

Rift Valley Fever (RVF) risks in Senegal using high-resolution remote sensing

Y. M. Tourre ^{a,*}, J-P. Lacaux ^b, C. Vignolles ^c, J-A. Ndione ^d, M. Lafaye ^c

^a LDEO of Columbia University, Palisades, NY, USA- yvestourre@aol.com

^b OMP/CNRS, Laboratoire d'Aérodynamique, Toulouse, France- lacjp@aero.obs-mip.fr

^c CNES, Toulouse, France- cecile.vignolles@cnes.fr; murielle.lafaye@cnes.fr

^d CSE/LPA & Océan Siméon-Fongang/ESP-UCAD, Dakar, Sénégal- jacques-andre.ndione@cse.sn

Commission VIII, WG VIII/2

KEY WORDS: Remote sensing, Infectious diseases, Early Warning Systems

ABSTRACT:

During the rainy season, from rainfall events and ponds dynamic in the Barkedji area (Senegal), detailed zones potentially occupied by mosquitoes (ZPOM), and exposure to RVF virus transmission are produced. To that purpose, remotely sampled ponds (from high resolution SPOT-5 images) and rainfall events (from TRMM project) data combined with in-situ measurements (entomology, limnometry, hydrology, virology) and hosts location (parked ruminants, from QuickBird satellite), are used. The '*Aedes vexans* productive rainfall events' are associated with vectors embryogenesis (i.e., 6 days without rain are necessary to trigger hatching). The dynamical spatio-temporal distribution of the *Aedes vexans* density is presented. Combined with aggressiveness temporal profiles, detailed mapping of ZPOM are obtained on a operational basis. Risks zones (i.e., hazards + vulnerability) and percentage of parked animals under threats, can thus be derived. This methodology is meant to contribute to the implementation of a new operational Early Warning Systems for RVF, or RVFEWS, and is to be applied elsewhere for other vector-borne diseases.

1. INTRODUCTION

1.1 Rationale

Climate changes and varies on several spatio-temporal scales from the interactions between its five components i.e., the atmosphere, the hydrosphere, the cryosphere, the biosphere and the lithosphere. Adding to these natural cycles and fluctuations is the anthropogenic contribution from population increase, energy needs and associated pollution. Overall climate oscillations interact directly with ecosystems, environment, socio-economic conditions and public health (Lacaux and Tourre, 2006). Indeed climate and environmental changes alter regional/local social and economic

dynamics bringing inequalities around the world. The latter enhance economic migration, and associated public health issues. For example, there is a re-emergence of infectious diseases, respiratory and circulatory problems, pollution and allergen-related diseases and impaired immune systems. Public health issues also exacerbated by poor water quality and malnutrition. Moreover direct influence from demographic factors are expected to increase risks of infectious diseases being transmitted from person-to-person. Most emerging (or re-emerging) infectious diseases (including vector-borne diseases) are due partly to changes in 'microbial traffic', the introduction of pathogens from wildlife into human populations already at risks. Changes in

transmission of diseases by vectors (such as mosquitoes) may arise from new vector reservoirs in different habitats. As of today, the increase in occurrence of many infectious diseases reflects the compounded effects of climatic and environmental changes, population increases, economic, social and technological changes (Plan Bleu, 2008).

1.2 Climate and infectious diseases

The challenge for assessing socio-economic impact of infectious diseases (~75% of actual infectious diseases in humans are zoonoses) cannot be addressed without considering both abiotic and biotic environmental factors that affect the maintenance and transmission of the diseases. The last 25 years have witnessed an explosion of environmentally related diseases and disorders, with strong environmental forcing and adaptation or lack thereof. For infectious diseases, this includes increases in prevalence, incidence and geographical distribution across wide taxonomic ranges, related to climatic/environmental changes and practical changes in land-use. Indirect health effects arise from perturbation of more complex ecological systems, and include changes in the ecology, range and activity of mosquitoes/vectors and associated diseases (i.e. malaria, West Nile virus, Rift Valley Fever (RVF), avian flu, chikungunya, dengue fever and others, Takken et al., 2006).

1.3 Climate change and decision-making

Climate change affects regional socio-economic costs and losses, through changes in temperature and soil moisture, pest and pathogen activity.

Decision-making models to be used must include:

- (1) Identification of 'normal' impacts of a given disease (in lives and economic terms);
- (2) Definition of 'climate events' linked to 'health events' (epidemics, endemics, pandemics);
- (3) Definition of 'increased impacts' and socio-economic losses;
- (4) Identification of conceptual method to mitigate impacts;
- (5) Implementation of services such as Early Warning Systems (EWS) and Health Information Systems (HIS);
- (6) Quantification of real savings (including lives) if a 'health event' does not occur.

