

# ***Aedes aegypti* spatio-temporal modelling based on non homogeneous environment derived from remote sensors information.**

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**Abstract – A preliminary numerical model for the dynamics of *Aedes aegypti* study is proposed. We present spatio-temporal diffusion model that takes into account superficial wind and vector population dynamics parameters related with land uses such as birth, diffusion, attraction by mammals and deaths. Differential equations of transport, diffusion and conservation used in fluid mechanics in its continues approaches, are adapted for the study of mosquitoes population dynamics. Study site is located into a buffer zone of the Unite Nations Biosphere Reserve “Las Yungas”, in the southernmost part of the eastern mountainous forest of the Andean Chain in the Province of Salta - Argentina. It encompasses a rich diversity of landscapes from the high Andean ecosystems with mountain forest, ‘Chaco Serrano’, cloud forests to subtropical low mountain jungle, with montane forests, grasslands and agricultural land with sugar cane, citrus fruits, soya bean and cotton among others. One of the principal characteristic of the region is the high biodiversity, presence of economic importance species, landscape resources and convergence of great diversity of native Amerindian cultures. Model diffusion equations work on a non-homogeneous scenario and with non-uniform diffusion tensors. Landscape rugosity was derived from Landsat 5 TM image (Path 230 – Row 76), and generated from different kind of supervised classifications of the image and Texture Filter like Co-occurrence measures. Environmental texture image of study area was generated taking into account vegetation vertical development and land coverage. 6 different landscape rugosity classes were created: city, water, exposed soil, low vegetation, commercial/open forests, and jungle. Simulations in very variable and vast real landscapes, where good quality field data is very difficult to obtain, show the advantage of using remotely sensed and complementary meteorological data for modelling the geographic spread of a disease vector such as *Aedes aegypti* mosquitoes. Taking into account that geographic studies of epidemics are in general on their beginnings, this kind of models are the base of understanding of their spread behavior and parameters, indispensably to create proper vector control programs and epidemic early alert systems.**

**Keywords:** *Aedes aegypti*, remote sensing, diffusion model, population dynamics.

## **1. INTRODUCTION**

Since the beginning of Remote Sensing (RS) technology, studies on vector-borne diseases have focused on identifying and mapping vector habitats (Barnes and Cibula, 1979; Hayes et al. 1985) assessing environmental factors related to vector biology (Rogers and Randolph, 1991; Rogers and Randolph 1993; Kitron 1998)

and studying diseases epidemiology (Linthicum et al., 1999; Murray, 2003). Wood et al. (1991) and Glass et al. (1992) investigated the application of RS and spatial analysis techniques to identify and map landscape elements that collectively define vector and human population dynamics related to disease transmission risk. Landscape pattern analysis, combined with spatial statistical analysis, allow the definition of landscape scale predictors of disease risk that could be applied in larger regions where field data are unavailable (Dister et al., 1997; Beck et al., 2000; Tran et al., 2004). This makes Remote Sensing (RS) /Geographic Information System (GIS) a powerful tool for vector/disease surveillance and intervention programs (Morrison et al., 1998). In this context, Argentinean Space Agency (CONAE) is developing a research program in collaboration with the National Vector Control Coordination from the Argentinean National Health Minister to develop RS and GIS complementary tools for vector surveillance and outbreak prediction.

The main objective of this work was to explore the potential of spatio-temporal diffusion model, based on RS and GIS elements, for a better understanding of the environmental characteristics and vector population parameters that determined the distribution dynamics of mosquitoes in a dengue epidemic region of north-western Argentina.

This proposed model is based on a flying insect diffusion model that takes into account different phenomena determining vectors dynamics: transport, attractive and repulsive forces, landscape structure.

## **2. MAIN BODY**

Study test site is located in Hipólito Yrigoyen, a dengue epidemic city of Salta Province – Argentina, and its surrounding rural areas. This region is a buffer zone of the Unite Nations Biosphere Reserve of the eastern mountainous forest on the Andean Chain named “Las Yungas”. Characterized by high biodiversity, natural resources and convergence of great diversity of native Amerindian cultures, it encompasses a rich diversity of landscapes, from the high Andean ecosystems with mountain forest (Chaco Serrano), cloud forests to subtropical low mountain jungle, with montane forests, grasslands and agricultural lands of sugar cane, citrus fruits, soya bean and cotton among others. Two different Landscape areas of 5.7 km X 5.7 km, were chosen to run our model in this region. One is a characteristic rural area, with few isolated houses or farms, surrounded by crops, rivers and jungle (23° 9’ 31.08”S, 64° 14’ 52.58”W), and the other one the city of Yrigoyen, and its sub-urban region (23° 14’ 36”S, 64° 16’ 35.84”W).

