of syndromic surveillance systems. We have found that getting data electronically in large volumes is better than having doctors enter data, which results in statistically unknowable sensitivity to events even though specific information for an event may be more clinically appropriate. This is largely due to the undeterminable sampling statistics of clinician entered syndromic data. It may be able to see a specific clinical event, but there may be no way to know the pervasiveness of such an event. There are ways of getting large amounts of clinically relevant data without adding a single second to the time that a provider is dealing with a patient, i.e., without having to have "double-entry" of data. This would be the ideal. In any case, my only point is that there was a "clinical context" in the DC area for evaluating the presence of Anthrax. But this isn't sufficient to keep people from being "scared" of anthrax given a thought-to-be positive lab test. There was no lack of clinical context, but the response was out of fear of Anthrax based on earlier history. Rationality isn't always part of the process in responding to a potential BT event. I actually don't know if people even looked at the clinical data in this situation. There does seem to be a problem linking Biowatch data with medical surveillance data which DHS is at least beginning to address.

“Perhaps you have other data than I'm aware of, but there has been a "clinical context" in DC for some time from the use of ESSENCE in the National Capitol Region that should rather easily see Anthrax. As I understand [it], the problem [in] DC was an "error" in some data at USAMRIID. A "positive" of Anthrax in a lab test will cause a scare of significant magnitude especially in a heavily populated area even if there is lots of clinical surveillance data showing nothing.”

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[8] See: 2005 "Destroying the Life and Career of a Valued Physician-Scientist Who Tried to Protect Us from Plague: Was It Really Necessary?" Clinical Infectious Diseases, 40:1644-8.

Appendix 2

Used with permission from the City of Lubbock Department of Health

Experience with Syndrome-based Disease Surveillance in Lubbock, Texas: 1999 – Present

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Introduction

Since early 1999, the City of Lubbock Department of Health has evaluated several "syndrome-based" disease surveillance systems (SBDSS). This brief paper is intended as a preliminary summary of our experience focusing on the utility of SBDSS in accomplishing the following primary goals of public health services:

- Prevent epidemics and the spread of disease
- Protect against environmental hazards
- Prevent injuries
- Promote and encourage healthy behaviors and mental health
- Respond to disasters and assist communities in recovery
- Assure the quality and accessibility of health services

In this summary, we focus on infectious diseases (both communicable and noncommunicable) of public health importance.

In theory, SBDSS by virtue of their timeliness and volume of information flows could assist in meeting these central public health responsibilities. In practice however, the specific designs, and underlying technical features and scientific approach and ease-of-use is dramatically different across the dozens of SBDSS currently in existence, some of which have been implemented only in narrowly defined demographic settings or which have other limiting features. The promise is often not met in real-world use.

All SBDSS fall into two basic categories[9]:

> "Automated" or "passive" surveillance systems that seek to exploit existing data streams and employ various statistical algorithms to detect the presence of infectious disease. Some of the data sources that are "tapped" by these passive systems include: pharmacy sales (including over-the-counter medications), total volume of nurse "hot-line" calls, brief "chief complaint" summaries from emergency room logs, and school and work absenteeism

[9] Systematic Review: Surveillance Systems for Early Detection of Bioterrorism-Related Diseases. Dena M. Bravata, MD, MS; Kathryn M. McDonald, MM; Wendy M. Smith, BA; Chara Rydzak, BA; Herbert Szeto, MD, MS, MPH; David L. Buckeridge, MD, MSc; Corinna Haberland, MD; and Douglas K. Owens, MD, MS. *Ann Intern Med.* 2004; 140:910-922.

"Active" or "clinical" surveillance system that depend on selected reporting from physicians, veterinarians, EMS services and other healthcare providers based on the clinical judgment when assessing severity of illness among patients (whether animal or human)

It is also important to note that the overwhelming majority of SBDSS data gathering features focus solely on human patients, despite the fact that in all significant outbreaks of novel diseases over the past decade or more in North America, animals were the primary source of the diseases. In particular, the following very large or economically significant disease outbreaks among humans had animal sources:

Hantavirus Pulmonary Syndrome in the Four Corners Area (1991)
West Nile Fever (1999, 2000)
Human plague in New York City in visitors from New Mexico (2001)
Cryptosporidiosis in Milwaukee (1996) in which 400,000 people were sickened
Monkey pox in the midwest (2003)
SARS (2003)
H5-N1 Avian influenza in humans (1997, 1999, 2005)
Tularemia transmission from prairie dog-to human in Texas

We would further emphasize that *all* of the CDC's Class A and Class B bioterrorism diseases (with the sole exception of smallpox) are animal diseases (sometimes also called zoonotic diseases). Thus, it is highly likely that if there ever is a large-scale bioterrorism event, animals will almost certainly become ill in large numbers and probably with classical syndromes recognized easily by the veterinary community.

