REMOTE SURVEILLANCE TECHNOLOGIES FOR ASSESSING

BIOLOGICAL THREATS

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ABSTRACT

Recent advances in both experimental and operational Earth observations from orbital platforms promise synoptic and much more timely measurement of atmospheric, hydrologic, and terrestrial composition. Understanding Earth system processes in terms of carbon, nitrogen, and water cycles, climate and weather episodes, and anomalies detectable in the patterns of these processes are now being examined for more specific applications in homeland security, including biological threats, bio-surveillance, and human/animal health. Combined with geospatial data from demographic, social, economic, and biophysical parameters, information can be assembled for more reliable and realistic decision support, and packaged to manage incidents that have impacts ranging from municipal through county, regional, and global scales. Issues surrounding these new observation capabilities include sensor resolution, compatibility of data architectures, interoperability of analytical systems, and delivery mechanisms to meet stakeholder requirements. The presentation will focus on how satellite sensor data are used for direct observations of potential biological threats, as well as how they are used in an Earth science modeling framework to enhance threat forecasting and prediction. Discussion focuses on the elements of a New Mexico geospatial information infrastructure (NMGII).

INTRODUCTION

Background and Scope of Bio-threats[1]

The epiphany of September 11th (2001), like its historical antecedents of July 4th (1776) and April (1861) was a signature event in U.S. history. In most circles of American society, words like terrorism, vulnerability, risk, and mass evacuation were reserved for "other places;" but afterward, became defining elements of everyday concern. De Chardin (1978), writes that there is good in every adversity, that humanity and civilization progress despite adversity, and that human inventiveness always provides a means for overcoming adversity. In today's lexicon, it is called "just-in-time technology." If necessity is the mother of invention, then terrorism has become the stimulus for refining and applying whatever means are required to mitigate, prevent, and respond to threats.

This paper explores some of the more pervasive bio-threat applications addressable by America's civilian satellite technology, combined with geographic information science (GI-Science). Since these technologies are inherently geographical, and operate at the population and population "subsets-at-risk" level rather than at the organism level. Applications must be selected in which there are strong biological links to landscape and environmental factors. The paper describes the conceptual and organizational means for incorporating geospatial data into decision-making processes in context of national and state programs; and, will describe the existing elements of a New Mexico geospatial information infrastructure (NMGII) for data and information sharing in time of emergency. Organizing and energizing these elements would be in-step with national priorities for improving bio-surveillance, and would be timely for New Mexico for several reasons

1. President Bush's 2005 budget request includes a $274M Bio-Surveillance Program Initiative (BSPI) that has three elements (see http://dhs.gov/dhspublic/display?theme=34&content=309&print=true).
    a. $11M to the Department of Homeland Security's Information Analysis and Infrastructure Protection Program (IAIP) to "develop a real-time system for harvesting data on the health of our population, animals, plants, and food supply and integrate this information with environmental monitoring [remote sensing] and intelligence data as well."
    b. Under the Department of Health and Human Services, $130M would be allocated to the Centers for Disease Control and Prevention (CDC). The CDC would use these funds to: (a) improve

[1] All color illustrations have been removed from this article to conserve space for text. Illustrations can be found in the electronic PowerPoint presentation given at the Conference, March 18-19, 2004, Albuquerque, NM.

linkages between public health laboratories, and border health and quarantine stations; and (b) to automate analysis techniques on electronically available health-related data. Both of these functions would have a significant impact on New Mexico in terms of rapid syndrome validation efforts currently underway, and for international transboundary collaborations under development. The need for an NMGII is readily apparent.

c. Under the U.S. Department of Agriculture, $10M would be allocated to improve food and animal surveillance conducted by the Food Safety and Inspection Service and the Animal and Plant Inspection Service. Considering the number of cattle imported from Mexico and Canada each year, and the recent mad cow discovery in Washington State, a geospatially explicit tracking system for herds in New Mexico should be a top priority.

2. Governor Bill Richardson has issued Executive Order # 2003-018 establishing the Geospatial Data Acquisition Coordination Committee (GDACC). This committee, which reporta to the Information Technology Commission (ITC), has responsibilities and authority to coordinate and leverage funding requests and projects requiring geospatial data for New Mexico. Its first project is focused on statewide geospatial data acquisition and distribution, the first priority for which is to acquire digital aerial infrared and natural color photography of the entire state processed into a digital orthophoto quadrangle (DOQ) format (i.e., meets U.S. map standards for x,y coordinate accuracy). Subsequent requirements include: (a) acquiring Light Detection and Ranging (LiDAR) data for fine-resolution maps of topography, slope, and aspect to obtain the "z" coordinate for landforms; and (b) creating a state-wide cadastre of the extent, value, and ownership of land.

