Predicting dengue in Brazil:
Opportunities and challenges

Leo Bastos

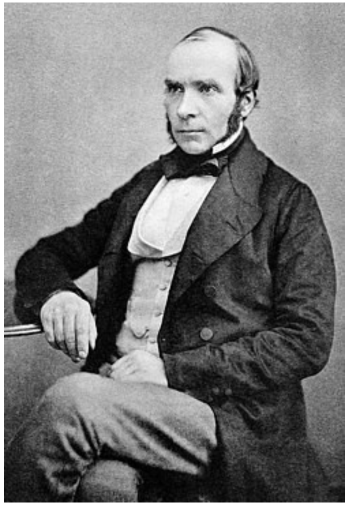
FIOCRUZ

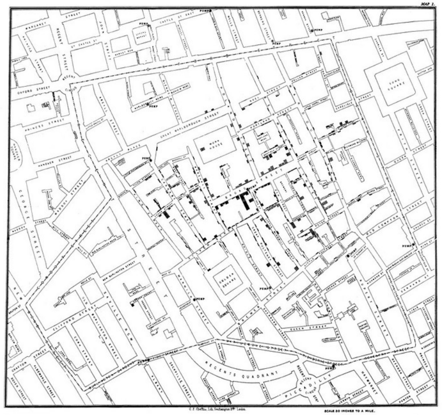
impa tech

Summary

- **Bayesian epidemiology**
- **An introduction to dengue**
- **Very short term forecast (Predicting now)**
  - Delay-correction models (nowcasting)
- **One-year ahead forecasts**
  - Baseline model to build probabilistic epidemic thresholds
  - Opportunities and challenges for dengue forecasting models

When Bayes meets John Snow





- **Thomas Bayes (1701-1761)**
- $p(\theta \mid x) \propto p(\theta)L(\theta; x)$
- **Father of Bayesianism**

- **John Snow (1813-1856)**
- **Studied cholera in London**
- **Father of epidemiology**

When Bayes meets John Snow

Generalised linear mixed models

Likelihood
$$Y_t \mid \mu_t, \phi \sim F(\mu_t, \phi), \qquad t = 1, 2, 3, \ldots, T$$

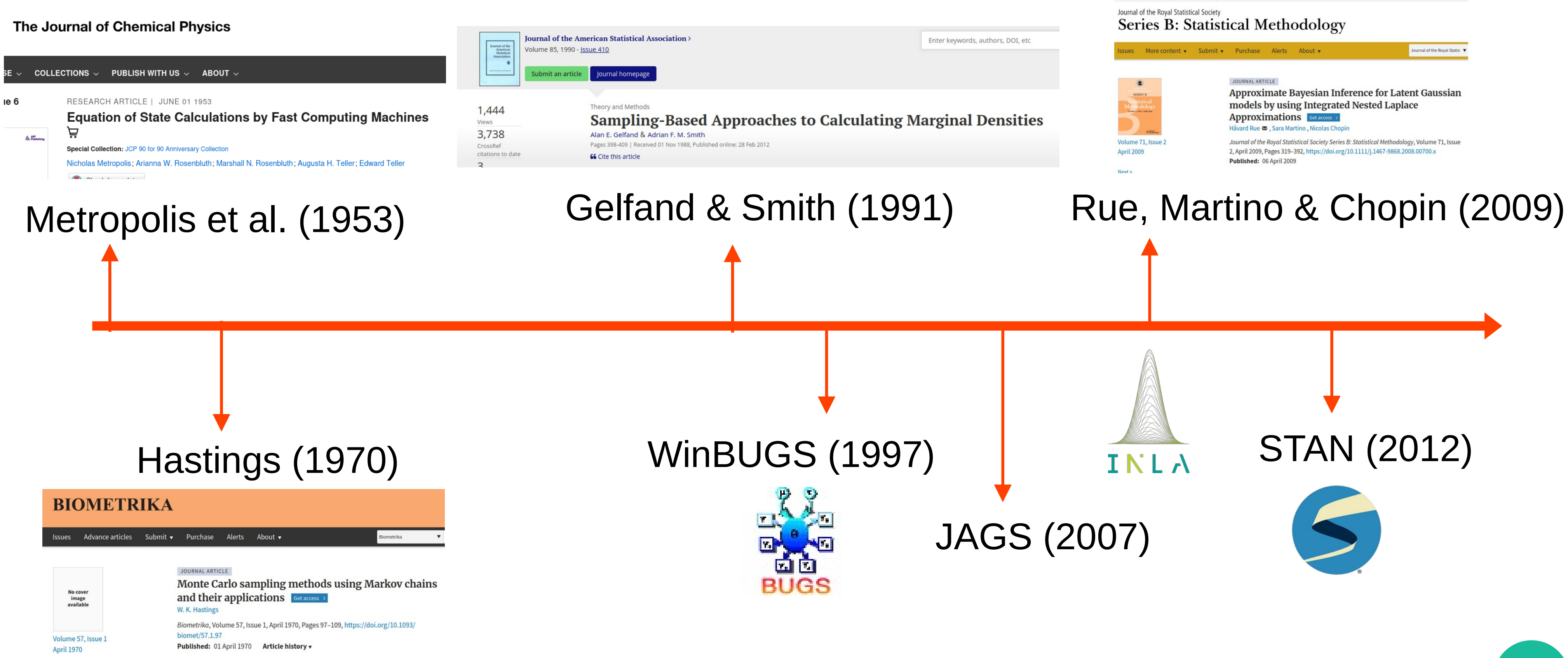
$$g(\mu_t) = \alpha + x_t^T \beta + \gamma_{R[t]}.$$

