Modeling Atmospheric Dust for a Public Health Decision Support System

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Abstract – Environmental health and public health are often 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. To study them, one needs education in atmospheric physics and chemistry, water chemistry, geophysics, and biology. *Public health* is related in large measure to degraded environmental parameters (mostly 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 may in turn 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. This paper describes an engineering system for linking atmospheric dust episodes to specific public health outcomes that can be verified and validated in medical terms. It requires forging new scientific partnerships from the environmental and medical professions.

Keywords: Remote Sensing, Public Health, Environment, Pollution, Weather, Modeling, Prediction, Engineering

1. INTRODUCTION

1.1 Background and Stimulus

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 force increases in atmospheric dust episodes and the ability of these to carry viruses, bacteria, radioactive isotopes, and pesticides 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 draw premature conclusions about cause and effect relationships. Behind these popular press contributions is a body of national and international evidence citing the perils of doing "business as usual" at the expense of environmental and public health (Woerden, 1999). In 2002, the National Aeronautics and Space Administration's (NASA's) *Earth Science Applications Division* (now part of the *Science Mission Directorate*) began an integrative program called Research, Education, Applications Solutions Network (REASoN) that echoes closely the views expressed by Woerden regarding core datasets, the collection of data having high quality, and their use for environmental policy.

1.2 Context

The first principle to emerge from the United Nations Conference on Environment and Development held in Rio de Janeiro (UN, 1992) was 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.*" Here, perhaps, is an early convergence of environmental with public health. Ten years later at the 2002 World Summit on Sustainable Development (WSSD), the Johannesburg Plan of Implementation (POI) 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."

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 next generation of modelers will be required to form teams that partner members from the biogeophysical realm with those from the medical realm to assess quickly changing and highly vulnerable situations.

People and Pixels (Liverman et al., 1998) was among the early publications to draw humankind into the arena of satellite remote sensing. Most earlier scientific literature focused on physical and natural applications in agriculture, forestry, rangeland, hydrology, and mineral exploration. After *People and Pixels*, interest has migrated to people-oriented issues like food security, environmental health, public health, disasters and hazards, and most recently on security and antiterrorism. Because of their immense humanitarian and policy implications, remote sensing and geospatial programs are moving quickly to address the consequences of climate change on human health, air and water quality degradation, and diseases following natural disasters.

For the photogrammetry, remote sensing, and geospatial information sciences, the key language in Paragraphs 53-57 in the POI includes the following (especially the underlined phrases). For the most part they are general aims and goals, but a few are quite specific.

§-54:

- Integrate health concerns into strategies, policies, and programs for sustainable development;
- Provide technical and financial assistance for health information systems and integrated databases;
- Target research efforts and apply research results to priority public health issues and reducing exposures to public health risks;
- Start international initiatives that assess health and environment linkages; and,
- Develop preventive, promotive, and curative programs for non-communicable diseases (like chronic respiratory diseases.

§ 56:

Reduce respiratory diseases and other health impacts resulting from air pollution;

2. COUPLING ATMOSPHERIC DUST WITH HUMAN HEALTH

2.1 Goals and Structure

Goals for the NASA REASoN project reported here are to (a) assimilate satellite data into a regional weather forecasting model; (b) baseline the value added to this model by incorporating satellite data 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 the scientific and societal benefits.

The project has three thrusts moving along a parallel front. The first focuses on assimilating satellite data from MODIS Terra and other sources into the Dust Regional Atmospheric Model (DREAM) developed at the University of Malta. DREAM, in turn, is driven by the National Centers for Environmental Prediction (NCEP)/Eta weather forecasting model, widely used around the world. 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 front focuses on optimizing DREAM model outputs by iterating model inputs with a variety of satellite products and assessing incremental improvements. The aim of this effort is to partner with a prototypical public health decision support system called the Rapid Syndrome Validation Project (RSVP) developed by Sandia National Laboratories. For this project, interest is concentrated on respiratory diseases that are known clinically to be triggered, at least in part, by atmospheric dust (asthma, Hantavirus Pulmonary Syndrome, and Acute Respiratory Distress Syndrome). 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 that dust 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 front involves working with public health authorities to determine whether there are statistically valid relationships between dust episodes and records for 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 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; but also that allows 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 its part, satellite-based dust forecast models must be recognized as a reliable source of information to issue medical alerts. Epidemiologists across the world are fearful of a pandemic flu outbreak and are very aware that devastating respiratory diseases can span the globe in 24 hours (Selinus et al., 2005).

