A non-homogeneous Markov spatial temporal model for dengue occurrence

M. Antunes, M.A. Amaral Turkman, K. F. Turkman (1) and C. Catita(2), M.A. Horta(3)

(1) CEAUL/DEIO/FCUL
(2) IDL/UL and (3) Fiocruz,RJ,Brazil

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Outline of the talk
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- Motivation.
  - Methodological issues.
  - Data Analysis.
  - Discussion and further work.
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Motivation: a spatial-temporal model for dengue fever
Dengue fever

- Infectious disease caused by four types of Dengue virus carried by *Aedes* mosquitoes.
- A person can be infected by at least two if not all four types at different times during a lifetime, but only once by the same type.
- Infection occurs from the bite of an infected *Aedes* mosquito. Mosquitoes become infected when they bite infected humans;
- the virus incubate for 8 to 10 days inside the mosquito and later transmit infection to other people they bite.
- Symptoms usually start within 4 to 7 days after a person is bitten by an infected mosquito.
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Dengue fever

- Dengue fever is found mostly during and shortly after the rainy season in tropical and subtropical areas predominantly in urban and semi-urban areas.
- *Aedes* mosquitoes are particularly successful at spreading Dengue because they feed almost exclusively on humans, are active during the day, and love urban areas, where they breed in any container holding water, like planters or waste tires.
- Worldwide, 50 to 100 million cases of dengue infection occur each year.
- Dengue is expanding: in 2009, dengue appeared for the first time in Cape Verde, Africa, and for the first time in 40 years in Florida, USA.
- In 2012 Dengue appeared in Madeira island in 26/09/2012. In 11/11/2012, 1357 cases had been reported.
- Since 06/02/2013 no more cases were confirmed. By then, 2170 cases had been reported and confirmed.
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Dengue and weather/urban/geographic conditions

- Dengue disease is sensitive to weather. The biological characteristic of *Aedes* mosquito is directly influenced by the temperature and the amount of rainfall.
- Warmer temperatures increase the chances that the vector and the virus will thrive.
- In raining season, the heavy rain flushes away the egg, larvae, and pupae of *Aedes* mosquitoes in the short term but it create huge breeding habitat for mosquito in the long run.
- *Aedes* breed in any container holding water, like planters or waste tires; in fact in any container easily found in a backyard.
- Links between dengue and weather suggest the feasibility of predicting dengue occurrence using weather or climate data.
- Also, urban areas characteristics and house/people density seem to be associated to the spread of the disease.
- How should this be done?

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Dengue cases and climate conditions

Number of dengue cases

Precipitation

Temperature
Dengue cases and local characteristics

Coronel Frabriciano’s building density
Dengue cases and local characteristics

Coronel Frabriciano’s case reports, 2002-2009
Non-homogeneous Markov spatial temporal model
Non-homogeneous Markov spatial temporal model

Let \( \{ Y(i, t) \} \) be a non-homogeneous Markov chain with two states, 0 and 1, such that
- \( Y(i, t) = 1 \) if in location \( i \) at time \( t \) there is at least one dengue case
- \( Y(i, t) = 0 \) otherwise

and transition probabilities
- \( p_{01}(i, t) = \frac{\exp(a_{01}(i, t))}{1 + \exp(a_{01}(i, t))} \)
- \( p_{11}(i, t) = \frac{\exp(a_{11}(i, t))}{1 + \exp(a_{11}(i, t))} \)

where

\[
a_{01}(i, t) = \alpha_0(i, t) + \sum_{k=1}^{K} \alpha_k x_k(t) + W(i)
\]

and

\[
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Non-homogeneous Markov spatial temporal model

$W(i)$ is a spatial structured random effect – Intrinsic Conditional Autoregressive (ICAR) model

$$W(i) | W(-i) \sim \mathcal{N}\left( \sum_{j \in \mathcal{N}(i)} W(j)/m_i, m_i/\tau \right),$$

where

- $\mathcal{N}(i)$ is the neighborhood of location $i$
- $m(i)$ is the number of locations in $\mathcal{N}(i)$
- $\tau$ is the precision
Non-homogeneous Markov spatial temporal model

