ON THE USE OF RADARSAT-1 FOR MONITORING MALARIA RISK IN KENYA

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ABSTRACT

The incidence and spread of vector-borne infectious diseases are increasing concerns in many parts of the world. Earth observation techniques provide a recognised means for monitoring and mapping disease risk as well as correlating environmental indicators with various disease vectors. Because the areas most impacted by vector-borne disease are remote and not easily monitored using traditional, labour intensive survey techniques, high spatial and temporal coverage provided by spaceborne sensors allows for the investigation of large areas in a timely manner. However, since the majority of infectious diseases occur in tropical areas, one of the main barriers to earth observation techniques is persistent cloud-cover.

Synthetic Aperture Radar (SAR) technology offers a solution to this problem by providing all-weather, day and night imaging capability. Based on SAR's sensitivity to target moisture conditions, sensors such as RADARSAT-1 can be readily used to map wetland and swampy areas that are conducive to functioning as aquatic larval habitats. Irrigation patterns, deforestation practises and the effects of local flooding can be monitored using SAR imagery, and related to potential disease vector abundance and proximity to populated areas.

This paper discusses the contribution of C-band radar remote sensing technology to monitoring and mapping malaria. Preliminary results using RADARSAT-1 for identifying areas of high mosquito (*Anopheles gambiae* s.l.) abundance along the Kenya coast will be discussed. The authors consider the potential of RADARSAT-1 data based on SAR sensor characteristics and the preliminary results obtained. Further potential of spaceborne SAR data for monitoring vector-borne disease is discussed with respect to future advanced SAR sensors such as RADARSAT-2.

INTRODUCTION

Remote sensing is widely used in natural resource applications such as agriculture, forestry, geology, hydrology and ice/oceans. However, significantly less research has been done using satellite remote sensing in the social sciences or public health. In recent years, several scientists have considered the applicability of remote sensing in conjunction with Geographic Information Systems (GIS) for monitoring human health, with varying levels of success. For the most part, it has been found that space-borne remotely sensed data can provide the spatial resolution and coverage needed to assess disease risk (specifically malaria) in a given area, and that GIS provides a useful tool for image analysis (Bryceson, 1989; Wood *et al*, 1991, 1994; Pope *et al*, 1992; Conner *et al*, 1997; Thomson *et al*, 1997, 2000; Hay *et al*, 1997, 1998, 2000; Beck *et al*, 2000).

Several issues need to be addressed, however, including the need for a multi-disciplinary approach, and the need for an effective tool with characteristics suitable for disease habitat identification. The need for a multi-disciplinary approach when considering the use of geomatics technology to human health applications is clear (Wood *et al*, 1993; Mayer, 1983). A combined effort from remote sensing scientists, geographers, and epidemiologists is required in order to make efficient use of satellite imagery for medical purposes. This study combines the expertise of researchers in all these fields, in order to assess the applicability of SAR remote sensing for monitoring malaria in coastal Kenya.

A further limitation noted in much of the past research done using remote sensing for disease monitoring is the problem of cloud cover. Since most of the vector-borne diseases in question are prevalent in tropical areas, there is a high incidence of cloud cover, which results in limited imaging opportunities with optical sensors such as Landsat TM. The obvious solution to this problem is the use of radar data. However, there has been little research done on the use of SAR remote sensing technology for monitoring and mapping disease risk, likely due to the complexity associated with SAR image interpretation and usability. This paper ~~will~~ addresses this concern and considers the needs of the user community in order to facilitate the use of SAR remote sensing, specifically RADARSAT-1, for monitoring vector-borne disease risk.

RADARSAT-1

Launched in November 1995, RADARSAT-1 is a Canadian initiative involving the Canadian Space Agency (CSA) and private industry. The RADARSAT-1 spacecraft carries a C-band Synthetic Aperture Radar (SAR) sensor that transmits and receives horizontally polarised (HH) microwave signals to image the earth both day and night. The chosen frequency of RADARSAT-1 (5.3 GHz) can penetrate clouds and haze, increasing the temporal coverage significantly over optical sensors. RADARSAT-1 technology has been proven useful for monitoring many of the Earth's natural resources and environmental changes, including land applications related to hydrology, agriculture, and land use mapping.

