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Satellite, Environmental and Medical Information Applied to Epidemiological Monitoring[a]

Improved communications and space-science technologies, such as remote sensing, offer hope of new, more holistic approaches to combatting many arthropod-borne disease problems. The promise offered by these technologies has surfaced at a time when global and national efforts at disease control are in decline. Indeed, these programs seem to be losing ground against the arthropod-borne diseases just as rapidly as we seem to be moving forward in technological development. Given these circumstances, we can only hope that remote sensing and geographic information system (GIS) technologies can be pressed into service to help target the temporal and spatial application of control measures and to help in developing new control strategies.

Arthropod-borne diseases include those which encompass a vertebrate host, an invertebrate vector, and the causative agent of disease. The vertebrate host may be a human or some other animal. The vector is responsible for transmitting the agent of disease from one host to another.

In the case of human malaria, the vertebrate host is the human, the invertebrate vector can be one of about 40 species of anopheline mosquitoes, and the causative agent of disease is one of 4 species of intracellular plasmodial parasites.

Many arthropod-borne diseases are strongly associated with certain environmental conditions. Environmental conditions include climate parameters, e.g., air temperature, humidity, and rainfall; and landscape parameters, e.g., topography, vegetation, and soil. The principal environmental parameters, such as temperature and rainfall, regulate the geographical distribution of these diseases. Environmental conditions also regulate the seasonal occurrence of disease.

Recognition of the interactions between man, disease vectors and the environment date back far into the history of infectious disease research. The disease-environment relationships were formalized in Pavlovsky's research in the U.S.S.R. and his writings on landscape epidemiology[1]. Pavlovsky noted that arthropod-borne disease exists when there are specific climate, vegetation, soil, and favorable microclimate in the places where vectors, donors, and

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recipients of infection take shelter (the spatial aspect). Furthermore, he noted that disease circulation takes place only *when* the environmental conditions are favorable (the seasonal aspect). Today we realize that many arthropod-borne diseases are closely associated with particular landscapes and environmental conditions. Examples of diseases that are regulated by environmental conditions include leishmaniasis, American trypanosomiasis, African trypanosomiasis, scrub typhus, Lyme disease, schistosomiasis, malaria and various arboviruses. Disease occurrence is largely regulated through control exerted by environmental conditions on the presence, abundance and activity of vector populations.

Of all the transmissible diseases, malaria continues to be the leading cause of morbidity and mortality in humans throughout the tropics, with an estimated 270 million people affected. Despite efforts to eradicate the disease, it has made a dramatic resurgence within the last 20 years. Furthermore, morbidity and mortality from malaria are at almost unprecedented levels[2]. This conclusion is illustrated in the figure of annual parasitic indexes for the Americas (figure 1) showing that malaria rates have increased dramatically since the late 1970s.

Application of space-science technologies to study and assist in the control of malaria and other arthropod-borne diseases is the subject of a National Aeronautics and Space Administration-sponsored study[3]. This multidisciplinary "Malaria Project" employs expertise in remote sensing, geographic information systems, malaria epidemiology and vector ecology. The project is designed to demonstrate the use of remote sensing technologies to develop predictive models of malaria vector abundance on a local and regional scale. Organizations participating in the project include the NASA-Ames Research Center; the Uniformed Services University of the Health Sciences; the Malaria Research Center in Tapachula, Mexico; the GeoIPS lab at California State University, Fresno; the University of California at Davis; and the University of Texas.

Rationale for the project is illustrated in the relationships between models A, B and C (figure 2). Model A illustrates the linkage between the presence and abundance of malaria vectors and dynamic environmental conditions, such as rainfall, temperature and vegetation. Model B is a graphical statement to the effect that remotely sensed data can be used to reliably monitor and quantify changes in many environmental variables. Given that models A and B are true, it is reasonable to expect that remote sensing can be used to monitor environmental conditions critical to the development of malaria vector populations.

The Malaria Project was initiated in 1985. The project is being conducted in three phases. The first phase was conducted in the Central Valley of California and was designed to demonstrate "feasibility of concept." Phase II is presently being conducted in a malaria endemic area of southern Mexico; specifically in the area of Tapachula, Mexico. The Phase III locality will be ecologically similar to the Phase II site.