Differences in population vulnerability could arise from heterogeneity of human culture, social relations and behaviour. Non-linear uncertainties arise from the stochastic nature of the biophysical systems being modelled. Local anthropogenic deforestation may directly alter the distribution of a vector-borne diseases.

1.4 Climate/environmental changes and remote sensing

Public health indicators and disease surveillance activities must be integrated with other in-situ monitoring systems developed by the United Nations, such as Global Climate Observing System (GCOS), Global Ocean Observing System (GOOS), Global Terrestrial Observing System (GTOS) and the integrated Global Earth Observation System of Systems (GEOSS). Today, the use of satellites allows high-resolution monitoring of changes in environmental and climatic parameters. This provides an important continuum of observation on various spatio-temporal scales for both oceanic and terrestrial environment.

1.4.1 Tele-epidemiology

Infectious diseases remain a considerable challenge to public health. Some epidemics are emerging or re-emerging such as the Rift Valley Fever (RVF) over West Africa, dengue fever over northern Argentina and chikungunya in the Indian Ocean, among others. Following the French contribution at the Johannesburg Summit of 2002, a brand-new conceptual approach has been developed: so-called *tele-epidemiology*. It aims to monitor and study from space the spread of human and animal infectious diseases which are closely tied to climate and environmental changes. By combining satellite-originated data on vegetation (SPOT), meteorology (Meteosat, TRMM), oceanography (Topex/Poseidon; ENVISAT, JASON), with hydrology data (distribution of lakes, water levels in rivers, ponds and reservoirs), with clinical data from humans and animals (clinical cases and serum use), products and predictive mathematical models can be constructed.

This integrated and multidisciplinary approach (Lafaye, 2006) includes:

- (1) monitoring and assembling multidisciplinary in-situ datasets to extract and identify physical and biological mechanisms at stake;
- (2) remote-sensing monitoring of climate and environment, linking epidemics with 'confounding factors' such as rainfall, vegetation, hydrology and population dynamics; and
- (3) use of bio-mathematical models for epidemic dynamics, vector aggressiveness and associated risks.

As such an interactive tool contributing to HIS on re-emergent and new infectious

diseases (RedGems) was born (Marechal et al., 2008). It constitutes the main pillar of tele-epidemiology by facilitating real-time monitoring of human and animal health and the exchanges of epidemiological, clinical and entomological data. The primary mission of RedGems (<http://www.redgems.org>) is to contribute to the development of early warning systems (EWS) for infectious diseases. The overall objective is to attempt predicting and mitigating public health impacts from epidemics, endemics and pandemics.

2. The Rift Valley Fever (RVF) case

The various components of the conceptual approach described above have been thoroughly tested with regard to the emerging RVF in the Ferlo (Senegal). This successful approach has led the Senegalese government to provide funding, and extend the approach to all risk zones (i.e. hazards + vulnerability) where populations and cattle are exposed (Vignolles et al., 2009).

The Ferlo region in Senegal, became prone to RVF in the late 1980s with the appearance of vector/mosquitoes such as *Aedes vexans* and *Culex poicilipes* species (Lacaux et al., 2007; Tourre et al., 2008). 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 flu-like syndromes but can include more severe forms of encephalitis and haemorrhagic fevers. As a result, local socio-economic resources can be seriously affected. The ultimate goal has been to use specific Geographical Information System (GIS) tools (Tourre et al., 2007) and remote-sensing (RS) images and data to detect potential breeding ponds and evaluate RVF transmission and areas potentially at risk, characterized as Zones Potentially Occupied by Mosquitoes or ZPOMs.

A schematic design of the integrated conceptual approach to determine the environmental risk levels of RVF is presented in Fig. 1.

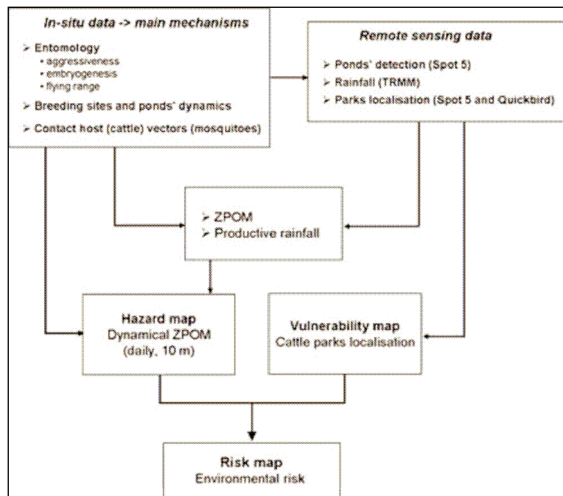


Fig. 1. Integrated conceptual approach. The basic components for the concept are presented in the top three boxes: in-situ data (upper left), remotely sensed data (upper right) and Zone Potentially Occupied by Mosquitoes or ZPOMs and 'productive rainfall' in terms of production of mosquitoes/vectors (centre). The bottom three boxes distinguish between hazards (bottom left), vulnerability (bottom right), both leading to the environmental risks (very bottom).

