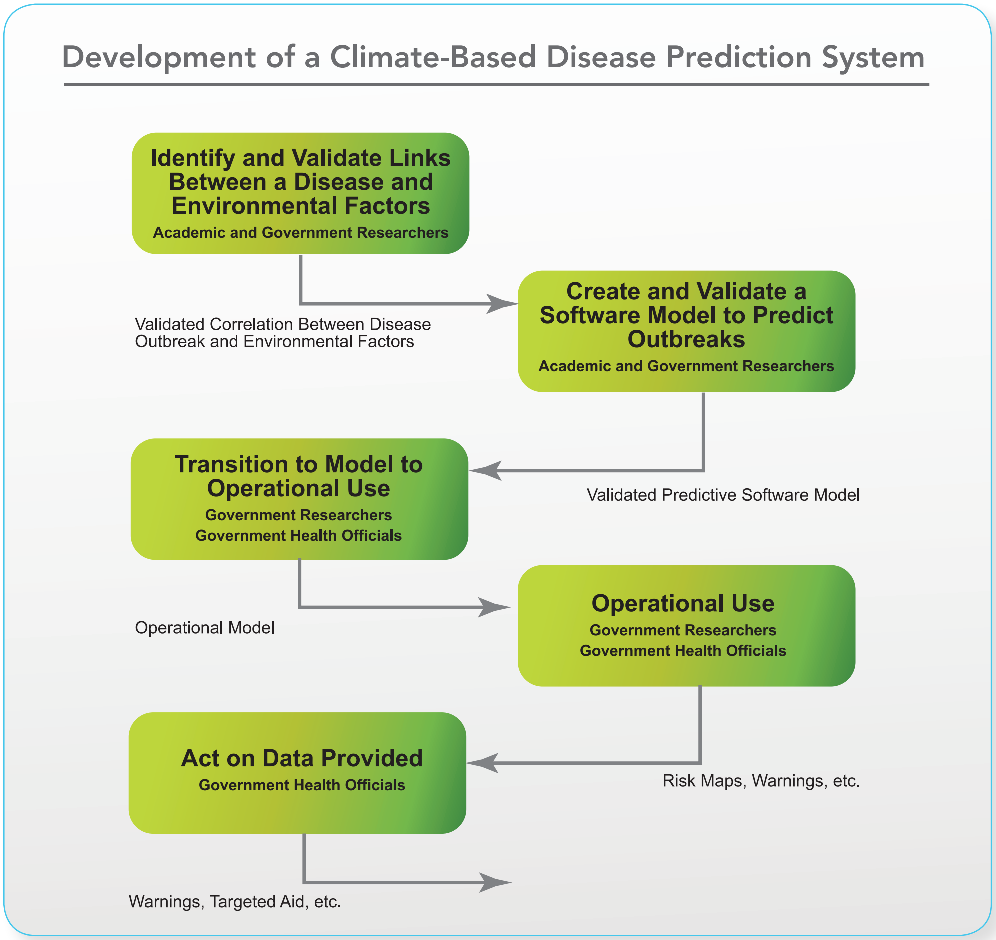
Disease and Pandemic Early Warning

Introduction

Millions of people die every year from preventable diseases such as malaria and cholera. Pandemics put the world population at risk and have the potential to kill thousands and cripple the global economy. In light of these dangers, it is important to make use of technologies that can help address these issues. The data and imagery gathered by environmental remote sensing satellites can be used to develop models that predict areas at risk for disease outbreaks. These early warnings can help decision makers undertake preventive and control measures. There are already many Earth observing satellites with the ability to provide relevant data and imagery. Researchers have created models based on this information, and some are already being used. The Space Foundation believes these capabilities should be further developed and supported by governments and international organizations to benefit as many people as possible.



To understand the benefits and challenges of space-based disease early warning models, it is useful to understand how they are developed. A number of steps must be taken for satellite data and imagery to be used to prevent disease outbreaks; each requires a variety of inputs and may include a range of experts and other stakeholders.