3. Finally, the speed at which bio-threats can emerge is orders of magnitude faster than ever before in history. In a recent article in *National Geographic*, it was reported that hypersonic aircraft can get anywhere on the planet within four hours (Klesius 2003). Assuming that commercial hypersonic aircraft will someday be a reality, the possibilities for connecting people everywhere in a matter of hours will not all have positive consequences, but certainly will demand rapid bio-threat response system.

Bio-threats defined

Any threat to human lives or food supplies might be considered a threat. If so, then aging itself, is a bio-threat. A more restricted definition for this paper might be *…threats to populations of humans, their collective health, their food supplies, or the condition of the ecosystems (natural or built) in which they live.* Biogeographically, all organic migrations represent invading species that alter, and sometimes thoroughly disrupt, normal ecosystem functions. People serving as agents of transport, either passively or purposefully, are a bio-threat, especially commercial air travelers. While most people are benign in their effects on systems, the SARS "epidemic" of 2003 exemplifies global concern about the speed of viral diffusions. Airborne spores, bacteria, and fungi are also bio-threats. So are animals and plants, whether in commercial transit, through natural migrations, or malfeasant activities. "Normalcy" in ecosystems rides the edge of order and chaos, so the introduction of foreign biological materials stimulates the delicate balance of any ecosystem (natural, economic, or social) to adapt (Waldrop 1992, Gleick 1987, Kauffman 1993). Until recently, species on the move by natural means were considered a positive sign of an organism's ability to expand its range; but in today's world, even natural processes have potentially deleterious effects on economic activities.

Bio-terrorism 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) forecasting or preventing airborne and vector-borne contagious, or infectious, diseases; (b) monitoring the safety of commercial food supplies as species are imported and exported; and (c) tracking hazardous or toxic materials in transport that, if released, could represent horrific means for massive and extensive biological damage. The definition of bio-threats presented here only represents a subset of the full scope of threats, but it highlights applications addressable by remote surveillance technologies.

1. Respiratory and Infectious Diseases

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.

2. Tracking Species

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. Hapless introductions of such plants as salt cedar (*Tamarix pentandra*), tumbleweed (*Salsola* spp.) and cheat grass (*Bromus* spp.) have permanently altered the rangelands of western America. Other noxious invaders expanding their ranges through overgrazing include creosote bush (*Larrea divaricata*) and cholla (*Opuntia* spp.). The rates and directions of spread in these species are not only detectable, but measurable from satellite or aerial images. Clearly, the combined effects of these invasive species, gradual though they are, reduce rangeland productivity, increase the area prone to dust, and generally drive the economics for regional land-use change. The fact that these changes can be identified and measured argues for remote surveillance systems that monitor them in virtual time and space for use when needed.

Likewise, commercial shipments of food supplies can be, and are increasingly being, monitored throughout their journey from remote farms to distributed dining room tables. For many applications, tracking technologies such as radio tags on animals, or On-star trackers on trucks, exist that in future could provide interdiction, prevention of spread, or mitigation information; but these have not been implemented widely because geospatial data modeling and information extraction technologies need to be developed in conjunction with the tracking technology. Modeling and testing bio-threat scenarios requires vast amounts of data and information accessed from numerous distributed sources, and aggregated into specific requirements for management decisions, almost in real-time.

The recent episode of mad cow disease in Washington State illustrates how vulnerable the U.S. livestock industry, is in time of emergency. As a key state in the U.S./Mexico transborder region, there is an explicit need for tracking livestock imports from Mexico (Curry 2004). Existing systems in the U.S. and Europe have served well, but they evolved over many decades in a pre-terrorist, *laissez faire* economy, and need to be modernized (Barcos 2001, McGrann & Wiseman 2001). Sentinel surveillance systems are a recognized priority for gauging animal health at the border; but once animals are released on the U.S. side, there is no comprehensive tracking program to follow their movements. Moreover, there is apparently only a rudimentary tracking system on the Mexican side of the border (Barcos 2001). Animals are funneled through the State of Chihuahua where holding pens are utilized while they await transshipment to a border crossing. Not much is known about the history of those animals prior to their arrival in Chihuahua. Considering the economic importance of New Mexico's livestock industry, it seems prudent to develop an inventory and tracking system for intra- and interstate cattle that can utilize geospatial technologies. It is known, for example, that Mexican cattle imports are correlated with droughts and declining range conditions in Chihuahua. Range conditions are observable every day throughout Mexico and Central America and these data can be animated into monthly, seasonal, annual, or, if necessary, decadal products that can then be merged with related Mexican and New Mexican livestock data for interpretation.