The upper left box in the figure identifies key entomological factors for *Aedes vexans* (flying-range, aggressiveness and embryogenesis), environmental factors (rainfall distribution, limnometry and pond dynamics) as well as pastoral data such as the zones where animals are penned at night. From the upper right box, the detection of lead environmental and climatic factors (mainly rainfall) favouring keys mechanisms are highlighted. For example, optimal pond conditions for the breeding and hatching of *Aedes vexans* can be modelled (Bicout et al., 2003). The central box refers to the ZPOMs derived

from pond dynamics after a so-called 'productive rainfall' event, and which includes the flying ranges of *Aedes vexans*. The integration of all the above components leads to the notion of risks: hazards and exposure vulnerability of hosts. This original approach bridges the physical and biological mechanisms, linking environmental conditions to the 'production' of RVF vectors and accompanying potential risks.

Possible hazards in the vicinity of fenced-in hosts are displayed in Fig. 2, where the Barkedji area is shown with the mapped ZPOMs. Thus, parks and villages can easily be identified. Out of 18 rainfall events obtained from TRMM for the 2003 rainy season, seven were considered as 'productive' with regard to *Aedes vexans* production (based on entomological studies).

Climate variability and change, environmental risks and public health are all associated. In the case of potential RVF epidemics, mechanisms linking rainfall variability (and trends), density and aggressiveness of vectors and vulnerability of hosts are presented. Using observations from space, the dynamic evolution of ZPOMs can be seen (Fig. 3; see also animated on-line version available at www.geospatialhealth.unina.it) (see also CNES, 2008).

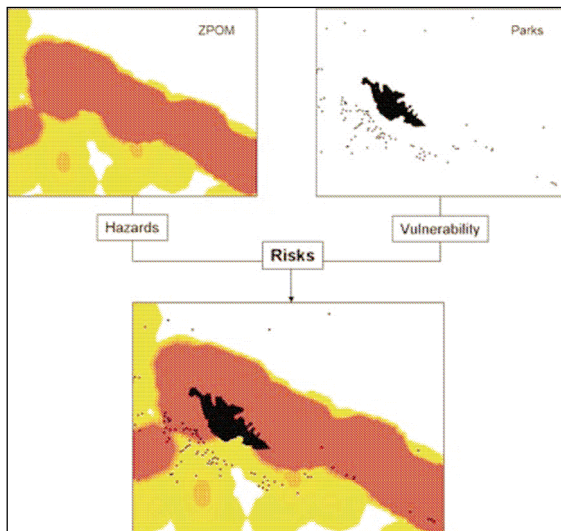


Fig. 2. Zone Potentially Occupied by Mosquitoes, or ZPOMs with ranked hazards from yellow (low hazards) to red (high hazards). ZPOMs in the Barkedji area is constructed from the ponds distribution after a single rainfall event (top left). Localization of the Barkedji village and ruminants' fenced-in areas (vulnerability, from QuickBird) in black for the same period (top right). Potential risks i.e. hazards + vulnerability are shown by superimposing the two pictures (bottom).

3. CONCLUSION

Climatic and environmental variability and changes identified from space provide the elements for the mapping of risk zones in which necessary conditions for the RVF virus to circulate and be transmitted exist. The evolution of the ZPOMs during the rainy season reveals areas in which populations and cattle of the Ferlo region in Senegal are exposed. There are many strengths in this approach. It can be used in quasi real-time, and results can be linked with biological modelling for virus transmission and circulation and more classical epidemiological models. Socio-economic risks may be reduced and mitigated, based upon statistical evaluation of the seasonal rainfall forecasts which can be assessed a few months prior to the rainy season and subsequently updated. For example, results can be immediately applied upstream by the former Senegalese Direction de l'Élevage (DIREL), now Direction Surveillance Vétérinaire (DSV) though strategic displacement of fenced-in

areas for cattle penned at night, during the course of the rainy season. Nonetheless, socio-economic problems may still arise if the relevant information has not been distributed operationally to all parties involved, through regional HIS. Ultimately, the fully integrated approach should help in understanding the mechanisms leading to potential RVF epidemics and improve the RVFEWS.