RADARSAT-1 has the unique ability to steer its variable mode radar beam over a wide area. The flexible swath width (50-500 km), spatial resolution (8-100 m), and incidence angle (10-60 degrees) provides users with many data options which can be suited to a variety of applications (see Table 1 for RADARSAT-1 operating beam mode specifications). When selecting remotely sensed data, users must consider the trade-off between spatial coverage and spatial resolution. RADARSAT's wide area swaths provide excellent regional coverage (up to 500 km) with a coarse spatial resolution, while detailed studies may be carried out using fine resolution data with a swath coverage of 50 km.

RADARSAT-1 operates in a sun-synchronous polar orbit at an altitude of approximately 798 km, providing complete global coverage on a regular and timely basis. The ground track of the satellite is repeated every 24 days, however the steerable beam capability and wide swath coverage allows for most regions on the Earth to be imaged more frequently. High latitudes (north of 70°) may be imaged on a daily basis, as is done in the Canadian Arctic regions, while areas closer to the equator can achieve repeat coverage every 3-6 days.

Mode	Approximate Incidence Angle [degrees]	Approximate Swath Width [km]	Approximate Resolution: [1] Rg x Az [m]	Approximate Looks [2] [Rg x Az]
Standard	20-49	100	25 x 28	1 x 4
Wide	20-39	150	25 x 28	1 x 4
Extended Low	10-23	170	40 x 28	1 x 4
Extended High	50-60	75	20 x 28	1 x 4
Fine	37-48	50	10 x 9	1 x 1
ScanSAR Wide	20-49	500	100 x 100	4 x 2
ScanSAR Narrow	20-40	300	50 x 50	2 x 2

[1] Ground resolution varies in range, [2] Range and processor dependent

Table 1: Characteristics of RADARSAT-1 operating beam modes

SAR and VECTOR-BORNE DISEASE MONITORING

As mentioned, there have been few published results on the applicability of SAR imagery specifically for disease monitoring, particularly using recent spaceborne SAR sensors. Pope (1992) considered the use of a high-resolution airborne three-band polarimetric radar system (ERIM / NADC P-3 SAR) for the identification of central Kenyan Rift Valley Fever vector habitats. This work concluded that airborne SAR imagery is useful for detecting flooded areas that can be related to active vector habitat sites of the Kenyan Rift Valley Fever virus. In particular, Pope notes the advantage SAR's 'all-weather capability' and sensitivity to moisture as major advantages.

There have been several published concerns that may account for the limited use of SAR imagery for health applications. In particular, the complexity of SAR imagery is associated with difficult image interpretation and information extraction (Hay *et al*, 2000). With this, a steep learning curve is often required in order to understand what is seen in a SAR image, as opposed to the more inherent interpretation of optical images. In addition, in the past, there has been a lack of well-calibrated SAR data, which limits confidence in results obtained from SAR data. RADARSAT-1, however provides fully calibrated data in all operating beam modes so that the user is not faced with this challenge. A final noted challenge relates to topography problems unique to SAR images, as well as inherent image speckle. These are valid concerns based on historical use of SAR data, which has for the most part been airborne. However, current commercial image processing software packages are available to deal with unique SAR characteristics, such as speckle interference and topographic effects. Although many of these packages require significantly more effort to facilitate accurate analysis, increasingly user-friendly packages are being developed as the availability and use of commercial SAR data increases with sensors such as RADARSAT, ERS, JERS and ENVISAT. Some of the advantages of spaceborne SAR imaging for disease monitoring are the capability for long-term monitoring, regional coverage, and near-real time data access capabilities. Additionally, interpretability of areas of flooded vegetation is likely easier with SAR, as opposed to optical remote sensing.

PROPOSED METHODOLOGY

The methodology of using SAR data for disease monitoring is similar to that used with optical remote sensing in recent years. With well-calibrated, multi-temporal RADARSAT-1 imagery, a geo-referenced, co-registered dataset may be used for image classification. Advanced intelligence-based classification routines such as object-oriented algorithms are most suitable for SAR data, since an assumption of normal data distribution can pose a problem with common routines such as parameterised supervised classifications. The availability and usability of advanced classification algorithms is increasing with the development of advanced classification software packages, which are designed to contend with some of the inherent challenges of SAR data. For this research, *eCognition* software was used to apply an object-oriented segmentation routine to the SAR data.