Prior
$$\alpha \sim N(0, V_\alpha) \quad \beta \sim N(0, V_\beta) \quad \{\gamma_r\} \sim N(0, Q_\gamma)$$

Posterior
$$p(\alpha, \beta, \{\gamma_r\}, \phi | y_1, y_2, \ldots, y_T)$$

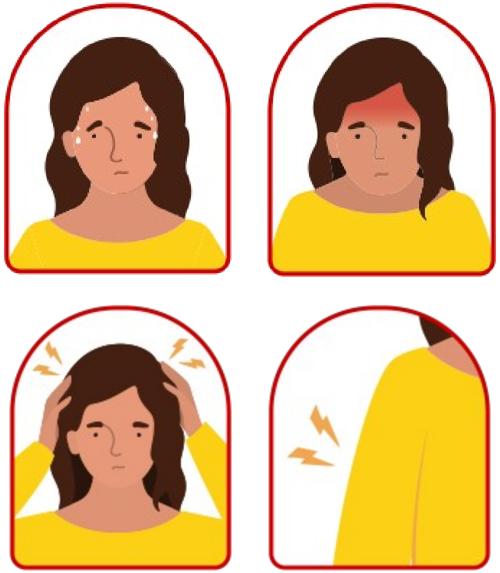
The inference/learning process with respect to the parameters is based on the posterior.