Model description. A preliminary numerical model for the dynamics of *Aedes aegypti* study is proposed, taking into account

superficial wind and vector population dynamics parameters related with land uses, such as birth, diffusion, attraction by mammals and deaths. Differential equations of transport, diffusion and conservation used in fluid mechanics in its continues approaches, are adapted for the study of mosquitoes population dynamics. Equation (1) represents a basic model, based on Tran (2004) thesis. The first term represents the diffusivity, the second is the wind transport and the third the attraction by mammals. The last corresponds to the source and sink terms. This equation is solved by a finite difference scheme.

$$\frac{\partial \rho(P, t)}{\partial t} = \nabla \cdot (D_R \nabla \rho) - \nabla \cdot (\rho D_W V) - \nabla \cdot (\rho K_H \nabla H) + \alpha - \beta \quad (1)$$

Where:

$\rho$ =mosquitoes density  
 $D_R$  = Difusivity tensor  
 $D_W$  = Roughness tensor  
 $V$ =surface wind velocity  
 $K_H$ =attraction tensor  
 $H$ =attraction Field  
 $\alpha$ =birth rate  
 $\beta$ =death rate

All the tensor are consider here as scalars in this preliminary work. The  $D_R$  and  $D_W$  tensors are depended on the landscape and we consider the classes of landuse and the corresponding values similar to Tran (2004)

The model diffusion equations work on a non-homogeneous scenario and with non-uniform diffusion tensors. 5 different landscape rugosity classes (Ogunjemiyo et al, 2005) were generated based on Landsat 5TM image took on January 25<sup>th</sup> 2004 (Path 230 – Row 76) and from its Normalized Difference Vegetation Index (NDVI) (Jensen, 1986), and the Tasseled cap vegetation index factors (Crist and Kauth, 1986; Crist and Cicone (1984). NDVI index transforms multispectral data (Near Red – Near Infra Red) into a single image band that represent vegetation distribution, indicating the amount of green vegetation present in the pixel. Tasseled cap layers: Brightness, Greenness, and Third are obtained by specific linear combination of the original landsat 5TM bands, representing the “soil brightness index” (like a panchromatic image), the “green vegetation index” and the “third component” related to soil features, including moisture status (water or soil with high humidity). Moreover a “Texture Filter” of Co-occurrence measures was applied to NDVI band. **Water** class (Rivers and superficial water sources) was obtained by supervised Maximum likelihood classification of three tasselled cap bands and Landsat 5TM’s band 1-2-3-4-5-7. **Exposed Soil** band was derived from NDVI values lower than 0.25. Three vegetation classes “**low vegetation, commercial/open forests, and jungle**” were created by Regions of Interests derived from three different band thresholds of NDVI’s Texture Filter. Vegetation vertical development and land coverage of green areas classifications were supervised by the use of high resolution images. All image’s processing procedures including the matching of all classes to create a unique “Texture Classes Image” (Band Math tool) were performed with ENVI software. Rural attrator areas and Urban attrators are represented by farms and houses location. Breeding Sources for Culicidae mosquitoes’s are represented by lagoons

created after river flood for rural areas, and for *Aedes aegypti* mosquitoes, in several breeding focus as cemeteries, and tyre deposits near the city.

## Results and discussion

Mosquitoes density 48 hours evolution is shown in figures 1 and 2, such as the speed, sense and intensity of wind. Results show the correction of wind diffusion effect by rugosity of landscape. Mosquito’s diffusion plums, under the same low intensity wind direction and intensity, have a regular circle shape in Jungle, but a slender shape in wind direction for rugosity classes with less friction, such low vegetation or exposed soil. Moreover, there are no mosquito’s diffusion, neither transport by wind when the effective wind velocity is higher than their own speed and the attraction depends not only on the attraction range of humans if not on the effective size of attractors.

The simulation into the city or Yrigoyen, with 5 sources or different breeding sites, shows that mosquitoes remain only in areas with high density of attractors. In rural landscape diffusion, the spatial attraction range of houses is not enough to maintain mosquito’s high density when landscape roughness allows high effective wind’s velocity.

In both figures (1 and 2) the density distribution of mosquitoes is shown each 12 hours with the following evolution.