3. Hazardous, Toxic, and Nuclear Transport

Theft of nuclear materials from federal or other laboratories is a high-profile bio-threat in New Mexico. Since 9/11, however, planners have imagined a wide array of bio-threats from deliberate industrial accidents, hijackings, and sabotage. The primary concern is for populations in the immediate vicinity, down-wind, or down-stream from the point of release. Hazardous materials are transported across the United States using Interstate and U.S. highways, and in some cases state and local roads. Although not as visible as surface roads, pipelines transport vast quantities of volatile liquids and gases through underground urban and rural networks. Commercial pipeline companies are beginning to use satellite imagery in their geospatial databases to lessen threats of terrorism and to prevent or mitigate explosions in populated areas

With growing demand for consumer products manufactured with materials that are harmful if released in nature, there is heightened awareness by officials and the public of the risks posed by hazardous cargoes. These concerns demand improved assessment and risk avoidance technology. Safe transport of hazardous materials, risks to cargo, and risk to human lives and the environment are a major concern of every state and county. Planning for worst-case scenarios calls for an operational, geospatial system that provides enhanced route assessment, risk evaluation, mass evacuation planning, and response capabilities.

ELEMENTS IN AN NMGII

States are working diligently to develop and improve their rapid response systems to bio-threats. Most have concentrated on expanding the physical infrastructures for first-responders, and implementing policies for better communication and data sharing. What is often missing from these efforts is a recognition that data and information sharing is a complicated virtual system requiring its own infrastructure, operating procedures, communication protocols, data standards and architecture, and commitment to create and maintain it. The basic elements of such an infrastructure already exist in New Mexico, but have yet to be organized into a prototypical operating system that can be tested with bio-threat scenarios.

National assets

At the national level there are several programs and organizations whose activities and products are core to developing a statewide geospatial information infrastructure. Among these are the nation's space program, the National States Geographic Information Council (NSGIC), The Federal Geographic Data Committee (FGDC), which includes the National Spatial Data Infrastructure (NSDI), National Map and Geospatial One-Stop.

1. Satellite Resources and Applications for Bio-Surveillance

Until 1998, Earth observations from orbital and sub-orbital altitudes were aimed primarily at natural resources monitoring by federal, state, and local government agencies. By the late 1990s, traditional requirements shifted toward people and understanding the role of environmental factors affecting populations (Morain 1998). Climate variability and the potential societal and economic consequences of change became the rallying concept for pre-9/11 assessments (National Assessment Synthesis Team (2001), and Southwest Regional Assessment Team (2000). Post-9/11 concerns stem from this knowledge, adding the elements of terror and surprise. Climate and weather events become vehicles for bio-terror.

The National Aeronautics and Space Administration (NASA) is the nation's custodian for space research and development, while the National Oceanic and Atmospheric Administration (NOAA), Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), U.S Department of Agriculture (USDA), U.S. Department of Transportation (USDOT), and perhaps someday the Department of Homeland Security (DHS) are responsible for operational sensor systems. The latter lag far behind the former, but systems now being planned could close the gap by 2010. The question is whether appropriate geospatial infrastructures will be ready to accept these new data sources, or whether their absence will hinder the potential of rapid response systems?

The means for Satellite Earth observations are designed and built by government and commercial space providers based on requirements set in collaboration with government, non-government, academic, and commercial inputs. Data returned by the sensors are then calibrated, validated, and converted into "products" by instrument teams consisting of scientists and collaborating stakeholders throughout the international community. Incremental improvements in sensor design, sensitivity, and reliability are gradually incorporated into follow-on operational sensors for broad public and scientific use.

