

Estimating the Attack Ratio of Dengue Epidemics under Time-varying Force of Infection using Aggregated Notification Data

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Motivation

Building blocks

Variable Force of Infection
Vector dynamics

Modeling Dengue

Single-strain model
Variable Force of Infection

Parameter estimation

Estimating S_0
Attack Ratio

Summary

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Dengue Dynamics

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- Dengue is a Multi-Strain vector-borne disease

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- ▶ Dengue is a Multi-Strain vector-borne disease
- ▶ 4 major viral strains in circulation in Brazil

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- ▶ Dengue is a Multi-Strain vector-borne disease
- ▶ 4 major viral strains in circulation in Brazil
- ▶ Case-notification data is aggregated, i.e., does not discriminate serotype except for a handful of cases.

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- ▶ It's a Seasonal disease, but recurrence pattern is hard to predict
- ▶ Vector population dynamics plays a major role in the modulation of incidence
- ▶ Immunological structure of the population is also a key factor, but is mostly unknown.

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4 epidemics

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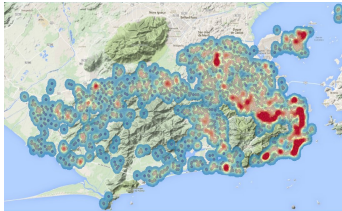
- Variable Force of Infection
- Vector dynamics

Modeling Dengue

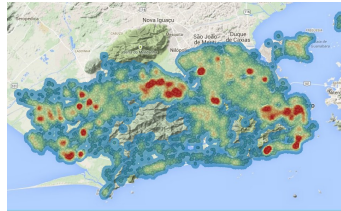
- Single-strain model
- Variable Force of Infection

Parameter estimation

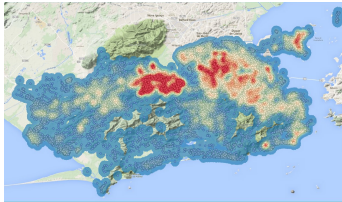
- Estimating S_0
- Attack Ratio



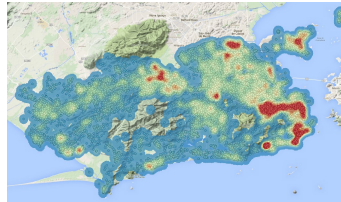
(a) 2010



(b) 2011



(c) 2012



(d) 2013

Effective Reproductive number(R_t)

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The effective reproductive number can be easily estimated from the incidence time-series, Y_t :

$$R_t = \left(\frac{Y_{t+1}}{Y_t} \right)^{1/n} \quad (1)$$

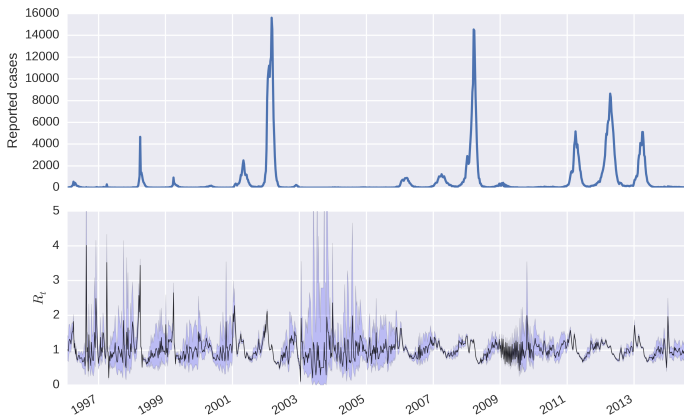
Where n is the ration between the length of reporting interval and the mean generation time of the disease.

Nishiura et. al. (2010)

R_t 's uncertainty

But what about the uncertainty about R_t ?

If we assume that the counts Y_t are Poisson distributed for all t , we can derive the probability distribution of R_t ¹



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¹Coelho, FC and Carvalho, LM (Submitted)

Environmental determinants

- ▶ A. Aegypti population dynamics display marked seasonality

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- ▶ Temperature, Humidity and rainfall are important factors

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- ▶ A. Aegypti population dynamics display marked seasonality
- ▶ Temperature, Humidity and rainfall are important factors
- ▶ Environmental stock of eggs

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- ▶ A. Aegypti population dynamics display marked seasonality
- ▶ Temperature, Humidity and rainfall are important factors
- ▶ Environmental stock of eggs
- ▶ Effects on mosquito reproduction are non-linear

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Environmental determinants

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- ▶ Temperature, Humidity and rainfall are important factors
- ▶ Environmental stock of eggs
- ▶ Effects on mosquito reproduction are non-linear
- ▶ Delayed influence

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R_t vs. Temperature

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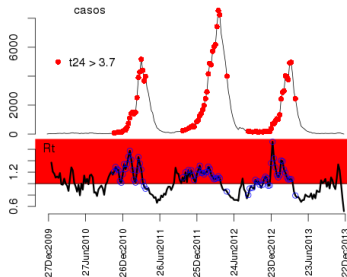
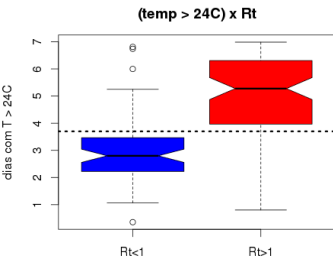
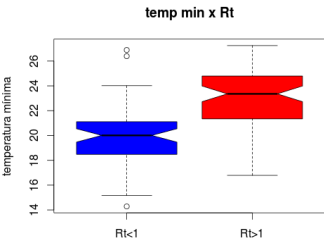
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Single Strain SIR

