11.3 USE OF SATELLITE IMAGERY FOR EPIDEMIC SURVEILLANCE AND RESPONSE

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INTRODUCTION

Remotely sensed epidemic surveillance (RSEPI) represents an emerging field of research devoted to the use of satellite imagery to identify proxy indicators of risk for infectious diseases. Satellite imagery has been used to characterize areas endemic to a given infectious disease and identify periods of enhanced transmission potential in. Such information is important for the public health community in the four phases of preparedness, response, recovery, and mitigation of epidemic management and is the most significant potential impact of this collaborative field of research.

CLIMATIC MODULATION OF INFECTIOUS DISEASES

Many well known infectious diseases exhibit seasonal patterns of incidence such as influenza, rotavirus, and respiratory syncytial virus. Several tropical infectious diseases also exhibit seasonal epidemiological patterns that appear to coincide with rainy periods of the year such as Ebola hemorrhagic fever, yellow fever, malaria and dengue. It has long been postulated by the public health community that diseases such as yellow fever, malaria, and dengue exhibit seasonality due to precipitation and other meteorological parameters enhancing the breeding habitats of mosquitoes responsible for transmission of these diseases. However, much of this debate has been based on limited and, at worst, anecdotal information regarding “heavy rainfall” and the appearance of a given disease.

Nevertheless, several infectious diseases such as Rift Valley fever [Linthicum 1987 and 1999], cholera [Lobitz 2000], hantavirus pulmonary syndrome [Glass 2000], lymphatic filariasis [Crombie 1999] and Ebola hemorrhagic fever [Tucker 2002] have been studied using ground and remotely sensed data that suggest climatic modulation of incidence. Modulation of incidence is likely due to climate-induced changes in the endemic environment of the animal species that either serve as a reservoir or vector of these diseases. Such environmental change can effect the population of these species to enhance the maintenance and transmission of the pathogen to the point of ecological amplification and enhanced probability of introducing the pathogen to humans and/or animals and trigger an epidemic. This is referred to as “enviro-climatic coupling”. For example, Rift Valley fever (RVF) is caused by a virus transmitted by mosquitoes that breed in aquatic habitats referred to as “dambos” in East Africa. Excessive seasonal rainfall contributes to the appearance of dambos, thereby enabling large-scale breeding and amplification of mosquito populations and RVF virus. This enhances statistical probability for epidemic triggering and propagation in human and livestock communities. Proxy indicators of excessive rainfall, as measured by the Advanced Very High Resolution Radiometer Normalized Vegetation Index (AVHRR-NDVI), can be monitored and utilized as an early warning surveillance system for “epidemic high risk conditions” in East Africa, as has been investigated for RVF by Linthicum et al [Linthicum 1987 and 1999].

Agricultural infectious diseases also are of concern and several likewise exhibit seasonality. Many human pathogens like Rift Valley fever virus also affect livestock as well, thus creating a multi-sector economic crisis in the midst of an epidemic. Plant pathogens may be able to induce stress that can be detected by AVHRR-NDVI, which raises the possibility of RS surveillance system development for crop security.

DEVELOPMENT OF AN RSEPI SYSTEM

Candidate infectious diseases for development of an RSEPI system include the following:

1. Vectorborne diseases.

2. “Infectious disease disasters” whereby an epidemic is triggered that involves multiple pathogens causing dissimilar forms of disease.

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3. Simultaneous epidemic initiations involving the same pathogen over large geographic areas, with special attention to simultaneous appearances of multiple serotypes of the same pathogen.

4. Seasonality of infectious disease incidence.

5. Large-scale outbreaks, especially those involving tens of thousands of people.

Idealization of the process includes a comprehensive understanding of the mechanisms involved in movement of the pathogen from its reservoir to humans and how it is maintained in the environment. Clear identification of how climate modulation effects this process is key to the development of a remotely sensed surveillance system that has practical application. Ground truthing RS-derived data against epidemiological data is an additional requirement. A wide range of RS databases exists that have utility in the development of an infectious disease surveillance system[6].

EXAMPLES

Rift Valley Fever is a viral hemorrhagic fever transmitted by mosquitoes that breed in aquatic habitats referred to as "dambos" in East Africa. Excessive seasonal rainfall, as modulated through El Nino cycles, enhances the size of dambos in East Africa, which in turn enhances the breeding environment for the RVF vector mosquitoes. The RVF virus is passed from adult to eggs to larvae and then adults ("transovarial transmission"). With amplification of mosquito populations through expansion of dambos, environmental load of RVF virus is increased significantly, statistically increasing chances of triggering an epidemic in communities with a low level of immunity to the virus. Advanced Very High Resolution Radiometer (AVHRR)-derived Normalized Difference Vegetation Indices (NDVI) from polar orbiting United States National Oceanic and Atmospheric Administration (NOAA) meteorological satellites were used as proxy indicators of ground precipitation and led to the development of the enviro-climatic coupling model for RVF, with implications for a RS early warning surveillance system. [Linthicum 1987 and 1999]

