Monitoring Environmental Indicators of Vector-borne Disease from Space: A New Opportunity for RADARSAT-2 S. Kaya, J. Sokol, and T.J. Pultz

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Abstract

Environmental vector-borne diseases are plaguing much of the world, and are a serious concern on a global scale. Many of these diseases are clearly associated with specific environmental conditions and landscape variables. The science and technology associated with remote sensing and Geographic Information Systems (GIS) is suitable for identifying these environmental targets, and since vector-borne diseases are most often found in tropical environments and during rainy seasons with persistent cloud cover conditions, radar is a particularly important sensor for monitoring and mapping the environmental indicators of disease. Preliminary investigations using RADARSAT-1 C-HH imagery have proven especially useful for identifying wetland habitats and flooded areas. It is anticipated that the advancements associated with the upcoming RADARSAT-2 sensor will improve the science of mapping vector-borne disease risk in tropical areas, particularly with access to increased spatial and temporal resolution, and fully polarimetric data. This paper will discuss the concept of using radar remote sensing for epidemiology applications, results using RADARSAT-1 for malaria risk mapping in coastal Kenya, and expected results with RADARSAT-2's advanced capabilities.

Introduction

Many environmental diseases are carried and transmitted by a disease "vector" (e.g. the *Anopheles* mosquito is the vector for malaria). These vector-borne diseases are most often prevalent in areas with specific environmental conditions conducive to vector breeding. With this direct link to the environment, space-borne remote sensing technology can be used to identify breeding grounds, and relate these targets to areas populated by the disease host (e.g. humans are the host in the case of malaria).

With nearly one-half of the human population inhabiting areas where they are at risk of one or more vector-borne diseases (WHO, 1998), an effective surveillance tool is required to identify populations and timing of potential risk. Strategic assessment of areas at risk of a vector-borne disease will facilitate rapid action by those in charge of mitigation and control initiatives, such as targeted pesticide application or distribution of medication (Hay *et al.*, 1997). Information extracted from remotely sensed data can provide critical input to decision-making processes by health organizations around the world.

Although the concept of using satellite-based mapping techniques for surveillance of disease is not new (Woodzick and Maxwell, 1977; King, 1979; Wagner et al., 1979; Hayes et al., 1985; Jovanovic, 1987), the use of radar remote sensing technology has not been extensively explored by the health community (Hay et al., 2000). This may be related to the limited amount of commercially available radar image data in the past, as well as the complexity associated with radar data interpretation and analysis. Further, early spaceborne radar sensors have had limited sensor configurations (C-VV and θ = 23°) for many applications. However, the current generation of radar satellites including Canada's RADARSAT-1, the European ENVISAT, and Canada's future RADARSAT-2 are changing this trend. Since many infectious diseases are prevalent in tropical areas with substantial cloud cover, it is often difficult to obtain useful cloud-free satellite data from commonly used optical sensors. Radar offers a solution to this with its capability to penetrate clouds and haze, as well as to image both day and night. This "all weather" capability makes satellites such as RADARSAT-1 useful tools for surveillance in tropical areas. RADARSAT-2 will build on this capability by offering higher resolution data, both spatially and temporally, as well as fully polarimetric C-band imagery.

Scientists at the Canada Centre for Remote Sensing (CCRS) have been exploring the potential of RADARSAT-1 for mapping vector-borne disease, with a case study on malaria risk assessment in coastal Kenya. This effort demonstrates the capability of radar remote sensing for vector-borne disease monitoring, and assesses the potential of RADARSAT-2 for the future.

Results using RADARSAT-1 for malaria risk mapping in coastal Kenya

Beyond radar's primary advantage of "all-weather" capability, SAR also has particular application to disease monitoring due to its sensitivity to surface moisture conditions and target geometry. C-HH SAR's, such as RADARSAT-1, have been found to be a suitable tool for mapping flood area extent, wetland regions, and flooded forest areas (Crevier and Pultz, 1996a; Costa *et al.*, 1997, Ramsey, 1995; Pope *et al.*, 1997).

As a demonstration project, multi-temporal standard mode (S7) RADARSAT-1 data were collected over a study site in coastal Kenya, near the town of Mombasa, in 1999 and 2001 during both wet and dry seasons. The area is home to two-thirds of the rural population of coastal Kenya, where malaria is a severe health concern. The environment mainly consists of a mix of indigenous forest, grassland savanna, mangrove swamps, and wetland vegetation. Plantation agriculture (mainly coconut, sisal and cashews) is also found along the coast. The ground elevation ranges from sea level to approximately 400 metres above sea-level (ASL) and there are several small rivers that flow from the highlands to the Indian Ocean.