Based on SAR's sensitivity to vegetation structure and surface moisture conditions, ecological variables relating to vector breeding grounds may be readily identified with a classified SAR image. The land cover parcels associated with the disease vector under investigation may then be correlated with ground data of vector abundance. With this, areas of high vector abundance are tagged as high to low risk, depending on proximity to areas populated by the vectors host (e.g. human hosts for malaria carrying mosquito vectors). The use of GIS for cluster analysis and buffer zone generation around host areas can serve as a tool to produce disease risk maps, and will be investigated by the authors in future research.

CASE STUDY: COASTAL KENYA

Preliminary research was conducted over a 30-site area on the coast of Kenya. The area covers three main districts: Kwale, Kilifi and Malindi. The full study site is home to two-thirds of the rural population of coastal Kenya, where malaria is a severe health concern. The environment consists of forest, savanna, mangrove swamps and wetland vegetation. Agriculture plantations (mainly coconut, sisal and cashews) are 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. The water bodies in the area fluctuate in size depending on the seasonal rainfall, with rainy seasons typically occurring in May/June and October/November.

Figure 1 provides a map of the study area, with ground truth sites identified. During December 1997, *Anopheles gambiae* mosquito abundance data was collected for these 30 sites in the study area. This information was correlated with the land cover classification obtained from the RADARSAT imagery in order to assess the usefulness of SAR for identifying areas of potentially high mosquito abundance.

RADARSAT-1 Standard mode beam 7 data was collected over the study area in March 1999 and March 2001. These data have an approximate spatial resolution of 25 metres, swath width of 100 kilometres, and incident angle range of 45°-49°. These data were collected from the RADARSAT data archive and were the only data collected over the area in the past five years. Future data acquisitions will be carried out during the rainy season in the area, and compared with more timely ground truth collection. For the purposes of this study, the 1999 and 2001 data were used as input to the image classification. Figure 2 shows the original RADARSAT-1 (1999 and 2001) images analysed in this research.

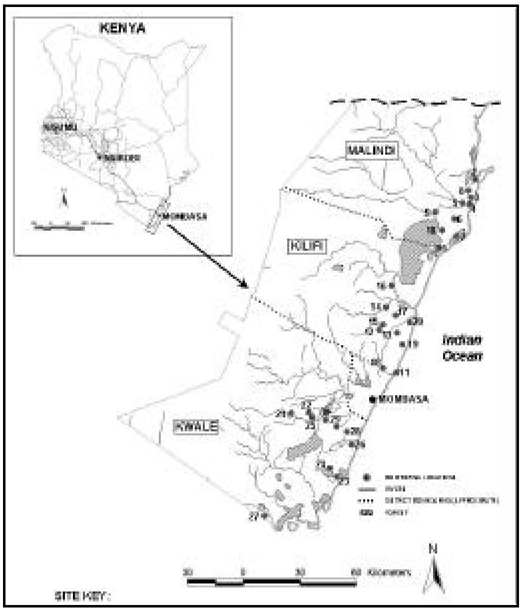

Figure 1: Coastal Kenya Study Area

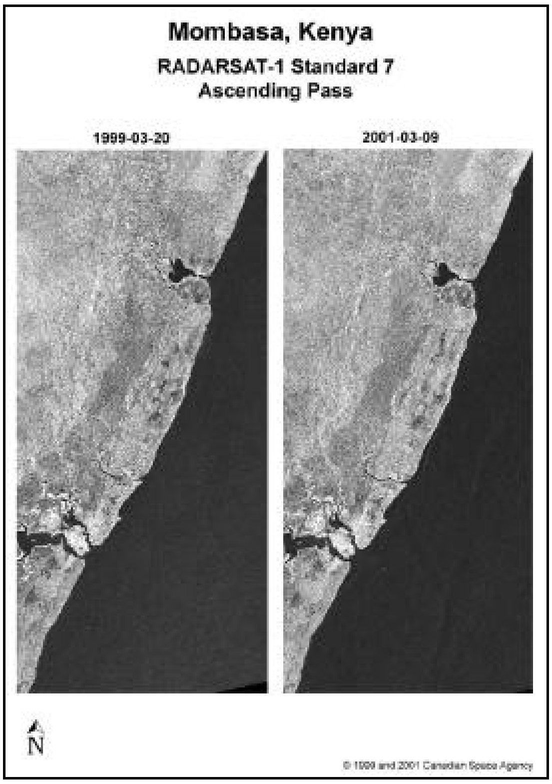

Figure 2: RADARSAT-1 Standard 7 images of the study area along Kenya coast.