Phase I research was conducted on a rice-field anopheline mosquito, *Anopheles freeborni*, in the Central Valley of California. The objective of Phase I was to demonstrate the use of remote sensing to predict which rice fields would be the more important anopheline producers. Interdisciplinary field studies were conducted in 1985 and 1987, on 46 and 104 rice fields, respectively. These studies demonstrated use of remote sensing and geographic information system technologies to predict with an accuracy of 85 percent which fields would be high producers of anopheline mosquitoes 2 months before peak production occurred[4,5]. This identification of high-producing fields was based on the detection by remotely sensed data of early developing rice fields located close to bloodmeal sources.

Following the success of Phase I research, the Phase II research program was initiated in Tapachula, Mexico. The objective of Phase II is to use remotely sensed data to develop predictive models of malaria vector abundance in time and space. The primary vector of malaria on the coastal plain in the Phase II locality is *Anopheles albimanus.*

Malaria cases occur frequently during the wet seasons in the small villages near Tapachula, Mexico. The appearance of cases is related to environmental conditions favoring the proliferation of *An. albimanus* mosquitoes. Simply stated, optimal environmental conditions consist of sufficient rain to produce an abundance of grassy, sunny pools. In addition to rainfall, environmental factors such as vegetation, topography, soil type, and temperature influence the availability of favorable breeding sites.

The presence and abundance of malaria vectors vary from time to time and area to area. This variation reflects the local environmental conditions and the ecological requirements of the anopheline mosquito. For example, *Anopheles darlingi* is the primary malaria vector in the Amazon Basin [6,7,8]. This species flourishes during the wet season as the levels of rivers rise above their banks. The anopheline breeds in inundated areas beyond the river margins. However, as river flow is determined by rainfall upriver, vector abundance may not correlate with rainfall where the mosquitoes are actually breeding. In fact, monitoring rainfall at upriver localities would be more predictive of *An. darlingi* abundance.

In contrast, at the study site in Mexico there seem to be relationships of *An. albimanus* abundance with both local and regional patterns of rainfall. The regional influence results from the movement of rainwater to a particular site by the hydrological system. The movement occurs as surface flows (rivers) and as lateral subsurface flows (through the soil). The coastal margin within the study area is frequently flooded, is vegetationally rich and produces dense populations of *An. albimanus* during the wet season. More inland areas of mixed agriculture are at higher elevations, with better drainage. Consequently, we see reduced numbers of breeding sites per unit area in inland localities. Additionally, as we move from the wet season to the dry season, a majority of preferred habitats dry out, and breeding of the primary vector becomes restricted to permanent bodies of water. In earlier research, we found that discriminant functions, with a variety of environmental variables, could be used to identify 60 to 100 percent of all positive and negative habitats of the local vector anophelines [9,10]. Eventually these specific environmental determinants will be employed to predictively model the temporal and spatial distributions of *An. albimanus* populations.

Work is currently underway to use remotely sensed, hydrological, meteorological, cartographic and field surveillance data to develop a model of *An. albimanus* population dynamics within a geographic information system. Remotely sensed data will be used to identify and quantify breeding sites near villages, to update map information and, in part, to monitor the rate and direction of change in critical environmental variables. Certainly rainfall is one of the important environmental variables. Spatial and temporal patterns of rainfall are related to spatial and temporal patterns of cloud brightness as remotely sensed in the geostationary meteorological satellite imager data.[11]

Malaria, of course, is a disease of humans. Although malaria vectors certainly occur in areas unoccupied by humans, the predictive modeling will focus on populated localities. Data on the distribution of human habitations will be included in the geographic information system and will become part of the predictive model.

In the future, we expect to see such organizations as the Center for Malaria Research in Tapachula, Mexico, routinely collecting various types of environmental data, as well as vector abundance and habitat availability data in the field. Various methods will be employed to collect the quantitative data, to include dipping for mosquito larvae, quantitative collections of resting adult mosquitoes, and area surveillance to determine the availability of breeding sites. We expect that these data, along with routinely acquired remotely sensed data, will be employed within geographic information systems to monitor and predict the temporal and spatial distribution of malaria vectors. Such models might easily become the centerpieces of local and national disease control programs.