Links between Disease and Environmental Factors

Remote sensing satellites cannot directly detect disease outbreaks but they are able to detect a wide range of environmental factors, such as ground water, vegetation, or flooding.[1] Before a model can be developed, an association must be found between environmental factors and the ecology of the disease agent or host. This is usually possible for vector-borne diseases, in which a third party, or vector, is necessary to transmit the disease. Malaria, which is spread by mosquitoes, provides a good example. Mosquitoes breed in water, so they are often more prevalent when there is a greater amount of surface water. Increased amounts of surface water or rainfall, which can be detected by remote sensing satellites, represent a possible predictor for an outbreak of malaria in regions where the disease is known to exist.[2]

These models are more effective when they integrate other data sources that help to identify multiple links between environmental factors and a disease. In addition, some models incorporate the biological process of susceptibility, exposure, infection, and recovery. This requires an understanding of what causes people to be particularly vulnerable to a particular disease, the ways in which people come into contact with the disease, the process by which the infection affects the body, and the process of recovery.[3]

It is also important for these models to include information about the region being studied, often referred to as geospatial information. For example, predictions of areas at risk of outbreak should take into account the population density throughout the region. If an area likely to have many mosquitoes is also near a village, there is a higher risk of a malaria outbreak than would be the case for a very sparsely populated area.

AVHRR

The National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) is a sensor that provides some of the most commonly used data for disease prediction models. The AVHRR is an instrument on board the NOAA Polar Operational Environmental Satellite (POES), which circles the Earth 14 times each day. AVHRR uses six detectors that collect light at different wavelengths, allowing it to monitor cloud cover, ground temperature, vegetation, land-water boundaries, snow and ice, and sea surface temperature.[4]

The POES satellites, one of which is shown here, are used for Earth observation. *Credit: NASA*

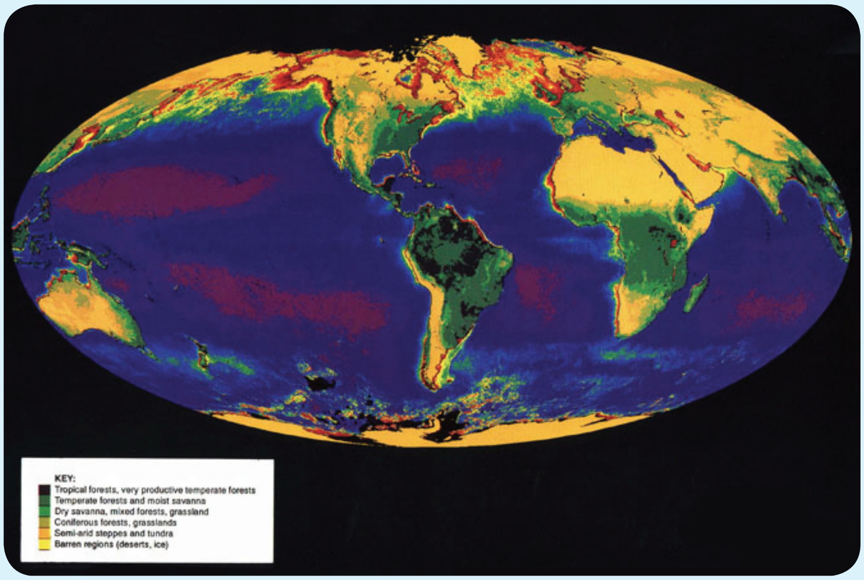


Image of the Earth created by the AVHRR instrument, which is often used in disease early warning models. *Credit: NASA*

Once these associations have been identified, historical data is used to demonstrate that there is a correlation between the environmental factors and disease outbreaks. In addition to the satellite imagery and population data, it is necessary to gather epidemiological data, including information about when and where outbreaks have occurred in the past, in order to validate the connection. This data can be difficult to acquire, particularly for rural areas or in developing countries. Because of the wide range of environmental factors that could affect the spread of disease in different areas, it is necessary to have data representing as much of the area of interest as possible. This first step, which includes identifying and validating links between diseases and environmental factors, is usually carried out by researchers either in academia or government.[5]

TABLE 1: Common Communicable Diseases, Their Distribution, and Sensitivity to Climate[6]