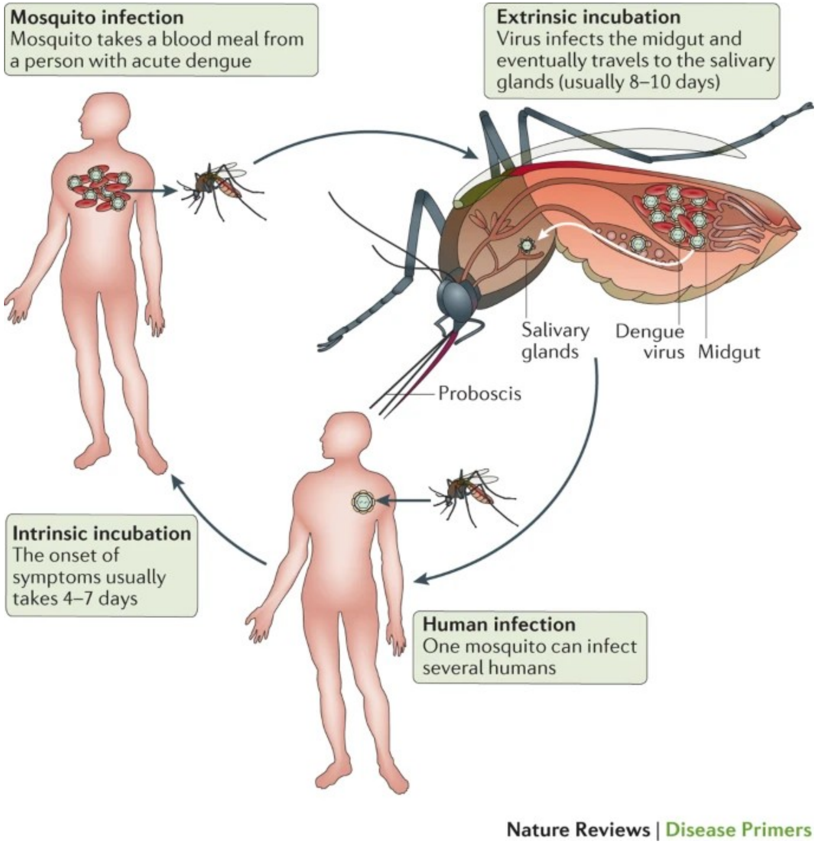
Timeline of Bayesian computation

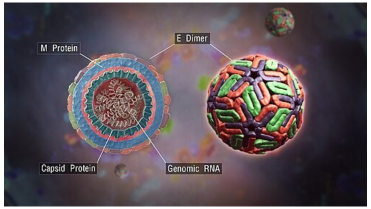


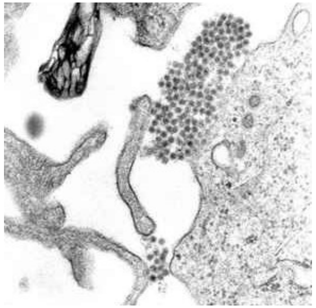
Dengue cycle

Symptoms

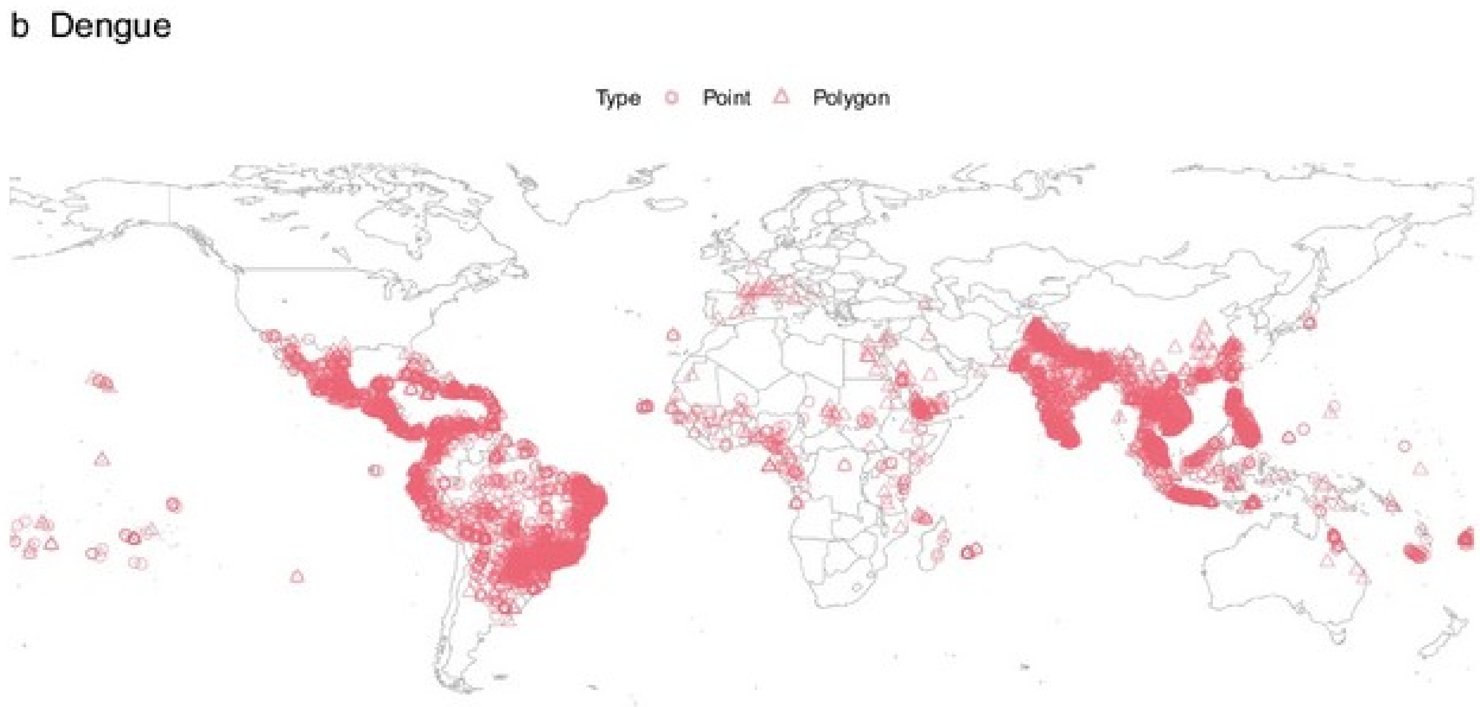