The model is fitted using WinBUGS

Prior distributions:

- \( \alpha_0 \) and \( \beta_0 \sim dflat \)
- \( \alpha_i \) and \( \beta_i \sim N(0, 0.001) \), \( i = 1, \ldots, K \)
- \( \tau_1 \) and \( \tau_0 \sim Gamma(1, 0.001) \)
Data analysis
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The data – Coronel Fabriciano Minas Gerais (CF data)

- **CF data**: spatial weekly dengue cases but temperature and precipitation common to all 121 spatial units.

- **Total population**: 103,673

- **Epidemics**: more than 300 cases per year per 100,000 inhabitants ⇒ more than 311 cases per year in CF ⇒ 6 or more cases per week in all CF

- From 2002 to 2009, only two weeks registered less than 6 cases of dengue

- **CF is divided in 121 sectors** ⇒ few people in each sector ⇒ even only 1 case of dengue is a matter for concern
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Coronel Frabriciano’s population distribution
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Coronel Frabriciano’s Total Number of Cases
A preliminary data analysis (cross correlations) suggested a lag $\ell = 11$ weeks for CF data.

- Box-Cox transformation applied to maximum temperature and total amount of precipitation
  - $\lambda = 0$ (logarithm) for temperature and $\lambda = 0.25$ for precipitation.
Preliminary analysis - Dengue cases and weather conditions

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Data analysis

The model – variables included

- \( \log(\text{temperature}) \) with lags 10 and 11

- \( (\text{precipitation})^{0.25} \)

- Interaction terms \((\text{temperature} \times \text{precipitation})\) for the 3 possible lag combinations (10-10, 10-11 and 11-10)

- Percentage of houses with company water per sector

- \((\text{number of houses}/\text{number of people})\) per sector
Data, estimated probabilities and prediction

Data:

- Weekly data from 2004 to 2009 (300 weeks)
- 2002 and 2003 data excluded due to excess of missings

Output:

- \( p(i, t) \): estimated probability of occurrence of at least one dengue case for each sector \( i, i = 1, \ldots, 121 \), and each week \( t, t = 1, \ldots, 300 \).
Prediction:

- For each sector $i$, $i = 1, \ldots, 121$,
  - consider values $u_{ij}$, in a fine grid from 0 to 1;
  - for each week $t$, $t = 1, \ldots, 300$, $\text{pred}(i, t) = 1$ if $p(i, t) \geq u_{i,j}$ and $\text{pred}(i, t) = 0$ otherwise;
- compute sensitivity($u_{ij}$) + specificity($u_{ij}$)
- find the value $u_i$ such that sensitivity($u_{ij}$) + specificity($u_{ij}$) is maximum
Data analysis

Data, estimated probabilities and prediction

Sector 44

Probability of occurrence of dengue cases

Apr 04  Jul 04  Oct 04  Jan 05  Apr 05  Jul 05  Oct 05  Jan 06  Apr 06  Jul 06  Oct 06  Jan 07  Apr 07  Jul 07  Oct 07  Jan 08  Apr 08  Jul 08  Oct 08  Jan 09  Apr 09  Jul 09  Oct 09  Jan 10
Data analysis

Data, estimated probabilities and prediction

estimated probabilities

occurrence
Data, estimated probabilities and prediction
Data analysis

Data, estimated probabilities and prediction

25 Jan 09   01 Feb 09   08 Feb 09

Ocorr   Cases
Predicted   Probability

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Data analysis

Data, estimated probabilities and prediction

08 Feb 09
Discussion and further work

- This is a work under progress;
  - Spatial division in Coronel Fabriciano is very fine. Local characteristics are very general (from census).
  - Temperature and precipitation are not spatially available.
  - Include in the model (finer) socio-economic and other environment characteristics which are relevant to explain dengue epidemics.
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