Again, recognition of the interactions between humans, diseases, disease vectors and the environment is not new. However, we now have powerful new tools that can be employed in a more holistic approach to study and to help control the transmissible diseases. Because of strong disease-vector-human relationship, use of remote sensing and GIS technologies in the public health arena seems to be a natural alliance. As computing power decreases in cost, and increases in power and speed, remote sensing and communication technologies are likely to become increasingly important in vector-borne disease research and, ultimately, in vector-borne disease control programs.

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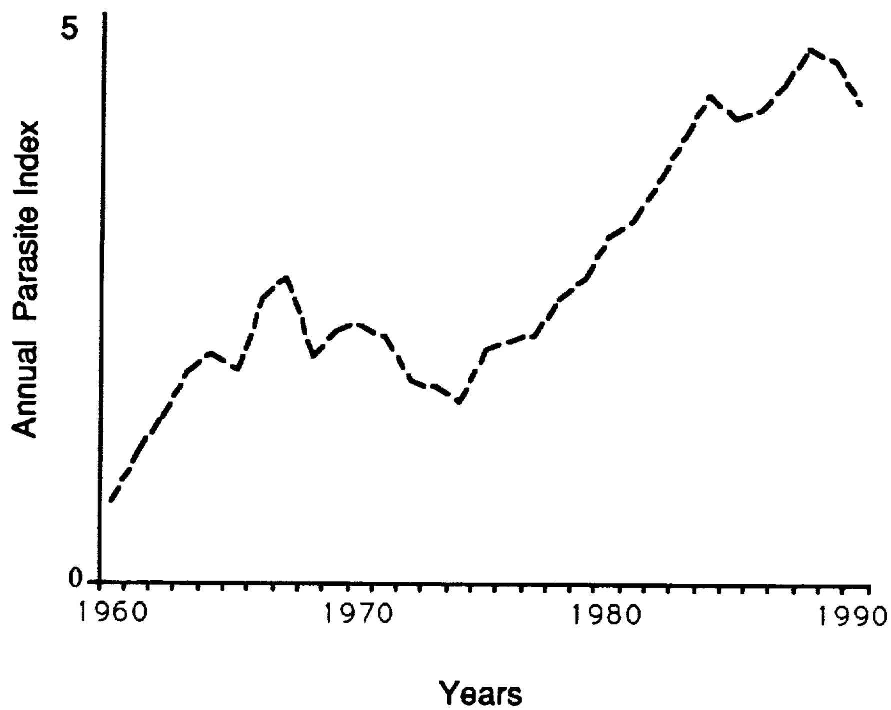

Figure 1. Annual parasite indexes of human malaria for 21 malarious countries in Central and South America.

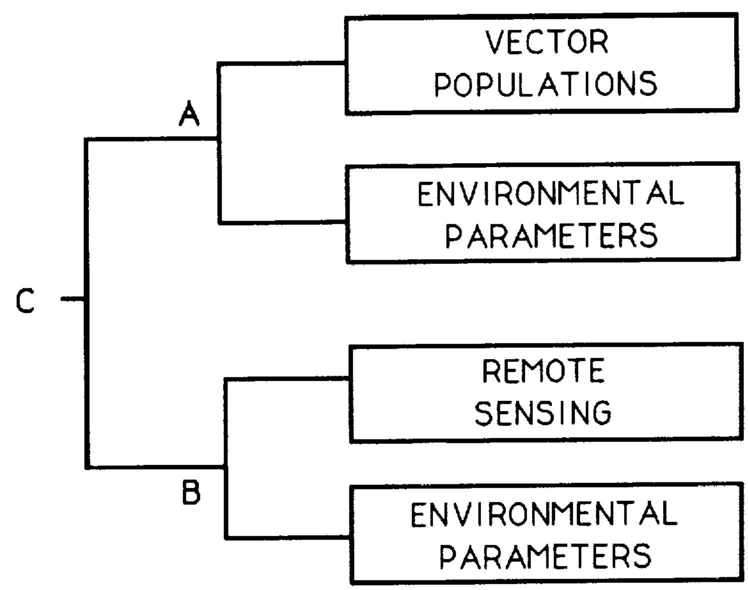

Figure 2. Conceptual model of the Biospherics Monitoring and Disease Prediction Project. Model C represents the use of remotely-sensed data to monitor and predict vector presence and abundance.