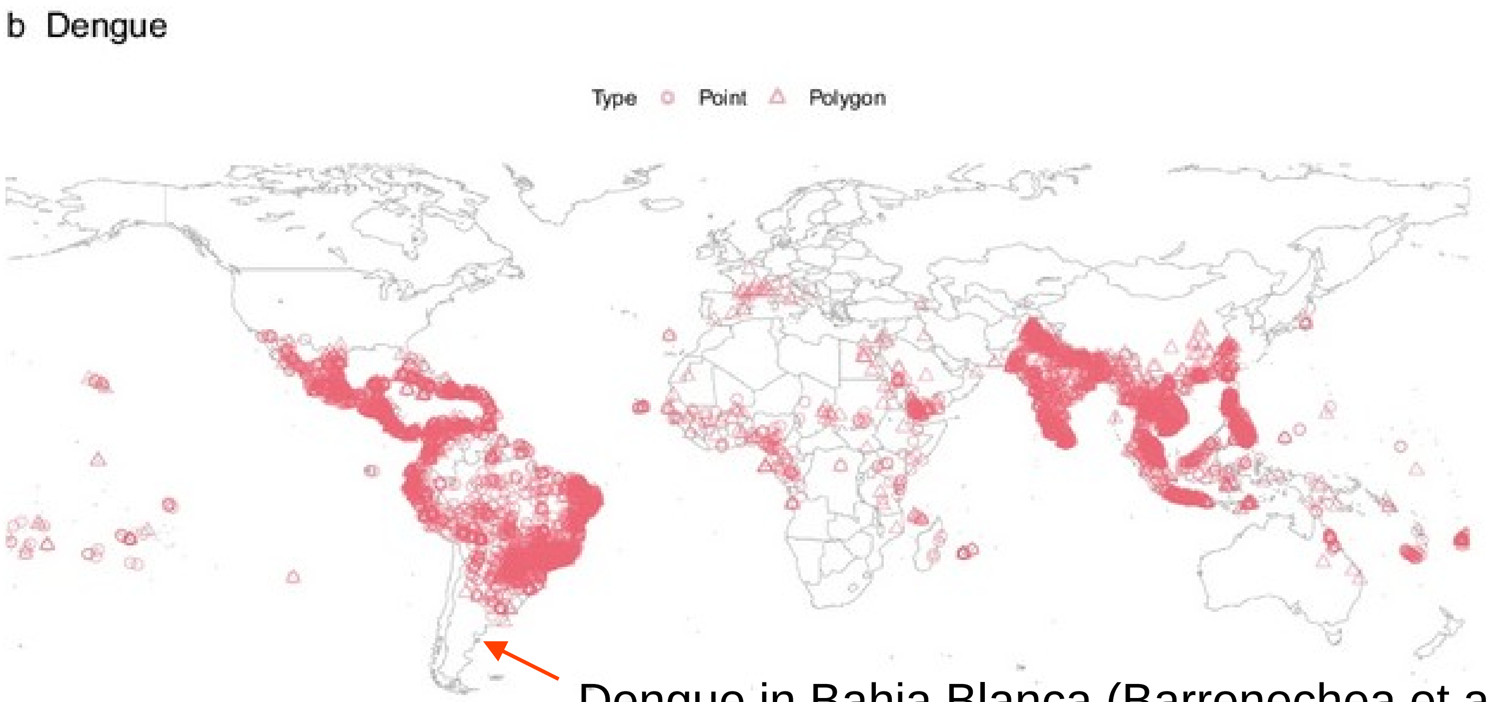


Dengue occurrence in the world



Lim et al. (2025, Nature communications)

Dengue occurrence in the world



Dengue in Bahia Blanca (Barrenechea et al. to appear)

