A non-homogeneous Markov spatial temporal model for dengue occurrence

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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

Motivation

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 \( \{(x_i, t)\} \) be a non-homogeneous Markov chain with two states, 0 and 1, such that

- \((x_i, t) = 1\) if in location at week there is at least one dengue case
- \((x_i, t) = 0\) otherwise

and transition probabilities

- \(01(x_i, t) = \frac{(01(x_i, t))}{1 + (01(x_i, t))}\)
- \(11(x_i, t) = \frac{(11(x_i, t))}{1 + (11(x_i, t))}\)

where

\[
01(x_i, t) = \alpha_0 + \sum_{i=1} \alpha_i (x_i) + \sum_{i=+1} \alpha_i (x_i) + (x_i)
\]

and

\[
11(x_i, t) = \beta_0 + \sum_{i=1} \beta_i (x_i) + \sum_{i=+1} \beta_i (x_i) + (x_i),
\]
Non-homogeneous Markov spatial temporal model

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

\[
(\cdot)|(-\cdot) \sim \left( \sum_{\in \mathcal{N}(\cdot)} (\cdot)/, /\tau \right),
\]

where
- \(\mathcal{N}(\cdot)\) is the set of indexes of the neighborhood of location
- ( ) is the number of locations in \(\mathcal{N}(\cdot)\)
- \(\tau\) is the precision
Non-homogeneous Markov spatial temporal model

The model is fitted using WinBUGS and GeoBUGS

Prior distributions:

- $\alpha_0$ and $\beta_0 \sim$
- $\alpha$ and $\beta \sim (0, 1/0.001), \tau_i = 1, \ldots,$
- $\tau_1$ and $\tau_0 \sim (1, 0.001)$
Data analysis
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 $\Rightarrow$ more than 311 cases per year in CF $\Rightarrow$ 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 $\Rightarrow$ few people in each sector $\Rightarrow$ 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 $\ell$ from 10 to 12 weeks for CF data.

Transformations applied to maximum temperature and total amount of precipitation were

- $\lambda = 0$ (logarithm) for max temperature and 0.25 power for precipitation.

Transformations were made so that the transformed variables would have an approximate linear effect in the linear predictor.
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The model – variables included

- $\log(\cdot)$ with lags 10 and 11
- $(\cdot)^{0.25}$ with lags 10 and 11
- Interaction terms $(\log(\cdot) \times 0.25)$ for the 4 possible lag combinations (10-10, 10-11, 11-10 and 11-11)
- Percentage of houses with company water per sector
- $(\text{number of houses/number of people})$ per sector

All variables were centered.
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:

- \((i, \omega)\): estimated conditional probability of occurrence of at least one dengue case for each sector, \(i = 1, \ldots, 121\), and each week \(\omega = 1, \ldots, 300\).
Data, estimated probabilities and prediction

Prediction:

- For each sector \( s = 1, \ldots, 121 \), and \( t = 1, \ldots, T \), fixed;
  - consider values \( x \), in a fixed fine grid from 0 to 1;
  - for each week \( w = 1, \ldots, 300 \), \((x, t) = 1\) if \((x, t) \geq \) and \((x, t) = 0\) otherwise;
- compute sensitivity\((x)\) + specificity\((x)\);
- find the value \( x \) such that sensitivity\((x)\) + specificity\((x)\) 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

week

sector

week

sector

50 100 150 200 250 300

20 40 60 80 100 120

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Spatial temporal model for Dengue

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Data analysis

Data, estimated probabilities and prediction

Total [2004-2009]

Correct predictions (%)  False positives (%)  False negatives (%)

[Map showing spatial distribution of correct predictions, false positives, and false negatives]
Data, estimated probabilities and prediction

25 Jan 09

01 Feb 09

08 Feb 09

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Data, estimated probabilities and prediction

08 Feb 09

[Map showing spatial temporal model for Dengue]
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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