Today, NASA has an array of eighteen orbiting platforms, each with a complement of sensors (nearly 81 in all) recording specific Earth system functions. Hundreds of products from these sensors are available for various application sectors, many serving cross-purposes among these applications. Almost none of them have been studied seriously for their utility in reducing bio-threats. Nevertheless, satellite environmental measurements, combined with information from ground networks and other geospatial data (e.g., demographic, transportation, health, air and water quality networks), provide a means for forecasting economic, environmental, and social conditions that would assist bio-threat reduction and rapid response capabilities.

NOAA has been the most aggressive government agency to gather operational climate and weather data. It now operates weather, climate, coastal, and marine data systems for thousands of users, worldwide. Sensors onboard their environmental satellites provide more than 30 years of data begging to be incorporated into long time-series observations in a geospatial architecture. Future sensors are being assessed now for NOAA's next generation of operations, all of which will build on the legacy sensors. Thus, bio-surveillance communities are currently assessing the utility of data and products from NASA's suite of experimental sensors, preparing for their operational use. This will happen through chance; there must be a plan to evaluate and incorporate these products into robust geospatial information infrastructures designed for the purpose..

2. National States Geographic Information Council (NSGIC)

The National States Geographic Information Council (NSGIC) began in the late 1980s to serve as a forum for states concerned with geospatial information technologies. It has evolved into an active, vocal organization on geographic information and technology issues. NSGIC advocates State interests in national issues such as Homeland Security and the National Spatial Data Infrastructure while it supports its member states in their individual initiatives. NSGIC is adamant in promoting "prudent geographic information integration and systems development." It keeps a watchful eye on legislative and agency actions that impact the geospatial information infrastructure and endorses positive legislative actions. The NSGIC Bylaws state "that the purpose of the Council is to encourage effective and efficient government through the coordinated development of geographic information and related technologies to ensure that information may be integrated at all levels of government." Areas of interest include policy, liaison/networking, research, and education/public relations. New Mexico is a member of NSGIC.

In context of Homeland Security, NSGIC is the conduit for information flow between the National level and the states. For example, they provided information on release of the recent Office for Domestic Preparedness (ODP), Department of Homeland Security (DHS) 2004 solicitation; and they are monitoring the status of the DHS Regional Information Pilot Projects. In addition to providing information on the status of Homeland Security issues and funding opportunities, NSGIC has been aggressive on other Homeland Security fronts. They drafted and accepted a resolution entitled "Supporting Homeland Security with Geographic Information Systems and Spatial Data Development" (NSGIC 2003). This resolution calls upon ODP to include clear geospatial guidance in subsequent rounds of their program. NSGIC produced a "Declaration of Interdependence" entitled Saving Lives and Saving Money: An Urgent Call to Build the National Spatial Data Infrastructure in Support of Public Safety (NSGIC 2002). New Mexico is a signatory on this document (signed by the New Mexico Geographic Information Council). Other Homeland Security initiatives undertaken by NSGIC include: (1) developing a "Data Access Decision Tree for Critical Infrastructure Data," (2) producing a list of relevant links and documents for "Domestic Preparedness and Homeland Security," (3) developing a "Homeland Security Data Elements List," and (4) reviewing proposed map symbols for emergency management applications.

3. National Spatial Data Infrastructure (NSDI)

On April 11, 1994 President Clinton issued Executive Order 12906, *Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure*, thereby establishing the NSDI. "Technologies, policies, and people necessary to promote sharing of geospatial data throughout all levels of government, the private and non-profit sectors, and the academic community" defines the NSDI (FGDC 2003). The Federal Geographic Data Committee (FGDC) was convened to facilitate the President's directive. Nineteen Federal agencies comprise FGDC, including representatives from the Executive Office of the President, Cabinet-level members, and independent agencies. FGDC's charge is to develop NSDI in cooperation with State, local and tribal governments, academic institutions, and the private sector. Fourteen working groups and 13 thematic subcommittees address a broad spectrum of topics and issues related to developing the NSDI. Standards, for example, are a critical item for many of the thematic topics. One of the first standards approved by FGDC was the *Content Standard for Geospatial Metadata*. Use of this standard has become essential for geospatial data developers at all levels of government.

The newest addition to FGDC is the Homeland Security Working Group (HSWG), which ensures that NSDI supports "…preparation for, prevention of, protection against, response to, and recovery from" incidents caused by intentional and related adverse events. FGDC has taken aggressive steps toward securing the Nation's geospatial information infrastructure with initiatives such as standardizing map symbolization and supporting policies involving homeland security and geographic information systems.

