*Geospatial Health 3(1), 2008, pp. 1-5*

# Satellite imaging and vector-borne diseases: the approach of the French National Space Agency (CNES)

Fabienne Marechal, Nathalie Ribeiro, Murielle Lafaye, Antonio Güell

*Centre National d'Etudes Spatiales, 18 avenue Edouard Belin 31, 401 Toulouse Cedex 9, France*

**Abstract.** Tele-epidemiology consists in studying human and animal epidemic, the spread of which is closely tied to environmental factors, using data from earth-orbiting satellites. By combining various data originated from satellites such as SPOT (vegetation indexes), Meteosat (winds and cloud masses) and other Earth observation data from Topex/Poseidon and Envisat (wave height, ocean temperature and colour) with hydrology data (number and distribution of lakes, water levels in rivers and reservoirs) and clinical data from humans and animals (clinical cases and serum use), predictive mathematical models can be constructed. A number of such approaches have been tested in the last three years. In Senegal, for example, Rift Valley fever epidemics are being monitored using a predictive model based on the rate at which water holes dry out after the rainy season, which affects the number of mosquito eggs which carry the virus.

**Keywords:** satellites, Earth-observation, tele-epidemiology, vector-borne disease, mathematical modelling.

## Introduction

Since 1999, and in the context of climate variability and climate change, a French multidisciplinary consortium on spatial surveillance of epidemics (S2E), has been developed with the aim to include innovative environmental monitoring and surveillance schemes from space. The core organizations and agencies of the S2E consortium are the French National Space Agency (CNES) and its subsidiaries, the Institute for Space Physiology and Telemedicine (MEDES) and the Partnership for Sustainable Development in the Mediterranean Basin and Sub-Saharan Africa (MEDIAS-France), Centre for collection and localisation of data by satellite (CLS), Institute National de la Recherche Agronomique (INRA)[1], the Veterinary School of Lyon (ENVL), and the Institute Pasteur of Paris. The consortium collaborates, when the need arises, with national scientific laboratories such as Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD)[2], Commissariat à l'Energie Atomique (CEA)[3], Institut de Recherche et de Développement (IRD)[4], universities, and/or industrial partners such as the European Aeronautic Defence and Space Company (EADS) group for Imagerie and Information (EADS-MS2I), Société Grenobloise d'Etudes et d'Applications Hydrauliques (SOGREAH)[5], the Spot satellite image and services provider SPOT-Image, and others.

During the last six years, the consortium has been involved in several projects such as:

(i) S2E Guyana (dengue fever in Guyana);
(ii) EMERCASE (Rift Valley fever in Senegal and Southern Mauritania);
(iii) S2E Argos (tropical diseases in Niger and Burkina Faso);

Corresponding author:
Antonio Güell
Centre National d'Etudes Spatiales
18 avenue Edouard Belin
31401 Toulouse Cedex 9, France
Tel. +33 5 61 28 25 77; Fax +33 5 61 28 28 99
E-mail: antonio.guell@cnes.fr

1 French Agronomic Research Institute
2 International Cooperation Centre for Agricultural Research and Development
3 Atomic Energy Commisson
4 Institute for Research and Development
5 Grenoble Association for the Hydralic Studies and Applications

(iv) S2E Migrating (avian flu in the Camargue area of France) with the National Institute for Health and Medical Research (INSERM);
(v) MATE (dengue fever in Argentina) with the Argentinean Spatial Agency (CONAE);
(vi) BIBO (avian flu) with the Chinese Space Agency (CRESDA; Lafaye, 2006); and
(vii) VIBRIO (a project including cholera in the Mediterranean) is being developed directly by CNES.

**The CNES methodology and approach**

Following the French contribution and presentation during the Johannesburg Summit 2002, among others, and under the aegis of the S2E consortium, a new interactive health information system or the re-emergent diseases global environment monitoring from space (RedGems) was born. Its two pillars, tele-epidemiology, and telemedicine, are used to facilitate real-time monitoring of human and animal health (i.e. epidemiology, clinical data, entomological data, etc.). The primary mission of RedGems is to analyze health-climate/environment relationships in order to contribute towards the development of early warning systems (EWS). The overall aim is to attempt predicting and mitigating public health impact from epidemics. This integrated and multidisciplinary approach includes three main objectives:
(i) deployment of in-situ health information systems for data information, exchange and management in real-time;
(ii) use of bio-mathematical models for epidemic dynamics; and
(iii) remote-sensing monitoring of climate and environment linking epidemics with “confounding factors” such as vegetation, hydrology, forest and water extent, and population dynamics.