Past Experience with SBDSS in Lubbock

Because public health offices are charged with wide-ranging responsibilities yet are relatively underfunded, the City of Lubbock Health Department began to explore means of leveraging limited resources by utilizing electronic SBDSS in1999. Although advertised as easy-to-implement and low-cost, we found that all of the "automated" SBDSS systems were problematic in at least four areas:

The vast majority of cases reported from hospitals and ER-s (based on chief complaints, billing codes or simple census information) resulted in a very large amount of "noise" (data that was of little utility) and which created a serious liability because of the possible need to respond to "spikes" that were merely manifestations of statistical randomness.

Pharmacy-sales data were inherently delayed or complicated by items being "on sale" at large pharmacy chains

Information is almost always reported in tabular or textual format without mapping (geographic information system) tools for analysis

In all cases, since the historical background was largely unknown for any of the data streams, comparisons to identify "true positive" deviations from normal was impossible.

At the same time as we were reviewing the automated disease-surveillance systems that were proliferating across the US, we identified one "clinician-based" or "active" SBDSS called the "Rapid Syndrome Validation Program" (RSVP™) developed by Alan Zelicoff, MD (then at Sandia National Laboratories). RSVP[10] defined six common syndromes worded in the daily parlance of medicine and public health, and further provided an electronic interface that operated on virtually any computer connected to the Internet. It also provided primitive, but useful geographic mapping tools. Key to the RSVP design philosophy was the central notion of "clinical judgment" in which participating physicians (some 10% of all of the practicing physicians in Lubbock) were asked to report those individuals seen in emergency rooms, clinics, and private offices where the patient was assessed as seriously ill (an assessment that clinicians make routinely) and who fit into one of six syndromes strongly suggestive of infectious disease of public health importance:

Fever with influenza-like illness
Fever with skin rash

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[10] Zelicoff A, J. Brillman, D.W. Forslund, J.E. George, S. Zink, S. Koenig, et al. 2001. The Rapid Syndrome Validation Project (RSVP). Albuquerque, NM: Sandia National Laboratories.

Fever with mental status change or neurological change
Severe diarrhea
Hepatitis (presumed to be non-alcohol and non-drug related)
Adult Respiratory Distress Syndrome

Only 15 – 30 *seconds* of physician time is required for reporting a case, and all new reports are immediately reflected on maps of the local public health jurisdiction along with the ability to analyze data using GIS tools. RSVP also allowed Lubbock public health officials to send out alerts on the "front page" of RSVP instantaneously to physicians.

Our experience with RSVP was uniformly positive. Physician compliance was *high* (contrary to the popular, but incorrect belief that physicians will not take time to enter cases) because the number of cases of seriously ill patients who fit into one of the syndrome categories was, on average, a case per month per physician (except during large epidemics). Further, RSVP provided information of immediate clinical importance to physicians thus increasing their cost-effectiveness in practice. Finally, on rare occasions, RSVP enabled public health officials to contact doctors within minutes of a case report when the data suggested unusually worrisome symptoms that might require immediate contact investigation. Thus, RSVP cut down the time from initiation of contact investigation from days to mere minutes.

Our criticisms of RSVP were as follows:

- Because it was a 'web-browser' based system, some particular operating systems or web-browsers would not fully accommodate the RSVP code and some of its features were inaccessible for certain users.
- Mapping functionality, while useful, was slow and cumbersome
- There was no ability to report key veterinary syndromes (see above) that would often presage human disease
- Statistical analysis via RSVP was somewhat difficult because of the nature of the database where all information was stored
- It was unclear to us that RSVP was NEDSS[11] compliant.

Despite these criticisms, we had two very important public health successes with RSVP. We were able to manage the threat of a plague bioterrorism event in January of 2002 when it appeared that strains of the organism were stolen from the Texas Tech University Health Sciences Center by monitoring respiratory disease cases on literally a minute-by-minute basis and providing diagnostic information via RSVP to clinicians. Panic was completely avoided, and there was no unnecessary diagnostic testing to waste public health resources. We predicted via RSVP that we were dealing with a false alarm and that there were no public health concerns – exactly as turned out to be the case.