Mosquito larval habitats in this area are diverse and change with the season. Coastal Kenya has two rainy seasons: from April to June and from October to November. Mean annual precipitation differs greatly in different parts of the coast, from over 1200 mm just

inland from Mombasa, to less than 750 mm on the western border of the inhabited area. During the dry season, some rivers and streams become completely dry, while others have reduced flow and numerous isolated, residual pools of water in the main riverbed. The wetland areas, both seasonal and permanent, are of particular importance to mapping malaria in the region (Hugh-Jones, 1989; Washino *et al.*, 1993; Beck *et al.*, 1994, 1997; Thomson *et al.*, 1997).

Figure 1 summarizes the methodology used for the research discussed here, including data input, geometric correction, image filtering, classification and analysis. The four standard mode images were co-registered, filtered using a mean filter (9 x 9 window), and a texture analysis was performed. The filtered and texture analysed images (total of 8 images) were used as input to the classification routine. An object-oriented approach to image classification was used to segment the images into homogeneous objects, and classify these objects into 6 primary classes: water, grassland, wetland, populated areas, indigenous forest (mainly mangrove), and rain forest. This procedure was carried out using land cover training areas, which were verified by scientists in the field (10-15 training polygons per class). An accuracy assessment of the results, using additional known land cover sites as test areas (10 test polygons per class), showed an overall classification accuracy of 85.5%, with varied accuracies for individual classes. Table 1 shows the confusion matrix for the object-oriented classification.



Figure 1. Summarized methodology for malaria risk mapping in coastal Kenya, using multitemporal standard mode RADARSAT-1 imagery.

Reference Class	WATER	WETLAND	GRASSLAND	FOREST 1	FOREST 2	AGRICULTURE	POPULATED	Sum
WATER	17514	0	0	0	0	0	0	17514
WETLAND	0	2355	0	3484	0	571	0	6410
GRASSLAND	0	0	22065	0	0	0	0	22065
FOREST 1	0	1249	0	10375	0	1044	0	12668
FOREST 2	253	0	612	0	6343	1299	0	8507
AGRICULTURE	0	0	0	0	2086	3400	0	5486
POPULATED	0	0	0	0	0	0	1034	1034
Unclassified	0	0	0	0	0	0	75	75
Sum	17767	3604	22677	13859	8429	6314	1109	
Accuracy								
Producer	0.986	0.653	0.973	0.749	0.753	0.538	0.932	
User	1	0.367	1	0.819	0.746	0.62	1	
Карра	0.981	0.62	0.961	0.696	0.72	0.501	0.931	
Overall Accuracy	0.855							
Overall Kappa	0.818							

Table 1. Confusion matrix showing accuracy assessment of object-oriented classification (in pixels)

For the purpose of this research project, the flight range (i.e. distance-to-infect) of the *Anopheles* mosquito is estimated to be 2-kilometres from the larval breeding site (Washino and Wood, 1993; Beck *et al*, 1994, 1997). With this information as a baseline, a proximity analysis was carried out whereby classified wetland parcels were extracted from the classified image, and integrated as a layer on the original RADARSAT data. Similarly, areas that were classified as populated were also extracted. A buffer zone routine created a 2-kilometre region around the wetland areas, and a proximity analysis allowed for extraction of the populated areas that were found within the buffered zone. The result of this methodology produced a malaria risk map, indicating the populated areas at risk of malaria infection. This sequence of activities is shown in Figure 2.

The results of this research indicate the potential of radar remote sensing for classifying land cover, specifically as environmental variables relate to malaria vector breeding grounds. Confusion in the classification results was seen with the wetland and mangrove forest classes, which can be explained by the similar target geometry and moisture conditions of the two classes, causing the radar backscatter signatures to have a limited separability. Both classes have suitable environmental characteristics of malaria vector breeding grounds, and further investigation will combine wetland and mangrove land cover classes to produce a more accurate classification for input into a risk mapping routine.



Figure 1. RADARSAT-1 standard 7 image with areas classified as populated (1), wetland areas (2), a 2-kilometre buffer zone around wetland areas (3), malaria risk map showing populated areas that fall within buffer zone around wetlands (4).

Opportunities for RADARSAT-2

The capabilities of RADARSAT-1 will be further developed with RADARSAT-2, which will provide all the imaging modes of RADARSAT-1, as well as some new modes that incorporate significant innovations and improvements. Hence, the satellite will offer data continuity to RADARSAT-1 users and new data that will support development of improved and new applications. The new capabilities associated with RADARSAT-2 that will be of particular significance to disease monitoring efforts are: high-resolution imaging, right and left-looking geometry, and fully polarimetric remote sensing. High

spatial resolution data will allow for small-scale regional analysis of vector breeding sites, as new ultra-fine mode will provide 3-metre spatial resolution data, covering a swath of 25-kilometres in a singular polarization. The selective look direction option will increase imaging revisit time and allow for increased temporal resolution to better provide near-real time imagery for monitoring disease outbreak situations. Polarimetric data will provide increased information content useful for improved land cover classifications with single-date imagery (McNairn, 2001), as well as information on water conditions within a wetland environment (Sokol, 2001).