Tele-epidemiology aims to study the spread of human and animal epidemics which are closely tied to environmental factors, climate change in particular. By combining satellite-originated data on vegetation (SPOT), meteorology (Meteosat), oceanography (Topex/Poseidon and Envisat) with hydrology data (number and distribution of lakes, water levels in rivers and reservoirs) with clinical data from humans and animals (clinical cases and serum use), predictive mathematical models can be constructed. This type of approach has been tested during the last three years. In Senegal, for example, Rift Valley fever epidemics are being monitored using a predictive model based on the rate at which water holes dry out after the rainy season as this affects on the number of virus-infected mosquito eggs (Bicout et al., 2003). This experiment has achieved good results, encouraging the Senegalese government to provide funding, with matching support from MEDES, to extend the approach initiated to all risk zones in which populations and cattle are exposed.

In French Guiana, a tele-epidemiology network was set up in mid-2003 to monitor hemorrhagic dengue fever. This network is jointly operated with the Institute Pasteur, IRD, MEDES and the Lyon School of Veterinary Science to study areas where the mosquito vector is thought to breed. Here again, combining satellite data and epidemiological data is contributing to make prevention more effective.

As part from the French Ministry of Research’s Earth-Space Network, a pilot sentinel network has been deployed in Niger and Burkina Faso to monitor infectious diseases whose spread is tied to environmental factors. For example, parameters such as dust clouds and wind appear to play a crucial role in triggering the spread of meningococcal meningitis. Lastly, a consortium formed by CNES, Institut Pasteur, Médias-France and Italian universities, and funded by CNES and Institut Pasteur, is monitoring cholera epidemics around the Mediterranean basin. This project is using mathematical models to assess the risk of a resurgence of the disease, which is linked to numbers of cholera-spreading zooplankton.

Fifty years of successful efforts in the prevention and control of infectious diseases and epidemics have inspired confidence and optimism in modern medicine and technology. Nevertheless, epidemics remain a conspicuous challenge to public health today. In the context of climate change and the rapidly increasing population, some epidemics are even re-emerging. For example, the Ferlo region in Senegal, became prone to RVF in the late 1980s with the appearance of infected vector mosquitoes of the *Aedes vexans* and *Culex poicilipes* species. The latter proliferate near temporary ponds and neighbouring humid vegetation. RVF epizootic outbreaks in livestock cause spontaneous abortions and perinatal mortality. So far, human-related disease symptoms are often limited to flulike syndromes but can include more severe forms of encephalitis and hemorrhagic fevers. As a result, local socioeconomic resources can be seriously affected. As highlighted in Bicout et al. (2003), this growing threat created an urgent need for a local EWS for RVF epidemics in Senegal. The goal was to use specific geographical information system (GIS) tools and remote sensing (RS) images/data to detect potential breeding ponds and evaluate RVF diffusion and areas with potential risks.

## The example of the RVF project: description and preliminary results

The RVF project in the Ferlo region was implemented by MEDIAS-France under the auspices of CNES. In this region, the mosquito population abundance is linked to rainfall, presence of ponds and their turbidity, including presence or absence of vegetation in the ponds (e.g. water lilies, wild rice). Initially, ENVI 4.3 software was used for spectral analysis of high-resolution (~10 m) SPOT 5 images to locate the ponds (Lacaux et al., 2007). First, image registration tools were used to warp the images to match and implement relative georeferencing for all SPOT 5 images collected, with further adjustment to minimize spatial errors. Then, new indices were obtained by using the classic normalized difference vegetation index (NDVI) transform tool to allow the combination of different spectral bands (such as the middle infrared [MIR] and the near infrared [NIR], red and green bands). The normalized difference pond index (NDPI) permitted the detection of all ponds, while the normalized difference turbidity index (NDTI) contributed to the evaluation of water transparency or turbidity. In situ observations by participants from the Centre de Suivi Ecologique, in nearby Dakar, validated both indices using a global positioning system (GPS) and GIS. Using these methods, it was possible to locate small ponds with precision, making it further possible to map the RVF-risk in zones that could potentially become occupied by mosquitoes (ZPOM) following recent studies from entomologists on flying ranges and spatial distribution of mosquitoes.

## A step towards adapted space products for EWS

Further refinement and simplification were needed, however, because of the complexity of the pond distribution and to develop an effective usage strategy for local health information services. Researchers wanted to identify degrees of risk from isolated and/or clustered ponds, calculate the target risk coverage area, and evaluate risk by mosquito density in overlapping zones. Because of researcher GIS expertise and the availability of new detailed information in the zones, the GIS approach became an obvious solution for the team. Using ESRI ArcView software and tools (i.e. conversion and data management for spatial projection and transformation, as well as overlay and proximity vector data analyses), maps obtained from SPOT 5 10 m multispectral resolution imagery were first transformed into appropriate formats, then converted from raster to vector formats. The georeferencing accomplished through universal transverse Mercator (UTM) WGS84 for zone 28N permitted further comparison and processing. The initial ZPOM was first divided into three bands chosen for defining risk levels for potential virus transmission by *Ae. vexans*:

(i) 0 to 50 m (~18% mosquitoes recaptured);
(ii) 50 m to 150 m (~29% mosquitoes recaptured); and
(iii) 150 m to 500 m (53% mosquitoes recaptured).