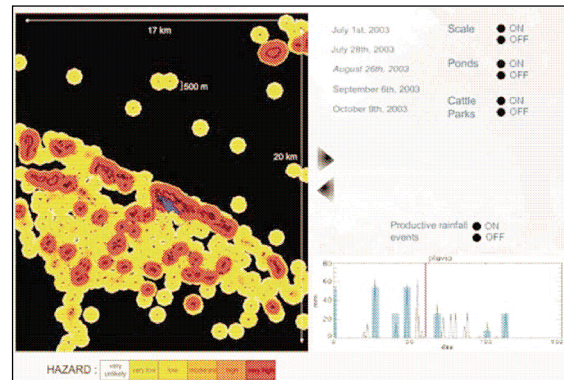


Fig. 3. Dynamic Zones Potentially Occupied by Mosquitoes (ZPOMs) and ranked hazards (from very unlikely and very low in yellow, to very high in red, bottom scale) and ponds distribution (in blue) during the 2003 rainy season. From the hyperlinked figure available in the on-line paper, by clicking on the two fat black arrows (center), animated ZPOMs from 'productive rainfall' (highlighted in blue, at the bottom right) are displayed (upper arrow for forward motion, lower arrow for backward motion) along with the relative parks' locations (i.e., cattle vulnerability). The starting date is 28 June 2003.

The conceptual approach presented might not apply directly for other vector-borne diseases, whose vectors have different behaviours. Thus, physical and biological mechanisms for other infectious diseases and places (including higher latitude regions) need to be studied individually. A similar methodology using space observations may be used, particularly in places where climate and environment are foreseen to change rapidly, as for example currently being implemented for malaria cases and dynamic in Burkina Faso.

4. Acknowledgements

The authors would like to thank Dr. Antonio Güell, Head of the Application and Valorisation department at CNES, for his unconditional support. Tourre would like to thank Drs. Philippe Dandin and Mike Purdy, Directors of the Climatology Department at METEO-France and of the LDEO of Columbia University, respectively.

5. References

- Bicout, D. F., Porphyre T., Ndione J-A., and Sabatier P., 2003. Modeling 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, 17-21 November, p. 84.
- CNES, 2008: Method for tele-epidemiology (Méthode pour la télé-épidémiologie). Patent pending # PCT/FR2009/050735.
- Lacaux, J-P., and Tourre Y. M., 2006. Impacts des changements climatiques. Le climat et sa variabilité ont-ils un impact sur la santé humaine? *Biofutur*, 270, pp 22-24.
- Lacaux, J-P., Tourre Y. M., Vignolles C., Ndione J-A., and Lafaye M., 2007. Classification of ponds from high spatial resolution remote sensing: application to Rift Valley Fever epidemics in Senegal. *J Remote Sensing Env.*, 106, pp 66-74.
- Lafaye M., 2006. Nouvelles applications spatiales pour la santé: la télé-épidémiologie pour le suivi des fièvres aviaires. Toulouse cedex, France, *CNES Magazine*, 30-31 February 2006.
- Marechal, F., Ribeiro N., Lafaye M., Güell A., 2008. Satellite imaging and vector-borne diseases: the approach of the French National Space Agency (CNES). *Geospat Health*, 3, pp1-5.
- Plan Bleu, 2008. Climate change and energy in the Mediterranean. Part 1, Chapter 1: Mediterranean Basin: climate change and impacts during the 21st century. Report. Sophia Antipolis, France: Le Plan Bleu; 2008, pp. 52-54.
- Takken, W., Martens P, and Bogers RJ., 2006. Environmental change and malaria risk: global and local implications. New York, LLC: Springer-Verlag; p. 139.
- Tourre, Y. M., Fontannaz D., Vignolles C., Ndione J-A., Lacaux, J-P., and 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, pp1-4.
- Tourre, Y. M., Lacaux J-P., Vignolles C., Ndione J-A, and Lafaye M., 2008. Mapping of zones potentially occupied by *Aedes vexans* and *Culex poicilipes* mosquitoes, the main vectors of Rift Valley Fever in Senegal. *Geospat. Health*, 3, pp 69-79.
- Vignolles, C., Lacaux J-P., Tourre Y. M., Bigeard G., Ndione J-A., and Lafaye M., 2009. Rift Valley Fever in a zone potentially occupied by *Aedes vexans* in Senegal: dynamics and risk mapping. *Geospat. Health*, 3, 211-20.