Cholera is caused by *V. cholerae*, a bacterium that adheres to specific zooplankton known as copepods. Ingestion of untreated water contaminated with *V. cholerae*-associated copepods results in cholera in humans and enhanced probability of triggering an epidemic. RS-derived proxy indicators of copepod expansion were developed by Obits et al[3] in Bangladesh. Copepods feed upon phytoplankton which exhibit a blooming pattern that is related to variables such as seasonal increases in Sea Surface Temperature (SST). Phytoplankton blooms typically precede zooplankton blooms and thus can serve as a proxy indicator of changes in zooplankton populations. Using the National Aeronautics and Space Administration (NASA) Sea-Viewing Wide Field of View Sensor (SeaWiFS) and AVHRR temperature data, risk for expansion of *V. cholerae*-associated copepods in the Bay of Bengal was monitored by proxy surveillance of phytoplankton blooms. Direct exposure to copepod-contaminated water was inferred through the monitoring of Sea Surface Height (SSH) data derived from the NASA Jet Propulsion Laboratory TOPEX/Poseidon radar altimeter. Elevated SSH implies flooding and extension of coastal water containing copepods to human communities living along rivers at points several miles from the ocean, placing them at increased risk for an epidemic of cholera.

Filariasis is caused by mosquito-transmitted parasitic nematodes that, in adult form, can obstruct the lymphatic system of humans. With obstruction of the lymphatic system, patients typically develop severe permanent deformities typically in the lower limbs. The vector mosquitoes responsible for transmitting filariasis breed optimally in standing water and appropriate humidity. Crombie et al studied surface soil moisture availability and fractional vegetation using Landsat Thematic Mapper data. Critical soil moisture values were identified that correlated with optimal vector mosquito breeding habitats. Mapping of these habitats offered useful information to local public health officers seeking to apply limited resources towards better targeted mosquito control efforts and thus lower potential for filariasis transmission. [Crombie 2000]

APPLICATION TO HOMELAND SECURITY

In late 1999, West Nile fever, which is caused by a mosquito-vectored virus, was identified in New York City during an epidemic involving 62 human cases and 7 fatalities [Nash 2001]. This was the first documentation of West Nile virus (WNV) in the Western Hemisphere. It has been suggested the virus was transferred by accident via an infected human passenger arriving by airflight from the Middle East. The virus subsequently gained ecological establishment and now is been identified throughout the eastern United States, northward to Canada and as far south as Florida, with expansion from the Atlantic coast to the Pacific coast within 24 months [CDC 2002]. Serious concern remains that other insect-vectored exotic pathogens may also gain entry to the U.S by way of accidental or intentional importation.

Enviro-climatic and vector population baseline profiling of US cities to determine the seasonal patterns of disease transmission-capable mosquitoes would be an important component of biosurveillance. Knowledge of when disease transmission would be optimized based on the seasonal appearance of vectors and whether conditions exist for further enhancement or inhibition of vector breeding habitats (e.g., drought, flooding, etc.) is critical to assessing the level of intervention needed when dealing with an accidentally introduced bioagent such as WNV or intentionally introduced weaponized vectored bioagents.

CHALLENGES, BENEFITS, AND FUTURE DIRECTIONS

Much of the excitement generated in the early days of RSEPI research revolved around the notion of 'forecasting disease' or 'forecasting human morbidity and mortality'. This description placed undue emphasis and reliance on the data by public health officers and physicians who lacked the training to understand the limitations of the data and the manner in which it is produced. Epidemic triggering and propagation is the result of a complex interaction between a multitude of variables such as the type of pathogen involved, immunity of the effected population, where the pathogen is transmitted by a vector, meteorological parameters, and so on. RSEPI systems have the potential to monitor one or a couple of these variables but not all of them. Without a comprehensive analytic system that can draw upon all of the variables involved, 'forecasting' will remain an elusive and perhaps unrealistic goal.

Nevertheless, the public health community recognizes the potential benefit of 'anticipatory' information that suggests an environment is primed to trigger an epidemic and enable propagation. Such knowledge can assist public health officers allocate scarce resources to enhance surveillance in a given areas, intensify and target education of the local medical response community, and review response protocols. Further, RS-derived data can provide valuable information in regards to reservoir and vector habitats. Knowledge of where to spray for mosquitoes, for instance, can reduce the environmental impact of pesticides and enable more efficient control.

Challenges exist within the public health and remote sensing communities to validate and produce reliable, accurate, and timely data. Basic understanding of the multi-factorial nature of epidemic triggering and propagation remains a major requirement for epidemiologists. Development of RS-derived data that is accurate, rapidly accessible, and reliable has been a long-term challenge to the remote sensing community. And between the two communities, cross-education and fertilization of ideas is needed. Finally, leadership in the US government is an important over-arching requirement to drive and sustain this important research.

Monitoring climatic modulation of infectious diseases by RS systems offers great potential benefit to the public. Collaborative efforts between the remote sensing, meteorological, medical, and public health communities should be encouraged and maintained to enable realization of this benefit.

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