Then, using ArcView, researchers calculated mosquito density and evaluated cross-potential risks (Tourre et al., 2007). They noted that zones with very high and high risks were inhabited by potential reservoirs as snakes, frogs, and toads) for the RVF virus and produced an improved ZPOM (Fig. 1).

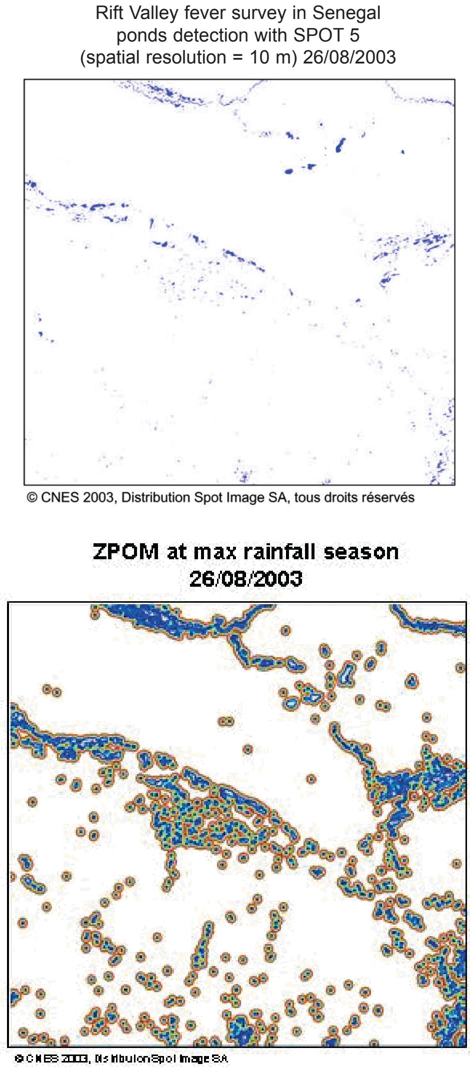


Fig. 1. Pond-detection and ZPOM.

## Results

The analyses using GIS technology allowed researchers to see that risks increase when ponds are close to each other. Using GIS technology, researchers created a new, more detailed and more useful ZPOM. The GIS tools provided new products and information for use by local EWS in the prevention of disease (Fig. 2).

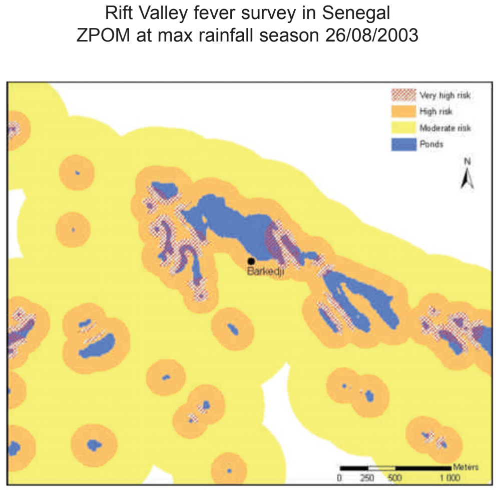


Fig. 2. Close ponds and risk impact on ZPOM.

This technique might be improved by adding digitized ecological zone layers. Multidisciplinary users can benefit from this data by using it to choose strategic positioning of villages and parks according to the perceived RVF risk. This new methodology is also being transferred to other teams in Africa for varied types of mosquito vector research.

## Conclusion

Tele-epidemiology has proven that existing resources such as satellites, medical kits, infrastructures and so forth, can be exploited to improve quality of treatment, particularly where environmental conditions are precarious. It can also achieve significant savings in public health costs. Ground-based data collection and transmission networks supported by satellite imagery can play a vital role in preventing the spread of diseases which are particularly dependent on environmental factors. An epidemic monitoring network can be a first step towards a European Health EWS.

## References


Bicout DF, Porphyre T, Ndione JA, Sabatier P, 2003. Modelling abundance of *Aedes* and *Culex* spp. in rain-fed ponds in Barkedji, Senegal. Proceedings of the 10th International Symposium on Veterinarian Epidemiology and Economics, Vina del Mar, Chile, p. 84.

Lacaux JP, Tourre YM, Vignolles C, Ndione JA, Lafaye M, 2007. Classification of ponds from high spatial resolution remote sensing: application to rift valley fever epidemics in Senegal. J Remote Sensing Environ 106, 66-74.

Lafaye M, 2006. Nouvelles applications spatiales pour la santé: la télé-épidémiologie pour le suivi des fièvres aviaires. CNES Mag février 2, 30-31.

Tourre YM, Fontannaz D, Vignolles C, Ndione JA, Lacaux JP, Lafaye M, 2007. GIS and high-resolution remote sensing improve early warning planning for mosquito-borne epidemics. Healthy GIS, GIS for Health and Human Services, ESRI, 1-4.