### Yrigoyen city and surrounding areas:

Hour 1: Show source of mosquitoes. Hour 12: Mosquitoes’s diffusion under wind and attraction effect. Hour 24: Plums changes due to changes in wind direction and new attractor’s effect related to landscape rugosity. It is easy to note how a part of mosquito’s plum penetrates into the city following attractor lines. Hour 36: Mosquitoes plums pass through attractors areas, in response to new wind variations. There are decelerations of mosquito’s plums due to different rugosity of landscape. Wind direction change, changes the direction of 24 hours mosquitoes’s plum, and introduce a plum into the urban area. At the same time, as a result of deaths, a cloud of mosquitoes remains in the jungle, with lower density and smaller range in comparison to first hours of diffusion. Hour 48. Mosquito’s high density clusters remain in big attractors and rugosity classes limits. In spite of strong wind effect into the city, some smaller cluster remains in stronger attraction areas.

**Rural Landscape:** Hour 12: Mosquitoes’s diffusion begins on the top region, with lower diffusion rate into the jungle.

Hour 24: Upper cluster change direction following the wind direction and the low vegetation line, reaching an attractor. Hour 36: In response to intense wind extended plums are generated in low rugosity classes, with decelerations of mosquito’s plums due to high rugosity in the jungle. The lower cluster shows the compensation of wind brush effect by attraction. Hour 48. The east horizontal wind brush mosquito’s plums to the limits of rugosity classes. In the southern clusters, a cluster remains between the forest and jungle limit and other high density clusters remain by attractors.

## Conclusions

Remote sensing information allows us to recreate different scenarios to simulate insect dynamics. Diffusion equations used in this model give us the possibility to identify the effects of parameters of insect population, climate, and landscape texture, on the space-time movements of potential diseases flying vectors.