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Why not multi-strain? No Multi-strain data!!

$$\begin{aligned}\frac{dS}{dt} &= -\beta(t)SI \\ \frac{dI}{dt} &= \beta(t)SI - \tau I \\ \frac{dR}{dt} &= \tau I\end{aligned}\tag{2}$$

where $S(t) + I(t) + R(t) = 1 \forall t$.

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From R_t , we can define a force of infection which varies with time:

$$\beta(t) = \frac{R_t \cdot \tau}{S} \quad (3)$$

But how do we get the value of S ? we need to estimate S_0 .

Bayesian framework:

- Define priors for S_0 in the range $(0,1)$

$$p(S_{0j}|\mathbf{Y}_j) \propto L(\mathbf{Y}_j|S_{0j}, R_t, m, \tau)\pi(S_{0j}) \quad (4)$$

Bayesian framework:

- ▶ Define priors for S_0 in the range $(0,1)$
- ▶ Samples from prior, calculate $\beta(t)$ and run the model

$$p(S_{0j}|\mathbf{Y}_j) \propto L(\mathbf{Y}_j|S_{0j}, R_t, m, \tau)\pi(S_{0j}) \quad (4)$$

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Bayesian framework:

- ▶ Define priors for S_0 in the range $(0,1)$
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- ▶ calculate Likelihood of data given current parameterization

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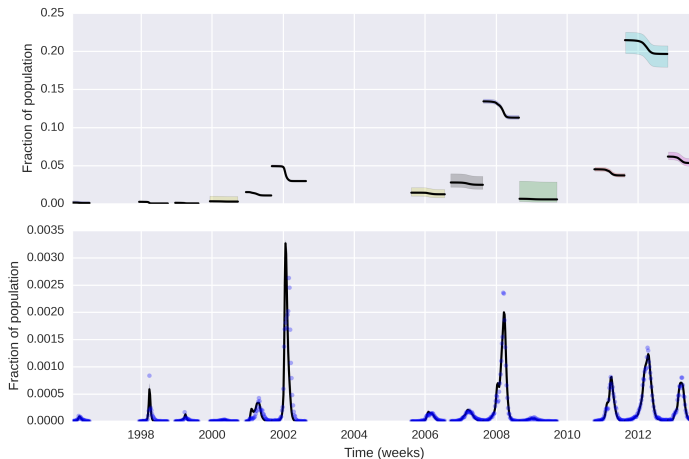
Bayesian framework:

- ▶ Define priors for S_0 in the range $(0,1)$
- ▶ Samples from prior, calculate $\beta(t)$ and run the model
- ▶ calculate Likelihood of data given current parameterization
- ▶ Determine posterior probability of parameterization

$$p(S_{0j}|\mathbf{Y}_j) \propto L(\mathbf{Y}_j|S_{0j}, R_t, m, \tau)\pi(S_{0j}) \quad (4)$$

Models vs Data

fitting the model to data (Rio de janeiro) to estimate S_0^2 .



Posterior distribution for Susceptible (S) and infectious (I) individuals. Blue dots are data.

²Coelho FC et al., 2011

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Once we have S_0 , we can calculate the attack ratio:

$$A_j = \frac{\sum Y_j}{S_{0j}} \quad (5)$$

Attack ratio

Table : Median attack ratio and 95% credibility intervals calculated according to (5). Values are presented as percentage of total population. [†]: Year corresponds to the start of the epidemic, however the peak of cases may occur in the following year. [‡]: Susceptible fraction. These results show considerable variation in AR between epidemics, consistent with the acquiring and loss of serotype-specific immunity.

Year [†]	median Attack Ratio	S_0^{\dagger}
1996	0.39 (0.17-0.54)	0.00171(0.0012-0.0038)
1997	0.87 (0.74-0.87)	0.00273(0.0027-0.0032)
1998	0.5 (0.49-0.5)	0.00142(0.0014-0.0014)
1999	0.11 (0.037-0.2)	0.00345(0.0018-0.01)
2000	0.25 (0.24-0.27)	0.0155(0.015-0.016)
2001	0.48 (0.47-0.49)	0.0495(0.048-0.051)
2005	0.15 (0.1-0.21)	0.0147(0.01-0.021)
2006	0.11 (0.08-0.14)	0.0281(0.022-0.037)
2007	0.15 (0.15-0.15)	0.135(0.13-0.14)
2008	0.14 (0.031-0.31)	0.00672(0.003-0.024)
2010	0.18 (0.17-0.19)	0.0454(0.043-0.048)
2011	0.086 (0.082-0.094)	0.215(0.2-0.23)
2012	0.14 (0.13-0.15)	0.0621(0.058-0.068)

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