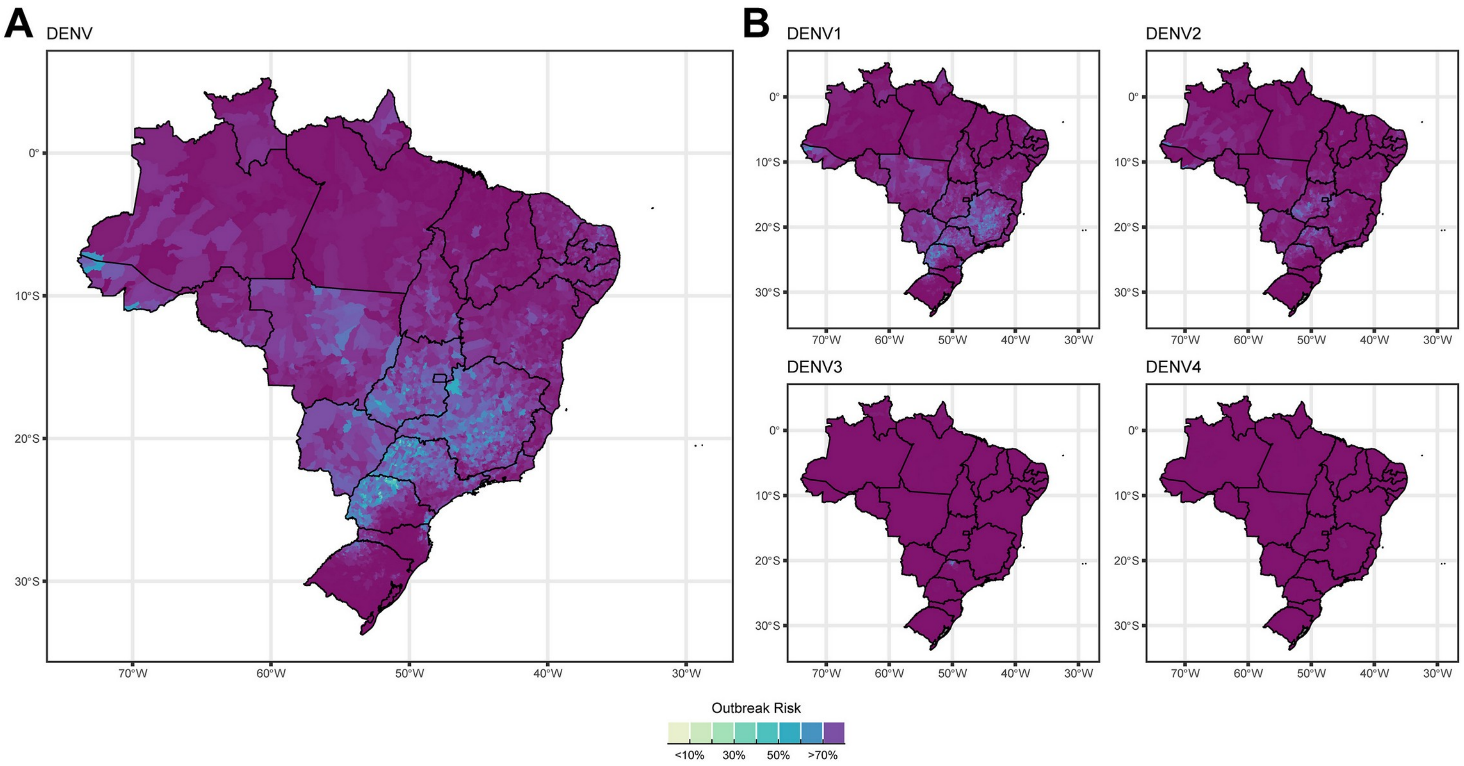
Lim et al. (2025, Nature communications)

Dengue immunity

- **There are four serotypes (DENV1-DENV4)**
  - long-term homotypic immunity
  - short-term heterotypic immunity

- **Vaccines**
  - Dengvaxia (Sanofi) {Recomended in the US, 3 doses; 9-16y*}
  - Qdenga (Takeda) {Recommended by the WHO; 2 doses; 6-59y}
  - Butantan-DV (Butantan) {Approved by ANVISA; 1 dosis; 2-59y}
- **ADE (antibody-dependent enhancement)**

Dengue outbreak risk based on possible susceptibles

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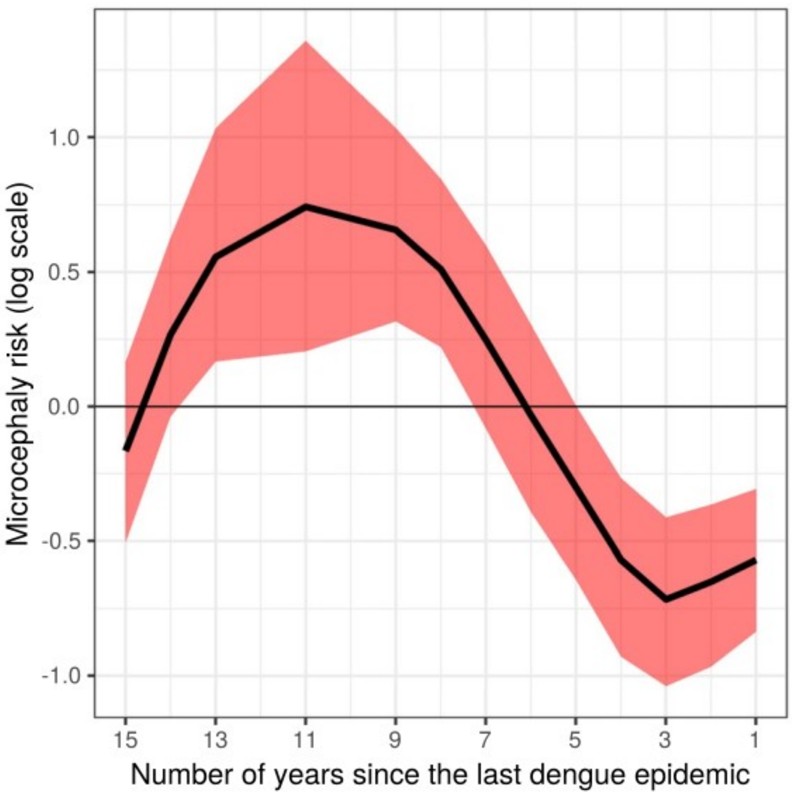
On the verge: outbreak risk after two years of record-breaking dengue epidemics in Brazil