2.2 Framework

For this project, the framework for coupling atmospheric dust processes with human health responses begins with experimental NASA satellite data products and modifies them for assimilation into DREAM. The output from DREAM becomes 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.

2.3 Challenge

Direct satellite observations have confirmed through numerous studies that moderate and severe dust events can be detected, and that dust can be traced in the atmosphere across continents and oceans (e.g. Kaufman et al., 2000; Grousset et al., 2003; Gu et al., 2003; Miller, 2003; 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, there is growing recognition that naturally dusty environments have long-term human health impacts (e.g., Goudie and Middleton, 2001; Wiggs et al., 2003). Direct coupling of specific dust episodes with health response statistics remains to be demonstrated. Whereas long-term (lifetime) exposures to dusty environments may lead to desert lung (silicosis), or pneumoconiosis in high altitude or desert dwelling populations, asthma is a chronic respiratory disease triggered by numerous indoor and outdoor environmental attributes. Asthma is a rapidly growing illness among children and elders throughout the industrialized world. It remains to be demonstrated that these populations respond to individual dust events in numbers high enough to issue public health alerts; or that such events can be forecasted and tracked in adequate time to issue effective alerts.

3. MODEL ELEMENTS

3.1 Dust Regional Atmospheric Model (DREAM)

DREAM is based on a Eulerian modelling approach (Nickovic et al., 2001). Its dust concentration module consists of three static surface parameters: topography and vegetation cover at 1x1 km resolution, provided by the U.S. Geological Survey; and soil types converted into texture classes at 2x2 minute resolution provided by the UN/FAO. Atmospheric inputs include both wet and dry deposition parameters, and seven ZOBLER soil texture classes at 1.0° resolution, provided by the NCEP/Eta model. Other NCEP/Eta parameters include lat/lon, 32 pressure levels from the surface to 100 hPa, geo-potential height, wind components, specific humidity, and soil temperature, moisture, and albedo. Resolution of the atmospheric inputs range from 0.1° to 1.0° lat/lon.

This set of inputs has been used to model a severe dust event that arose abruptly in Eastern New Mexico and West Texas on December 15, 2003. A Pacific cold front swept through the region bringing gale force winds and dry conditions, causing one of the worst dust storms in recent years. Since it was installed in 2001, Continuous Air Monitoring Station (CAMS) in Lubbock measured its highest $PM_{2.5}$ one-hour average (485.6 $\mu g/m^3$) between 1300-1400 hrs Central Standard Time. It also measured a daily average $PM_{2.5}$ of 76.7 $\mu g/m^3$. The PM_{10} daily average concentration of 384 $\mu g/m^3$ was estimated to be five times higher, than is considered "healthy" by the U.S. Environmental Protection Agency.

Results of a model run are encouraging and form a baseline for DREAM's capability. DREAM was used to model hundreds of weather reporting stations across more than 10° of latitude and 20° of longitude, whereas geostatistically produced map of ground level visibility was based on only six widely scattered $PM_{2.5}$ monitors. Both outputs show that a dust event was evolving in southeastern New Mexico, but DREAM failed to show the heaviest concentrations of $PM_{2.5}$ spreading eastward.

3.2 Satellite Data Assimilation into DREAM

An initial list of products has been 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.

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 satellite data replacements. 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 1 includes inputs that are direct replacements for baseline data sets, assuming the data are compatible in the model. If yes, then the second and following tasks for assimilation are to iterate the process with different kinds of products and resolutions, and to measure the incremental improvements in model outputs.

3.3 Health Data

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 carried by dust; and,
- Chemicals (including human made, funga, 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 (like over-grazing, the addition of fertilizers and pesticides, and other practices on the land) lead to industrial and agricultural pollution (e.g., cotton gin dust and aerosolized cattle feed-lot waste) that are aggravated 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. 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, behavioural- 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.

3.4 RSVP Decision Support

At present, science and technology increasingly support the *practice* of medicine; but, appropriate technology for medical *reporting* seems trapped in the paper world of the 20th Century. RSVP is one of several 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 has 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).

4. SUMMARY

Coupling biogeochemical 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 will someday 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.

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