Two programs for geospatial data have evolved recently in NSDI: The National Map and Geospatial One-Stop. The National Map is an initiative stemming from the FGDC in support of the NSDI. By collaborating with State and local governments, and other partners, the National Map strives to develop an integrated base of data that will become part of the critical information infrastructure in the event of intentional disruptions such as that of a terrorist attack. At about the same time, the Office of Management and Budget (OMB) announced its *E-Government* initiative in response to the President's Management Agenda for improving effectiveness, efficiency, and service government-wide. Included in this initiative is the Geospatial One-Stop, a web-based portal for geospatial data discovery and access. The vision of Geospatial One-Stop is to "…*spatially* enable the delivery of government services." It will provide a geographic component for all web-based E-Government activities from Federal through State, local, and tribal governments. The current model for discovering and accessing data is via the NSDI Gateway, which connects users to a network of databases that are compliant with specified NSDI standards. Once implemented, Geospatial One-Stop will be the front-end for the NSDI Clearinghouse, and will rely on the National Map for base content data. These technological advances in accessing and sharing data are key components for building a critical information infrastructure, which is vital for prevention of, and responding to, terrorist attacks. New Mexico is participating in the NSDI via the Resource Geographic Information System (RGIS) Clearinghouse, which is a registered node accessible through the NSDI Gateway.

New Mexico Assets

1. Resource Geographic Information System (RGIS) Clearinghouse

In its 12th year as a state-funded special project at UNM, RGIS has evolved from a collector and organizer of digital geographic data into a robust Clearinghouse for those data. Currently, RGIS offers a web interface to a database repository of geospatial data for New Mexico. Free data downloads and online mapping services support the needs of the state's geospatial users. By early 2005, the Clearinghouse will be enhanced significantly by: (a) extending current text-based data discovery tools to provide spatial queries; (b) providing live previews of all available data layers; (c) developing full FGDC-compliant metadata in SML format for all data; (d) providing losslessly compressed data; and (e) creating new functionalities such as interactive mapping applications and dynamic data delivery that provide tools for sub-setting, re-projection, and format selection.

RGIS (v.2) is poised to serve as a platform for such activities as: (a) tracking cattle movements throughout the state; (b) tracking cattle imports; (c) monitoring environmental conditions that trigger public health episodes; (d) improving route assessments for hazardous materials transport; and, (e) contributing data and information to bio-threat scenarios. To be effective, each of these applications would first have to define data inputs and outputs, and be tested for integrated system interoperability. Following these steps, the applications could be benchmarked against user requirements and risks to ascertain the level of threat reduction achieved.

2. New Mexico Geographic Information Council (NMGIC)

The New Mexico Geographic Information Council (NMGIC) arose from a languishing New Mexico State Mapping Advisory Committee (SMAC) in 1984. NMGIC was recognized by Executive Order (87-19) in 1987 and was incorporated as a non-profit 501(c) (6) organization in 1989. A nine-member elected Board of Directors manages NMGIC's activities such as workshops, bi-annual meetings, scholarships, and grants. Membership is open to anyone interested in geospatial technologies and includes representation from all sectors (federal, state, counties, municipalities, academic institutions, tribal, and industry). NMGIC has three standing committees, two of which officially represent the interests of New Mexico at the national level. The Geographic Names Committee interacts with the U.S. Board of Geographic Names concerning naming issues in the State. The SMAC coordinates with the U.S. Geological Survey to identify and acquire USGS-generated data for the state. In the spirit of cooperation and coordination, NMGIC also works closely with RGIS and the Geographic Information Systems Advisory Committee (GISAC) to promote a geographic information infrastructure for the state. NMGIC is a voting member of GISAC.