A new tool, *eCognition* software, was used to perform the image classification. Using a segmentation routine to extract homogenous areas in the image, the classification algorithm then classified segments based on user input ground training sites. The following general land cover classes were identified: Forest (type 1 and 2), grassland, agriculture, wetland, populated and water, using a minimum of 12 training sites per class. Input image layers for the classification included original images for each date, mean filtered (7 by 7) and homogeneity texture images (7 by 7). These input layers were found to provide the best classification results.

The resulting classifications clearly identified wetland areas around the town of Mombasa, and the many streams that drain into the Indian Ocean. Coconut plantations are identified in Kilifi and Kwale districts, as well as the Shimba hills (forest type 1: indigenous species). Mangrove forests (forest type 2) near the coast are also identified. Throughout the center of the study area, the Kaya-Bombo forest was classified correctly as forest type 2. Also, sisal plantations are classified as agriculture in the center of the area, along the coast. The Arabuko forest is identified in the north and mainly consists of indigenous tree species. Small wetland patches are identified throughout the scene.

Mosquito collections done six times in each of the 30 sites during the first year (1997-1998) revealed significant temporal variation, with most of the mosquitoes being collected in one 2-month period. By overlaying the mosquito abundance data, it was found that areas of high Anopheles mosquito abundance closely corresponded to wetland classified areas, as well as grassland and forest type 2, for both 1999 and 2001. Moderately high abundance areas were found to correspond with grassland and forest type 1 areas. Areas of low mosquito abundance mainly corresponded with agriculture areas. Wetland classes around water bodies were clearly identified, and are likely to correspond to areas of high mosquito abundance.

Quantitative accuracy assessment was difficult to conduct due to lack of ground truth information for test sites. Qualitative assessment shows obvious classification confusion found between wetland and urban areas, due to the high degree of corner reflection occurring with both targets. Forest type 2 and agriculture areas were also confused in some areas, due to similar backscatter properties. Differences in moisture levels between 1999 and 2001 were seen, with clearly wetter conditions occurring in 2001.

The preliminary research described here will be further developed using more extensive, time series data sets. Current bi-weekly ground data collection is being carried out (including mosquito larvae abundance, habitat size, pH, vegetation cover, nutrient levels, rainfall, etc.) and concurrent RADARSAT-1 data will be collected for late 2001, during the rainy season. In order to perform useful accuracy assessments of the resulting classifications, increased number of training and test sites will be identified.

Continued research will analyse classifications obtained from RADARSAT-1 data using a GIS in order to associate areas of potentially high mosquito abundance with proximity to populated areas. With this, areas of high malaria risk may be readily identified. The potential is significant for the application of SAR data to become automated and perhaps a web-based tool. Health officials, decision-makers and policy analysts all over the world could use timely and accurate disease risk map information in order to organize and implement effective disease control and mitigation strategies.

DISCUSSION

The successes of RADARSAT-1 will be further developed with the launch of RADARSAT-2 in 2003. RADARSAT-2 will provide all 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 will allow for high-resolution imaging (up to 3 metres), right and left-looking geometry and fully polarimetric remote sensing. The selective look direction option will increase imaging revisit time and allow for increased temporal resolution to better provide near-real time imagery for disease outbreak monitoring. High spatial resolution (3m.) data will allow for local analysis of small area larval habitats that persist through long dry seasons. Polarimetric data will provide increased information content useful for improved land cover classifications with single-date imagery.

One of the main advancements with RADARSAT-2 will be its capability for multiple and fully polarimetric imaging. Although the scientific community has not had much opportunity to explore the possibilities of space-borne polarimetry, several studies using airborne multi-polarized SAR have concluded that classification accuracy is higher as compared to single linearly polarized data (Foody *et al*., 1994; Lee *et al*., 1994; Schmullius *et al*., 1997). Although C-band, HH polarization is optimal for monitoring environments where vector breeding is likely to occur (e.g. wetlands), increased information content with multi and fully polarimetric data will facilitate accurate land cover mapping (Ambrosia *et al*., 1989; Pultz *et al*., 1991).

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