Rafael Lopes [a] • Leonardo S. Bastos [b]

Affiliations & Notes Article Info

Lopes & Bastos (2025)

Population immunity: Dengue and CZS



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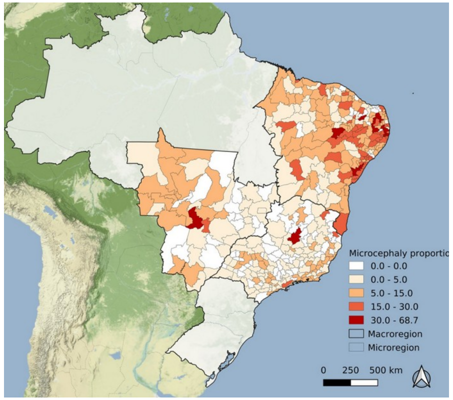
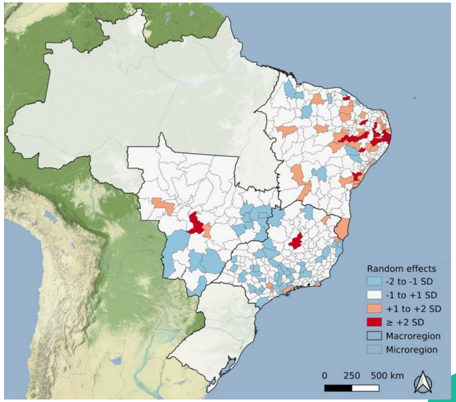
SCIENTIFIC REPORTS
natureresearch

Association of past dengue fever epidemics with the risk of Zika microcephaly at the population level in Brazil

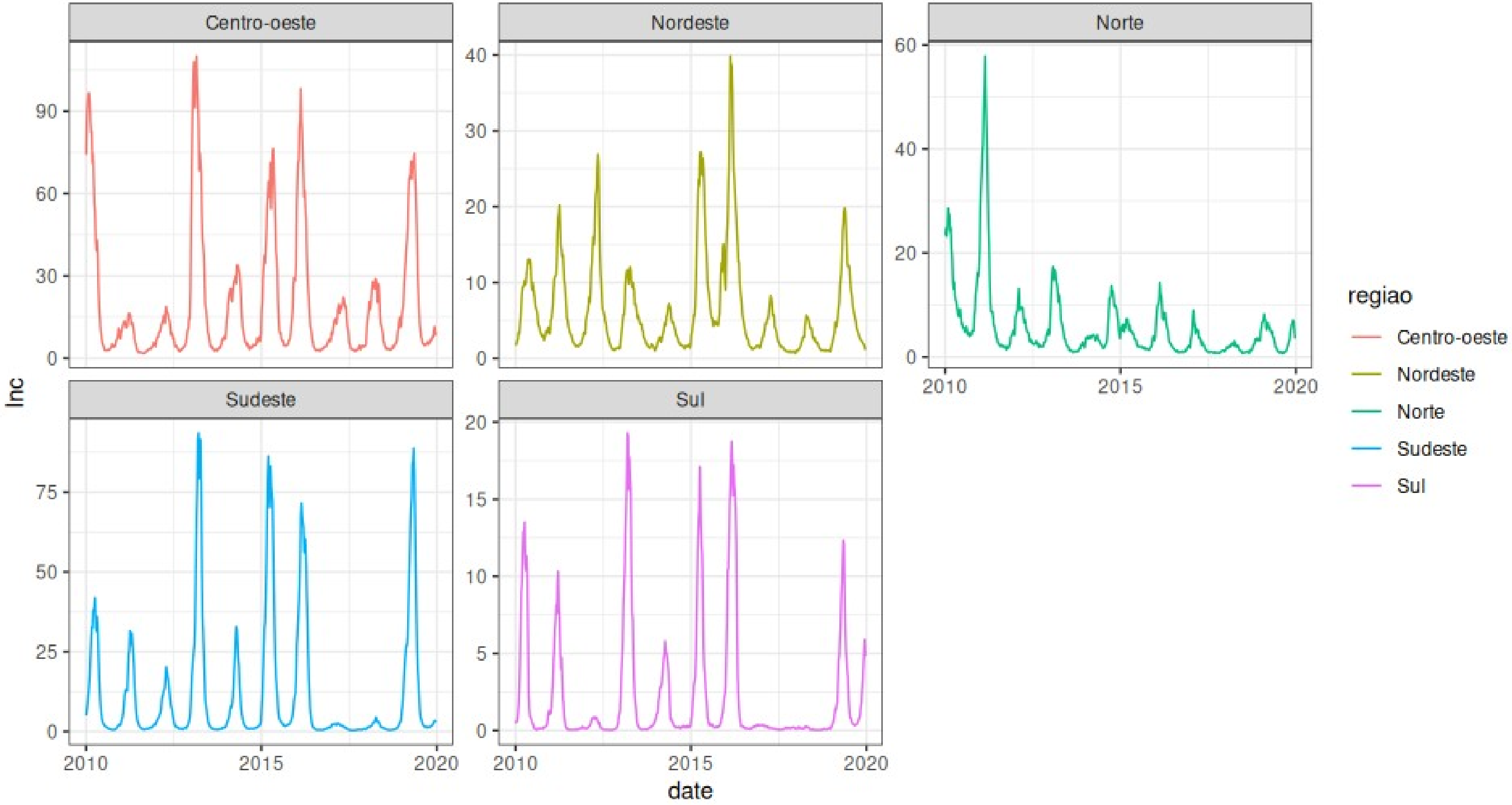
Marilia Sá Carvalho[1*], Laís Picinini Freitas[2], Oswaldo Gonçalves Cruz[1], Patrícia Brasil[3] & Leonardo Soares Bastos[1]