2. Geographic Information Systems Advisory Committee (GISAC)

The New Mexico Geographic Information Systems Advisory Committee (GISAC) is a standing subcommittee of the Information Technology Commission (ITC). GISAC serves as a forum for state agencies to coordinate geospatial activities among the agencies and for the state. Therefore, its composition consists primarily of state agency representatives; but, it also includes voting members from municipalities, counties, tribes, RGIS, and NMGIC. GIS technology has expanded rapidly, moving from the specialist's realm to the desktop. This broadening utility and the growing number of stakeholders demands greater collaboration between all participating entities, increased cost sharing, and elimination of redundancies. ITC approved the GISAC strategic plan on January 11, 2000. The plan identifies the Committee's ongoing goals and guides the development and use of geographic information technology for New Mexico's state government agencies (GISAC 2000). The goals are to "provide a forum for state and local governments to (1) coordinate geographic information systems in New Mexico state government; (2) develop policy recommendations and guidelines concerning geographic information systems in New Mexico state government; and (3) share geographic information among all government agencies and the public."

GISAC has a tremendous capacity for mobilizing state agency data sets. Through bio-threat "gaming," these agencies would learn what kinds of data are required for specific kinds of situations, which data sets must still be developed, whether the systems are truly interoperable, and how difficult filling of data gaps might be. Effective systems evolve from repeated testing and trouble-shooting.

4. Geospatial Data Acquisition Coordination Committee (GDACC)

The Geospatial Data Acquisition Coordination Committee (GDACC) was established by Executive Order 2003-018 on May 27, 2003. A committee of the Information Technology Commission (ITC), GDACC serves to assess and coordinate geospatial data acquisition for New Mexico State agencies. Committee members are appointed by the Governor and include representatives from GISAC (the Chair, one from state government, and one from local government), NMGIC, RGIS Program Director, and one "at-large" member of the geospatial data community. In addition, the Governor appointed two non-voting advisory members from outside state government. GDACC's responsibility and authority is to: (1) coordinate with GISAC, RGIS, and NMGIC; (2) coordinate and leverage funding requests and projects for acquiring geospatial data for New Mexico; (3) assess, prioritize, and request acquisition of these geospatial data; (4) identify funding sources for acquiring these data; (5) generate data acquisition scopes of work for RFIs and RFPs; (6) represent New Mexico's mapping priorities and requirements at federal and state levels, and (7) seek support of the state's Congressional delegation regarding geospatial data needs.

Collaborations

Unlike sister states having larger populations and even greater overlap in jurisdictions, the environment for collaboration in New Mexico is excellent. The entire community of qualified and involved geospatial analysts is probably no more than 300 people. The membership lists for GISAC, NMGIC, and GDACC are highly correlated. Furthermore, the core community is relatively stable. Collaboration is essential for the state to realize its needs for geospatial data and information, in large measure because there is no "GIS state coordinator," and many counties still do not have GIS programs. New Mexico has a solid tradition of collaborating with NSDI and NSGIC. Figure 1 shows functional relationships between New Mexico's entities, each of which has ties to national programs.

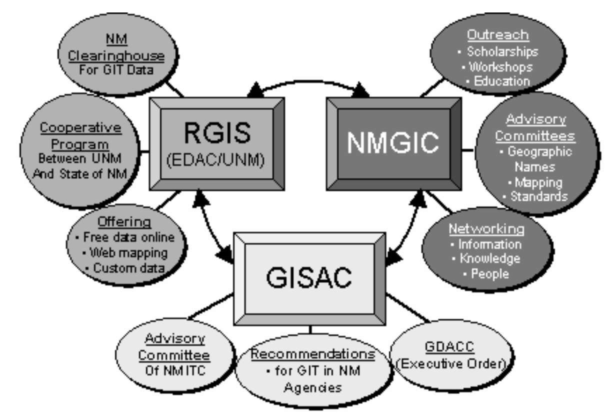

Figure 1. A New Mexico Geospatial Information Infrastructure (NMGII) is already taking shape for many routine applications. The goal is to extend this infrastructure into Homeland Security and Bio-threat reduction requirements.

GEOSPATIAL INFORMATION APPLIED TO RESPIRATORY HEALTH

Research underway at the University of New Mexico's Earth Data Analysis Center (EDAC) illustrates how satellite and related geospatial data can be incorporated into bio-threat reduction capabilities. The specific example focuses on acute respiratory disorders like asthma and Hantavirus Pulmonary Syndrome (HPS). The integrated system solution is based on an architecture developed by NASA, but other architectures are available (e.g. Dimosthenis et al. 2004). In Figure 2, NASA sensor measurements are indicated in the lower left box. The items represent specific satellite platforms (italics), sensors (bold, caps), and data products (e.g., 3A-25). These products represent outputs from Science Instrument Teams supported by NASA's Earth Science Division. Before their release for public use, these products are calibrated and verified for their technical quality, and validated for conveying the information they claim to convey (King et al. 2003). Each product is documented as to algorithms, though they often lack adequate metadata for non-science users. One or more Mission sensors collect data for many environmental parameters that drive models. Data currently used by many models are discontinuous geospatially and temporally, a shortcoming known to reduce model performance.