Disease	Transmission	Distribution	Climate-Epidemic Link
Cholera	Food- and waterborne transmission	Africa, Asia, South America, Russia	Increases in sea and air temperatures as well as El Niño events associated with epidemics. Sanitation and human behavior also are important.
Malaria	Transmitted by the bite of female *Anopheles* mosquitoes	Endemic in more than100 countries throughout the tropics and subtropics	Changes in temperature and rainfall associated with epidemics. Many other locally relevant factors include vector characteristics, immunity, population movements, and drug resistance.
Meningococcal meningitis	Airborne transmission	Worldwide	Increases in temperature and decreases in humidity associated with epidemics.
African trypanosomiasis	Transmitted by the bite of male and female tsetse flies.	Sub-Saharan Africa	Changes in temperature and rainfall may be linked to epidemics. Cattle density and vegetation patterns are also relevant factors.
Dengue	Transmitted by the bite of female *Aedes* mosquitoes.	Africa, Europe, South America, Southeast Asia, West Pacific	High temperature, humidity, and heavy rain associated with epidemic. Non-climatic factors may have a greater influence.
St. Louis encephalitis	Transmitted by the bite of female *Culex* and *Aedes* mosquitoes.	North and South America	High temperature and heavy rain associated with epidemic. Reservoir animal factors also are important.
Rift Valley fever	Transmitted by the bite of female *Culex* and *Aedes* mosquitoes.	Sub-Saharan Africa	Heavy rains associated with onset of epidemic. Cold weather associated with end of epidemic. Reservoir animal factors also are important.
Murray Valley fever	Transmitted by the bite of female *Culex* mosquitoes	Australia	Heavy rains and below-average atmospheric pressure associated with epidemic.
Lyme disease	Transmitted by ixodid ticks.	North America, Europe, and Asia.	Temperature and vegetation patterns associated with distribution of vectors and disease.

Creation of a Model

The next step in developing a disease early warning system is creating a software model. This model is based on the connection between disease outbreaks and environmental factors that have already been identified and validated. Its focus is on using the satellite data and geospatial data to predict areas at risk for disease outbreaks. For this step, it is worthwhile to consider the types of products that may be useful to stakeholders, such as color-coded risk maps. Again, historical epidemiological data will be necessary to validate the model's predictive capabilities. This step in the process requires significant effort and support from a customer interested in using such an operational model. Generally, this is carried out by government researchers.

Transition to Operational Use

After a predictive model has been developed and validated based on historical data, it can be put into operational use. This may require additional research and modification of the model, to allow its use in real time. Before making this transition, the cost and benefits should be considered. For a disease that is relatively inexpensive to treat, it may be more effective to spend available funds on broad distribution of vaccines or other preventive medicines rather than developing and operating a model to predict high-risk locations.[9]

If it is deemed beneficial to transfer a model to operational use, connections must be made with government health officials and other stakeholders. These stakeholders can help in identifying the type of outputs that will be most useful, including risk maps, text warnings, or other information.

FEWS NET

Disease outbreaks are not the only dangers that can be predicted using remote sensing data. The United States Agency for International Development (USAID) collaborates with NOAA, NASA, the U.S. Geological Survey, and other agencies to operate the Famine Early Warning System Network (FEWS NET). The program provides early warning and vulnerability information on food security issues.

FEWS NET uses satellite remote sensing data to monitor climate, ground vegetation, and other conditions, and combines this data with a variety of other geospatial data. When issues are identified, FEWS NET alerts officials in countries around the world.[7] FEWS NET also supports experimental malaria risk maps based solely on rainfall.[8] As operational disease prediction models become more common, they may be able to benefit from collaboration with the FEWS NET program.

Operational Monitoring

Once the predictive system is operational, it must actively monitor the region at all times so it can be used to produce risk maps, warnings, and other outputs as needed. This requires a source of continuous, timely satellite data and imagery as well as geospatial information. It is necessary to maintain a permanent facility to host the software model and accompanying hardware, as well as trained professionals to operate the model and work with stakeholders. Risk maps, warnings, and other products must be produced on a regular basis and provided to government health officials.

Taking Action

The final step in the process is carried out by the government health officials who receive the outputs from the operational disease prediction model and must decide how to act. They may choose to issue warnings in high risk areas along with suggested methods for reducing the population's risk from the disease. In the case of malaria, this may include avoiding outdoor activities during dawn and dusk, when mosquitoes are most active. Another option is to use risk maps to target high risk areas to receive aid resources, such as mosquito nets or preventive medicines. This type of targeted aid may be more effective because it reaches people most in need.