Carvalho et al. (2020)

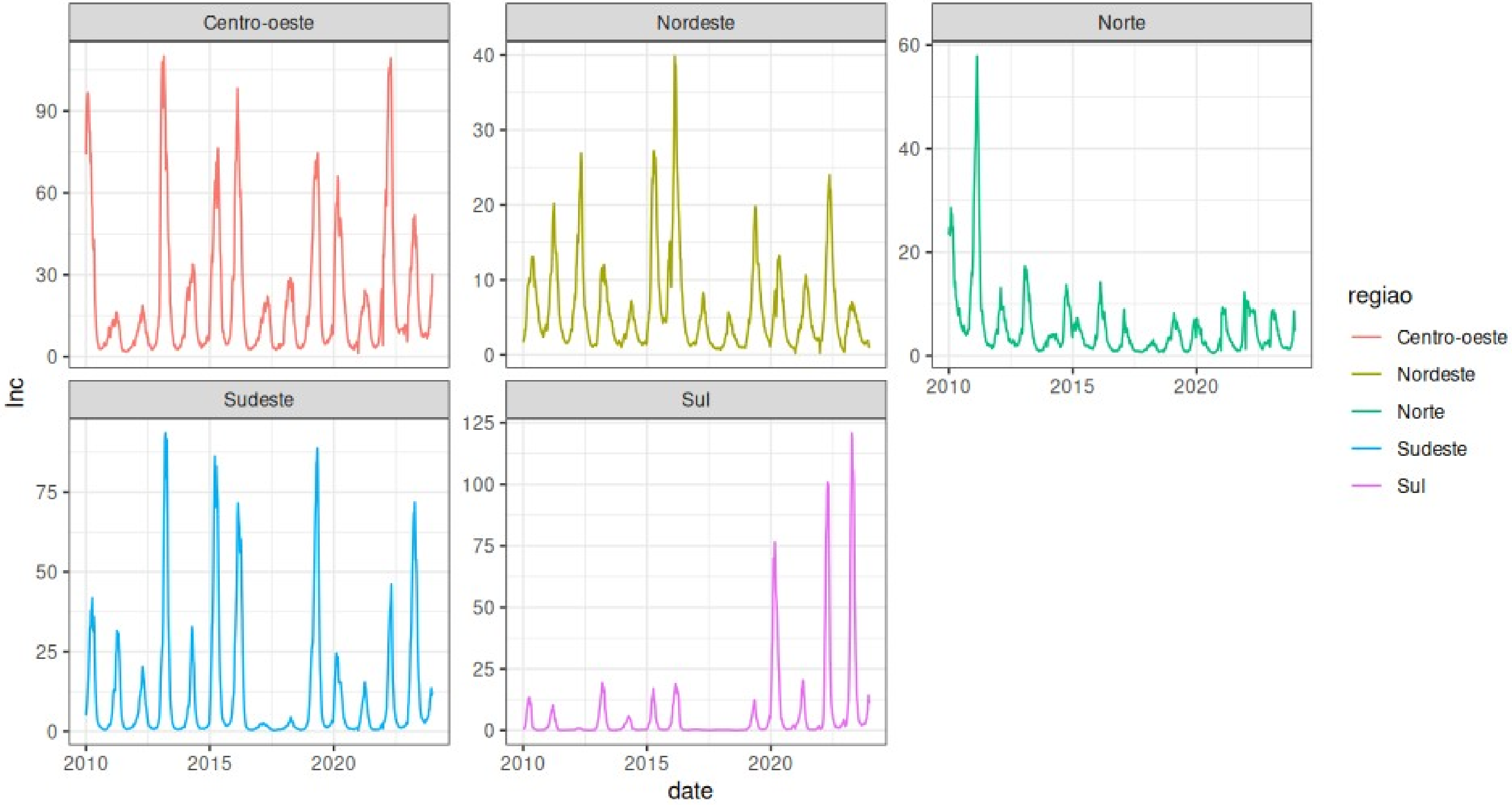