The modeling component of the system solution is represented in the upper left box, Figure 2. NASA has researched a large number of Earth science models and is collaborating with sister federal agencies to identify those most likely to be enhanced by replacing traditional data sources with NASA measurements that are continuous in the

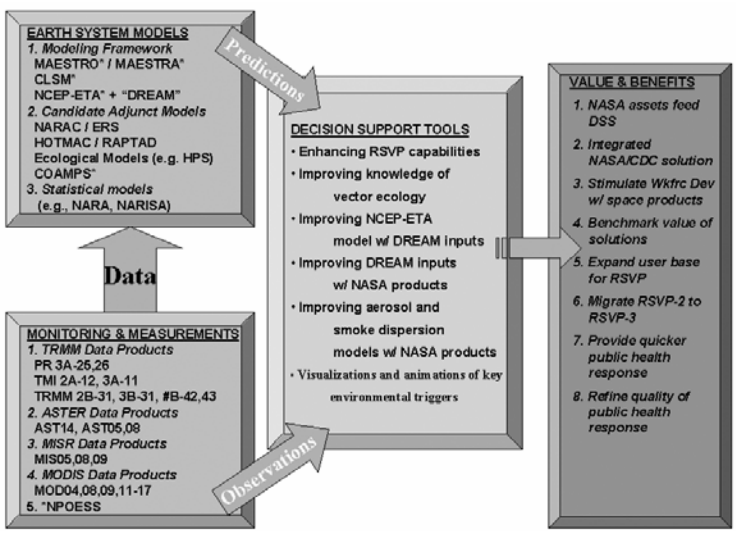

Figure 2. Schematic of a geospatial approach for enhancing bio-threat decision support systems

spatial domain and more frequent in the temporal domain. The collection of these models is referred to as the Earth System Modeling Framework (ESMF). For bio-surveillance, public health, and bio-threat reduction applications requiring environmental data, the National Weather Service's National Centers for Environmental Prediction (NCEP) mesoscale model (called the Eta model) has been selected from the ESMF as a candidate for ingesting NASA data products. The Dust Regional Atmospheric Model (DREAM) is an experimental component of NCEP/Eta designed specifically as a dust-forecasting model. Other important models also require environmental, statistical, or health data, or produce 2-D and 3-D visualizations, all of which are necessary for decision-making.

The center box in Figure 2 identifies a specific decision support system the EDAC research aims to improve. The Rapid Syndrome Validation Project (RSVP) under development at Sandia National Laboratories was selected because it addresses acute respiratory disorders using rudimentary geospatial vector data, but very little raster data from satellite sensors. By improving NCEP/Eta's performance and prediction capabilities, and by integrating these improvements into RSVP, there should be a net benefit to this decision support tool that can be benchmarked quantitatively by various public health officials (right box in Figure2).

For these improvements to occur, however, one must be assured that satellite observations provide enhanced (synoptic) data for situations that have heretofore been unobservable (Griffin 2002, Hay et al. 2002,). Observance of dust storms provides an example. Such a dust storm occurred over New Mexico and Texas in December 2003, the full color version, of which clearly shows calcareous and ferric dust distributions, the density of dust (i.e., degree of obscurity of the ground), sites of origin for dust (dry lakes, White Sands), and the general circulation pattern that shows dust being lifted and transported aloft. According to the schematic in Figure 2, these data would be ingested into DREAM and thence into the NCEP/Eta forecasting model to improve model performance and forecasting capability. Imagine, then, that ancillary satellite and thematic data acquired before the storm provided detailed information about human and livestock concentrations, bio-data on asthma risk, bio-terrorist intelligence, or any number of other bio-threat attributes, and a prospect emerges for mitigating such threats. Monitoring the conditions that trigger bio-threat episodes should lead to improved forecasting and mitigation, and in some extreme cases might prevent devastating consequences.