RADARSAT-2 will offer the highest resolution commercial SAR data available to the remote sensing community, with 3-metre spatial resolution capability. One of the main limiting factors in the use of SAR for many applications has been related to insufficient spatial resolution to identify important environmental targets. In the application of remotely sensed imagery for assessing environmental indicators of disease, identifying localized targets is critical to obtain a realistic result of the potential presence of disease breeding grounds. In the case of malaria, small pools of water often found in areas of particularly low standards of living and poor sanitation, can be prime locations for vector breeding. Seasonal ponding associated with extreme weather conditions (e.g. El Niño/La Niña) are also important vector breeding grounds, and often very localized. RADARSAT-2 will provide the potential to identify these areas with ultra-fine mode imagery.

Another critical requirement of disease surveillance from space is timely data capture and delivery. Currently, RADARSAT-1 offers near-real time data delivery, with a revisit period of approximately 1-3 days at high latitudes and an average of 3-5 days closer to the Equator. It is expected that the revisit periods for RADARSAT-2 will be significantly greater, particularly if the manoeuvre between right and left looking mode is made operational (Lukowski *et al.*, 2002). A preliminary assessment on standard beam only, using the RADARSAT Swath Planning Application (SPA), indicates that RADARSAT-2 will be capable of a revisit imaging period in tropical areas near the Equator of approximately 1-2 days, if all possible imaging opportunities are taken advantage of. This increase in temporal resolution will address the need for time-critical information as disease outbreaks and epidemic situations arise.

One of the main advancements with RADARSAT-2 will be its capability for multiple and fully polarimetric imaging. Although the scientific community has had limited opportunities to explore the operational possibilities of space-borne polarimetry, several studies using airborne multi-polarised SAR have concluded that higher classification accuracy can be obtained, as compared to single linearly polarized data (Foody *et al.*, 1994; Lee *et al.*, 1994; Schmullius *et al.*, 1997; Boerner *et al.*, 1998; Pope *et al.*, 1992). Although C-HH polarization can be used to monitor wetland environments where vector breeding is likely to occur, increased information content with polarimetric data will likely facilitate more accurate land cover mapping (Ambrosia *et al.*, 1989; Linthicum *et al.*, 1991; Crevier *et al.*, 1996b).

The breeding habitats of many vector-borne diseases can be very specific, and may require a detailed classification to identify individual habitats (Pope *et al.*, 1993). For instance, within the broad class of wetlands, it would be useful to identify different wetland types like swamps, bogs, and fens, since certain wetlands have more available standing water for mosquito breeding. The potential also exists to classify wetland types with polarimetric data, as will be available with RADARSAT-2. Researchers at CCRS have used airborne polarimetric C-Band SAR data to investigate wetland types along the shores of the St. Lawrence River in Ontario, Canada. Sokol et al (1998) identified five different wetland types using a number of polarimetric parameters (polarimetric plots, linear co- and cross polarizations, pedestal height, and polarization ratios). polarimetric data enabled a broad class discrimination of wetland vegetation. Differences in vegetation density, related to wetland type, were reflected in the linear polarized backscatter values, whereas the polarization signatures gave some indication of differences in vegetation structure. Using shallow incidence angles (greater than 50°), the polarization responses indicated beam interaction with the vegetation, rather than ground or water targets (which would likely be seen using steeper incidence angles). The results demonstrate the ability of polarimetric radar to discriminate wetland classes, and offer insight into the potential capabilities of RADARSAT-2.

Conclusions

As the global remote sensing community strives to develop operational applications for earth observation satellite data, uses relating to disease monitoring need to be explored. For decades, research has been carried out in this field using optical data from sensors such as Landsat, with results consistently challenged by frequent cloud cover that often persists in tropical areas where vector-borne diseases are most common. Although little research has been done on the use of space-borne radar imagery for disease risk mapping, results presented here demonstrate the potential for RADARSAT-1 to identify environmental variables conducive to the breeding of malaria-carrying *Anopheles* mosquitoes. In addition to its 'all-weather' capability, SAR's sensitivity to surface moisture conditions and target geometry are identified as the primary advantages of radar remote sensing for this application

It is anticipated that RADARSAT-2 will provide increased potential for this application, particularly with high spatial and temporal resolution data, and polarimetric capabilities. RADARSAT-2's ultra-fine mode will likely facilitate the identification of small areas that are associated with disease risk. Outbreak situations may be targeted and monitored on a timely basis with the increased imaging schedule that will be available with left and right looking operations. Finally, polarimetry will contribute to current research that indicates the potential for increased classification accuracy, and more detailed classification. With four linear polarizations and fully polarimetric parameters available with RADARSAT-2, information on vegetation structure and water conditions can be derived. This will contribute to the operability of radar imagery for disease monitoring, in terms of accurately identifying potential areas at risk of vector-borne disease.

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