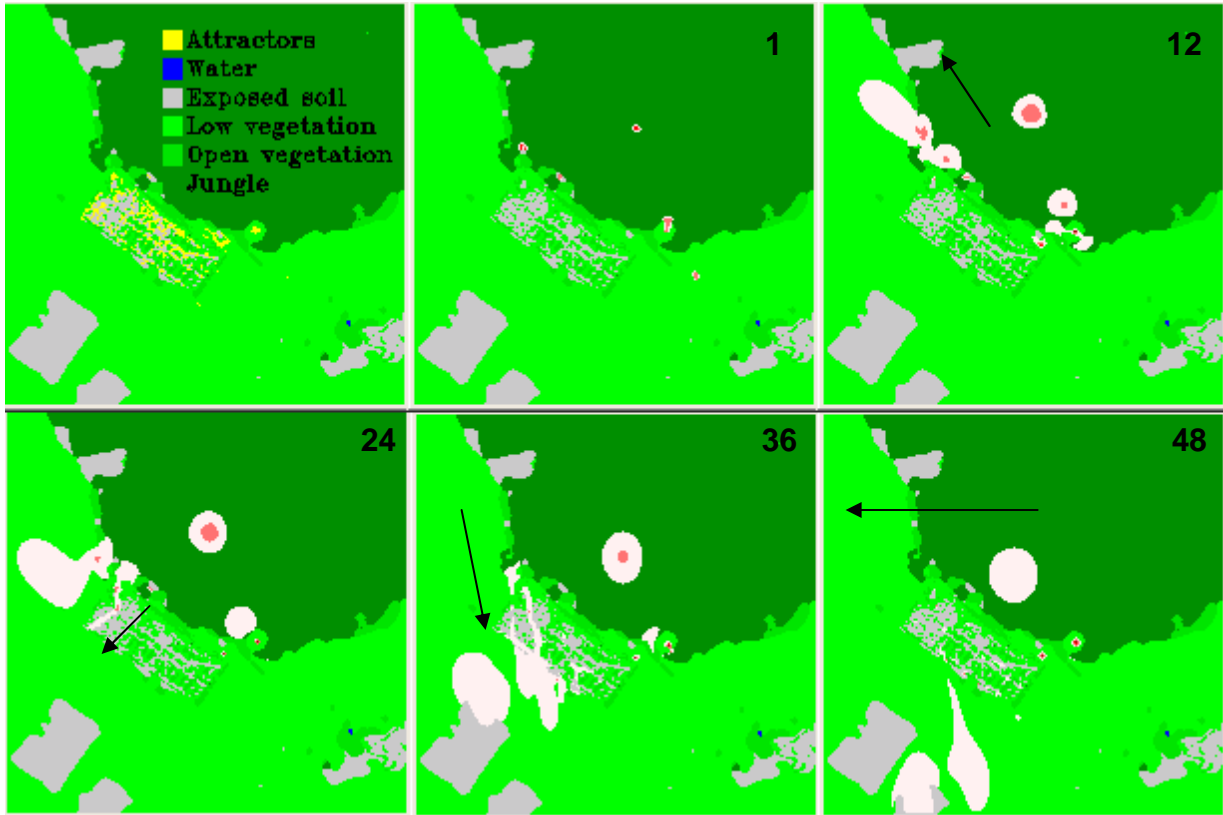
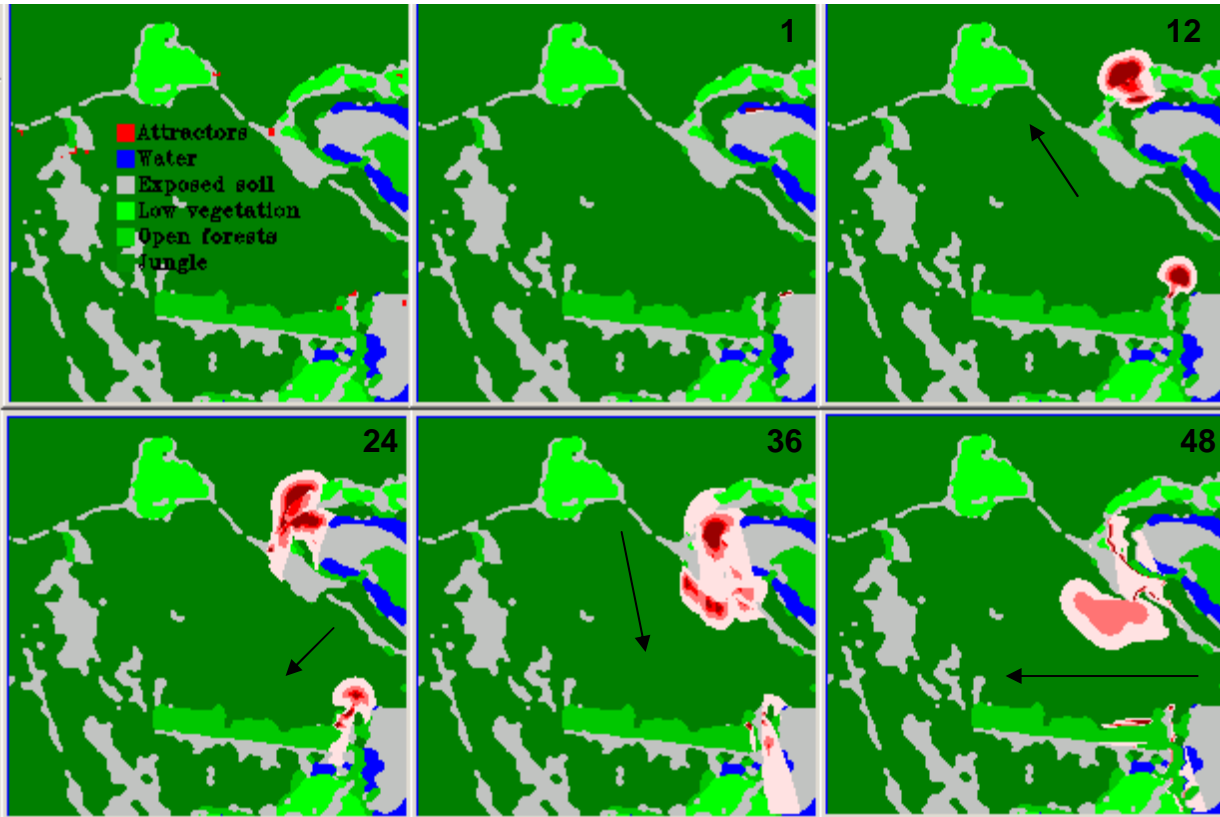


Fig. 1. Yrigoyen city and surrounding areas. Fig. 2. Rural Landscape. Both figures show mosquitoes diffusion from hour 1 to 48, attractions and landscape texture classes. The arrow symbolizes the wind speed, sense and intensity.



Parameters for these simulations are characteristics of Culicidae mosquito's family, focus on *Aedes aegypti* specie at a space-time scale at which the insect density can be considered as a non-discrete distribution. Taking into account the lack of good quality meteorological time series data for this region and that mosquitoes movement parameters were extracted from other country's studies, many parameters had been estimated and, as a consequence, results are shown in a qualitative way. The functional attraction of Raffy and Tran (2005) diffusion model, has been improved, and now it behaves as linear inside a cluster of attractors and decay outside them with a scale length of 30m (Bidlingmayer, 1980). In addition, for the wind transport we include a filter that limits it to the cases where the effective wind velocity of the class is smaller than the fly mosquitoes velocity (Van Dyk, 2003). Taking in account that we only consider attraction by human (homes), and not by other kind of mammals, the model, responds correctly to the attraction range of farms or city houses. Finally, we consider that an improve in the realism of this model could be performed after the incorporation of entomologic field data from studies that are being performed in Salta province.

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