Respiratory *predictors* and *triggers* for asthma are well identified by the public health community. Predictors include such attributes as "urbanicity" (a complex function of population density and air quality), traffic density (emissions), age, gender, temperature, precipitation, and humidity. Triggers are a combination of both "indoor" and "outdoor" variables. Here, only the outdoor variables are considered: dust and pollen. For other bio-threats, different attributes might apply. Interestingly, most of the major predictors of asthma are measures commonly extractable in existing geographic information systems, while the outdoor triggers are attributes that can be measured and modeled by remote means.

Slope, aspect, and elevation are important attributes for understanding disease habitats in any landscape. These variables are measurable electronically via Digital Elevation Models (DEMs) by a number of existing sensors having different x,y, and z resolutions. DEMs are available globally at roughly 1-km x-y resolution. Even at this coarse resolution there is enough topographic relief to model the effects of terrain on air movement and precipitation regimes. A shaded relief model, generated from the DEM is often used as a backdrop image when visualizing overlay data from other sensors and vector data layers, but their primary use lies in providing data that drive modeling scenarios in complex, multi-faceted planning.

Synoptic land cover maps important in bio-threat estimates are provided twice daily by the MODerate resolution Infrared Spectroradiometer (MODIS). One of the data products is a series of vegetation indices available at 250m, 500m, 1km, and 0.25° spatial resolution, either on a 16-day or monthly basis. A normalized difference vegetation index (NDVI), an enhanced vegetation index (EVI), and a quality assurance (QA) index are standard products from MODIS.

The Tropical Rainfall Measuring Mission (TRMM) is a single experimental satellite in equatorial orbit. Its purpose is to gather data about tropical rainfall rates, amounts, and patterns for a future Global Precipitation Mission (GPM) consisting of several satellites that record global rainfall data. TRMM sensors have been calibrated and validated largely for the humid tropics, but data over New Mexico have been studied to understand rain rate and rain amount dynamics in the Southwest. There are many opportunities for these data. The NCEP/Eta model currently uses ground station and NexRad radar data for its predictions, which in high relief areas equates to discontinuous data inputs and fairly low model performance.

Observations and predictions from the "missions-to-models" architecture feed into designated decision support systems and form the basis for bio-surveillance toolkits comprising analysis packages available through the RGIS Clearinghouse. Support systems are most often developed to aid stakeholders in a decision-making environment. Therefore, the expectation is that stakeholders and corresponding federal agencies (DHS, NMDOH, CDC, NIH, etc.) will collaborate to define system requirements. Once these have been articulated, the integrated system solution can be reverse-engineered to provide the needed observational and modeling inputs.

SUMMARY AND RECOMMENDATIONS

Bio-threats and Bio-surveillance involves more than "on-the-ground" medical and biological data collection and testing. The geographical extent of incidents having biological consequences precludes using 20th Century analytical and communication systems. Earth observation satellites allow not only global, but also regional and local surveillance capabilities for decision support. When combined with aerial and ground data from other relevant biological observations and from real-time, incident-specific observations, powerful means are at hand for faster, more intelligent incident and situation management. Functional elements of a high quality information infrastructure already exist in New Mexico. The settlement pattern in the state is highly concentrated in metropolitan to village-sized units, with large expanses of essentially unpopulated land. These population voids require remote means of surveillance that can only be accomplished economically by remote means, that is, having “eyes over the horizon.” Epidemiologists, veterinarians, first-responders, clinicians, and the medical professions all need data and information beyond their means to acquire, but which are essential for making more informed decisions. The grass-roots technical community of GIS and remote sensing experts understands the dire consequences of population and data voids for the state, and is struggling to fill these gaps through better collaboration and cooperation. There is, however, little perceived support within these communities for developing an integrated system for use during biological emergencies.

The authors suggest that New Mexico’s Office of Homeland Security and its bio-surveillance and bio-threat reduction teams could stimulate conversion of the existing elements of NMGII into a prototypical system for rapid response. The prototype (v.1) could then be enhanced, refined, and benchmarked using bio-threat scenarios, or in some cases, with actual emergency data such as those available from recent disasters in the state (e.g. Albuquerque’s bosque fire in 2003, or the Cerro Grande fire in 2001). Among the first steps are to: (a) identify the major geospatial data organizations, personnel, data holdings, extents of thematic, and availability of metadata; (b) evaluate the operating systems for players in (a) for interoperability at various spatial scales; and (c) systematically examine national assets for their potential to fill data voids at a variety of spatial scales.

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