Our second success was in early 2003 when we discovered, based on clinical symptoms, the need for earlier-than-usual testing for influenza. This resulted in finding influenza cases in our community approximately three weeks earlier than would otherwise have been possible, probably mitigating much morbidity in the population.

Current Experience

RSVP™ was a useful and highly successful "alpha" product, and the Lubbock City Health Department completed its beta testing of this product. We are currently employing a SBDSS from ARES Corporation in Albuquerque called SYRIS™ - The Syndrome Reporting Information System. In distinction to RSVP and all of the passive SBDSS in the marketplace, SYRIS addresses all of our critiques of past systems and offers the following:

[11] The National Electronic Disease Surveillance System (NEDSS) project is a public health initiative to provide a standards-based, integrated approach to disease surveillance and to connect public health surveillance to the burgeoning clinical information systems infrastructure. Note that NEDSS is not a reporting system per se but rather an architecture description promulgated by the Centers for Disease Control. See MMWR, March 28, 2001.

It is completely platform-independent and does not require a web-browser. Thus, it will run on virtually any Internet-connected device including many handheld devices.
SYRIS is comprehensive including *all* critical “health care providers”

- Physicians, physician-assistants, nurse practitioners and nurse clinicians
- School nurses (who report absenteeism and commentary)
- EMS professionals (reporting transport-cases by syndrome)
- Veterinarians (who have 9 separate syndromes covering all major domestic, agricultural and exotic animal species)
- Coroner/Office of the Medical Investigator (who also have a list of syndromes based solely on information from unexpected death reports)
- Laboratory technicians (who can report all lab tests for infectious agents in less than 1 minute per week)
- Animal control and environmental health officials (who report on captured stray animals or wildlife and the number requiring euthanasia due to severe illness)
- Wild-life rehabilitators

Enhanced mapping features based on the “open source” Minnesota Mapping Server that provides for near instantaneous map updating and query to any region where SYRIS is in use
Full NEDSS compliance
Extremely rapid data entry: less than 15 seconds for physicians and veterinarians
Automated and manual alarm features so that public health officials can be notified by digital paging and e-mail when cases that meet specifically defined criteria (at the discretion of local public health officials) are met.
Easy statistical analysis of all current and historical SYRIS data
Easy training: SYRIS is intuitive to use and a full manual is available online tailored to each of the 8 user communities defined above
Low cost: approximately 7 – 8 cents per capita. So, in our catchment area of 250,000 people, SYRIS will cost less than $18,000. This licensing fee includes 24/7 support, all database maintenance and storage and automatic updates to the software each time a user starts SYRIS

We believe that SYRIS will solve the vast majority of our disease surveillance and response needs (including emergency response in the case of bioterrorism) with a low false alarm rate and high sensitivity.

Summary:

Our experience with properly designed active, clinician-driven SBDSS demonstrates that physicians and other busy health professionals will report cases of suspected infectious disease if the system is fast (less than 15 – 30seconds), provides immediate feedback to clinicians on local infectious disease outbreaks, permits selective interaction between public health officials and clinicians on a real-time basis as warranted, and which is inexpensive. SYRIS meets all of these criteria. In addition, unlike the “passive” or “data-mining” approaches, SYRIS has a low false-positive rate (thus mitigating the investigation of a large number of false alarms and squandering limited public health resources) while at the same time facilitating enhanced relationships between local public health officials and all health care providers.

SYRIS makes public health part of daily human and veterinary medical practice and medicine part of daily public health operations.

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Appendix 3 – Terminology

Animation: Process of giving the illusion of movement to drawings, models, or inanimate objects. Computer animation is a form of animated graphics that has replaced "stop motion" of scale-model puppets or drawings.

Data Mining: Type of database analysis that attempts to discover useful patterns or relationships in a group of data. Analysis of data in a database using tools which look for trends or anomalies without knowledge of the meaning of the data. Data mining was invented by IBM who hold some related patents. Data processing using sophisticated data search capabilities and statistical algorithms to discover patterns and correlations in large preexisting databases; a way to discover new meaning in data (from WordNet ® 2.0, © 2003 Princeton University).

Decision Support System: An information system that accumulates input from a variety of sources such that authorities are able to make informed decisions about evolving situations. Such systems may include numerous subsystems for specific kinds of required information, and that prescribe the flow of data into models and the flow of outputs from those models into higher levels of abstraction for making decisions (see Kaupp et al., 2004 for a more complete tutorial).