It is also more efficient because funds are spent only in areas that are likely to need them. These warnings and other actions can result in lives saved and in the prevention of the outbreak of a disease. Many of the diseases discussed in this paper are endemic to the regions in which they are found. In these cases, the response to an early warning may simply be an amplification of controls that are already in place.

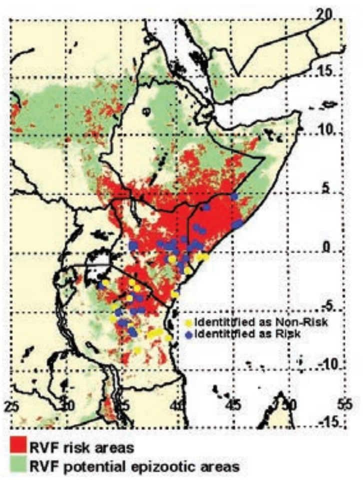
Although these activities are presented as discrete steps, many of them occur continuously, and there are many feedback loops. After an operational model is developed, researchers may continue to identify and validate links between the disease and additional environmental factors. New software models may be developed using improved algorithms. Any of these developments may improve the quality and effectiveness of a system that is already in operation. Similarly, the process of developing useful products for stakeholders does not necessarily stop after a model becomes operational. It is often worthwhile to improve the utility of outputs from the system.

Existing Models

A significant amount of research has been done regarding the link between remote sensing data and disease, and this research continues in academic centers around the world.[10] In the United States, NASA, the Department of Defense (DoD), and the Centers for Disease Control (CDC) and Prevention all have ongoing programs.[11] The European Space Agency (ESA) runs a project called Epidemio, which is intended "to provide Earth observation-derived information on the environment to epidemiologists working to study, monitor and predict threats to human health."[12] The Canadian Space Agency, in cooperation with Kenya's National Malaria Control Program, funded the demonstration of Earth observation technology for identifying natural mosquito habitats and predicting malaria risk in Africa.[13] International organizations, such as the United Nations, the World Health Organization (WHO), and the Group on Earth Observations (GEO) are also involved in this effort.[14]

In a 2004 report, the World Health Organization noted that efforts to prevent a number of diseases have the potential to benefit from environmental prediction models. These diseases include malaria, cholera, diarrheal diseases, meningococcal meningitis, leishmaniasis, African trypanosomiasis, dengue fever, St. Louis encephalitis, Rift Valley fever, Ross River virus, Murray Valley fever, and Lyme disease. Populations all over the world suffer from these diseases, and all could benefit from climate-based prediction models. Despite this widespread activity and the high number of relevant diseases, there are few operational models currently in use. The following section provides an overview of three such models.

Rift Valley Fever Risk Map



(Source: Anyamba et al., 2009)

Rift Valley Fever Early Warning Tool

Rift Valley Fever is a disease that affects both animals and humans. It can be spread by infected mosquitoes or through contact with an infected animal. The disease is almost always fatal for livestock, such as sheep or cattle, although it is rarely fatal for humans. Prediction of Rift Valley Fever outbreaks is available through NASA's Goddard Space Flight Center. NASA uses near-real-time satellite vegetation measurements and climate data to generate predictions of epidemics in East Africa several months before an outbreak might occur. NASA researchers analyze the data and provide monthly reports and risk maps. The model successfully predicted an outbreak in 2006-2007, providing warnings two to six weeks in advance. This allowed local health authorities to implement programs for public awareness, mosquito control, and vaccination.[15]

NASA Malaria Modeling and Surveillance

NASA carries out its Malaria Modeling and Surveillance project in partnership with U.S. Air Force Special Operations Command. According to the World Health Organization, there were 247 million cases of malaria and nearly one million deaths in 2008. Malaria is spread by mosquitoes and is particularly common in tropical areas.[16] NASA's monitoring and prediction program is focused on Thailand, with the aim of allowing U.S. overseas forces to deal with the threat of malaria in this location. NASA provides data, model outputs, and analytical and modeling experience. The goals of the project include identifying the habitats for malaria vectors (mosquitoes), estimating current risks and predicting future risks, and also better understanding transmission characteristics to allow more cost-effective malaria control. Climate data is gathered using a variety of remote sensing instruments on a number of different satellites. Epidemiological data is provided by the World Health Organization and the Ministries of Health in Afghanistan, Indonesia, and Thailand. Although predictions are not available online, data is shared with local public health organizations to help reduce risks among the general populations.[17]

Prediction for Flu Epidemics

In the spring of 2009, the World Health Organization (WHO) declared the H1N1 virus, commonly known as swine flu, a global pandemic, and millions of doses of H1N1 vaccinations have been manufactured and delivered.[18] WHO has previously noted that decreases in temperature during the winter season are associated with influenza epidemics, but that a range of human-related factors are more significant.