Grand Challenge: A call for a specific scientific or technological innovation that would remove a critical barrier to solving an important health problem in the developing world with a high likelihood of global impact and feasibility (Varmus, H. et al., 2003).

Model: There are many types of models (scaled physical models, conceptual models, mathematical models, and others). PHAiRS is using a mathematical model that provides forecasting capabilities of atmospheric dust episodes in the Southwest. Outputs from this model are used as inputs to a conceptual model for facilitating health reporting and consequent public health alerts electronically.

Surveillance: The ongoing, systematic collection, analysis, interpretation, and dissemination of health data (Binder et al., 1999); Also, for ethical and Institutional Review Board (IRB) purposes, "Public health surveillance is essentially descriptive in nature. It describes the occurrence of injury or disease and its determinants in the population. It also leads to public health action…, if we confuse surveillance with research, we may be motivated to collect large amounts of detailed data on each case. The burden of this approach is too great for the resources available…" quoted by Fairchild A.L. and R. Bayer, 2004 from World Bank Group "Public health surveillance toolkit (2002).

Syndrome/Syndromic: A number of symptoms occurring together that characterize a specific disease or a group of diseases, each having separate causes and health outcomes.

Visualization: Process of graphically displaying real or simulated scientific data (Concise Encyclopedia, Encyclopedia Britannica Online).

Appendix 4 – Acronyms

ACRIMSAT – Active Cavity Radiometer Irradiance Monitor Satellite

AIRS – Atmospheric Infrared Sounder

AMSR-E – Advanced Microwave Scanning Radiometer for EOS

AMSU – Advanced Microwave Sounding Unit

AOT – Aerosol Optical Thickness

AQS – Air Quality System

ASTER – Advanced Spaceborne Thermal Emission and Reflection Radiometer

CAMS – Continuous Air Monitoring Stations

CDC – Centers for Disease Control and Prevention

CERES – Clouds and the Earth's Radiant Energy System

DOH – Department of Health

DREAM – Dust Regional Atmospheric Model

ECMWF – European Center for Medium-Range Weather Forecast

EID – Emerging Infectious Disease

EOS – Earth Observation System

EPA – Environmental Protection Agency

ESSENCE – Electronic Surveillance System for the Early Notification of Community-Based Epidemics

EVI – Enhanced Vegetation Index

FPAR – Fraction of Photosynthetically Active Radiation

GRASS – Geographic Resources Analysis Support System

GSFC – Goddard Space Flight Center

HDF – Hierarchical Data Format

HSB – Humidity Sounder for Brazil

LAI – Leaf Area Index

LSM – Land Surface Model

MEDSIS – Medical Electronic Disease Surveillance and Intelligence System

METAR – Meteorological Aerodrome Report

MISR – Multi-Angle Imaging SpectroRadiometer

MODIS – Moderate Resolution Imaging Spectroradiometer

MOPITT – Measurements of Pollution in the Troposphere

NAAQS – National Ambient Air Quality Standards

NASA – National Aeronautics and Space Administration

NCEP – National Centers for Environmental Prediction

NCRS – Natural Resources Conservation Service

NEDSS – National Electronic Disease Surveillance System

NOAA – National Oceanic and Atmospheric Administration

NPOESS – National Polar-Orbiting Environmental Satellite System

OGC – Open Geospatial Consortium

OPeNDAP – Open-Source Project for a Network Data Access Protocol

OWE – Olson World Ecosystems

PDEQ – Pima County Department of Environmental Quality

PHAiRS – Public Health Applications in Remote Sensing

PR – Precipitation Radar

REASoN – Research, Education, and Applications Solution Network

RODS – Real-Time Outbreak and Disease Surveillance

RSVP – Rapid Syndrome Validation Project

SARS – Severe Acute Respiratory Syndrome

SBDSS – Syndrome-Based Disease Surveillance System

SRTM – Shuttle Radar Topography Mission

SYRIS – Syndrome Reporting Information System

TEOM – Tapered-Element Oscillation Microbalance

TMI – TRMM Microwave Imager

TRMM – Tropical Rainfall Measuring Mission

USAMRIID – United States Army Medical Research Institute of Infectious Diseases

VIRS – Visible Infrared Scanner

WCS – Web Coverage Services

WFS – Web Feature Services

WMS – Web Mapping Services