The seasonal variability of the disease suggests that it may be possible for a climate-based model to provide some advanced warning. However, it is not clear precisely how the seasonal variations are tied to climatic conditions. Scientists are continuing to research and attempt to identify any such connections. If they are able to do so, it may be possible to develop a predictive model for the H1N1 virus, or for other influenza viruses, based on satellite remote sensing data.

Meningitis Decision-Support Tool

The Group on Earth Observations (GEO) is coordinating efforts to use Earth observations to help predict outbreaks of meningococcal meningitis. Meningitis is a dangerous disease that can cause severe brain damage and is fatal in 50 percent of cases if untreated. Meningitis epidemics occur regularly, on a four to seven-year cycle, in an area of Africa known as the "Meningitis Belt," which stretches from Senegal to Ethiopia.[19] The World Health Organization estimates that 300 million people in this area are at risk each year. Between January and April 2009, a Meningitis outbreak killed more than 1,000 people in west Africa.[20] Unlike other diseases monitored by other operational systems, meningitis is spread person-to-person, not through a vector.[21] Despite this fact, research has shown that environmental factors such as temperature changes, humidity levels, and concentrations of sand and dust aerosols seem to influence the occurrence of epidemic outbreaks. Data on these factors can help to understand and predict the timing, occurrence, and extent of outbreaks. The GEO Meningitis Decision-Support Tool is still under development. A modeling framework will be tested using information from the 2009 season. Following this testing, GEO will incorporate environmental information into the model to demonstrate the new decision-support tool.[22]

Conclusion and Recommendations

The Space Foundation believes disease prediction using satellite remote sensing data represents a unique opportunity to combat disease and save lives. There are many things that governments and researchers can do to make this opportunity a reality.

Data

- Governments at all levels (national, regional, local) should support regular collection of geographically referenced data for their regions, including epidemiological and demographic data. This data would give the specific geographic location of population centers and past disease outbreaks.
- Governments and other organizations should make an effort to collect records electronically in geographically referenced databases, rather than on paper, to allow their use in the development of these models. In addition, paper records should be converted into electronic data.[23]
- While privacy should be respected, governments should make an effort to make epidemiological and other data available to researchers.
- Governments should ensure the continuation of remote sensing satellite programs that provide remote sensing data with sufficient quality for use in disease prediction models.
- Governments should explore ways to collaborate on the use of remote sensing data to improve the capabilities for disease prediction, similar to current agreements to provide remote sensing assets in the case of disasters.
- Governments, academics, and non-governmental organizations should coordinate to define data requirements, formats, and schema for data representation. When possible, they should attempt to provide interoperability with existing health management tools to facilitate the collection, codification, sharing, and use of data required for these models.

Research and Development

- Governments should support research aimed at better understanding the connection between environmental factors and the most prevalent or costly diseases.
- Interdisciplinary cooperation should be encouraged to ensure that researchers combating infectious diseases are able to work with medical, computational, and space professionals.
- Governments should support research to consider whether these models may be expanded to address additional challenges, such as new risks stemming from climate change or economic development planning.

Operational Models

- Government agencies should draw on research models created in academia to develop operational systems
- Regional and international collaboration should be undertaken in developing and operating disease prediction models to help share costs and ensure benefit for a wide range of nations.
- The socioeconomics of the affected regions present significant challenges to the implementation of an early warning system. Nations should pursue cooperative relationships with international organizations, such as the United Nations, to develop and operate models. At the same time, international organizations and countries with advanced remote sensing capabilities should actively seek to engage and work with nations that could benefit from this technology.
- Measures of predictive accuracy and response effectiveness should be developed to allow evaluation of the early warning models. This information can help to determine which interventions are most effective. Data collected may include measures of human life and economic savings resulting from the intervention.

Action

- Operational models should receive support from multiple government agencies, particularly those for public health and for space assets, to ensure information generated by the model can be used efficiently.

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End Notes

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