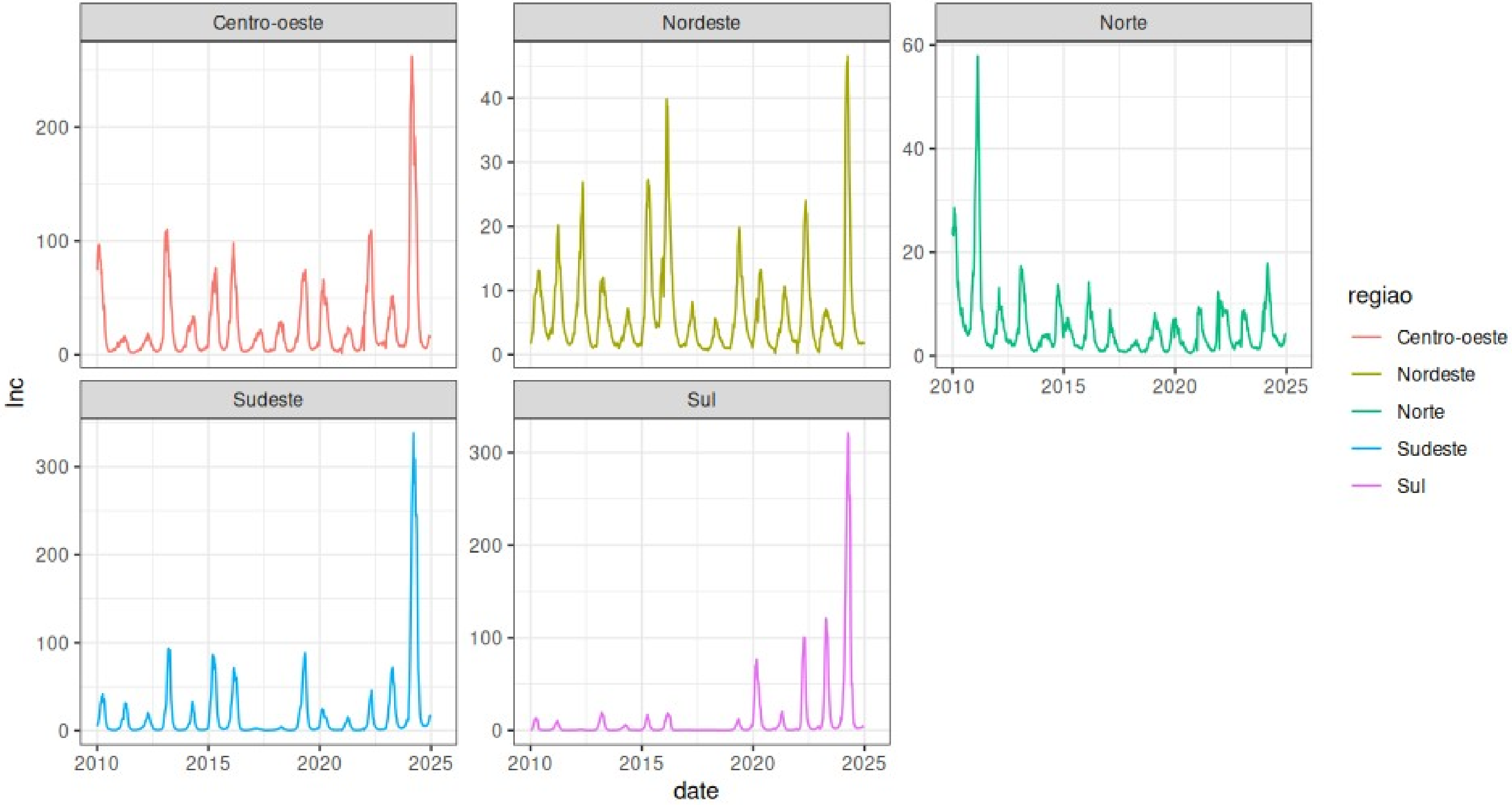
Dengue in Brazil (2010-2020)



Dengue in Brazil (2010-2023)



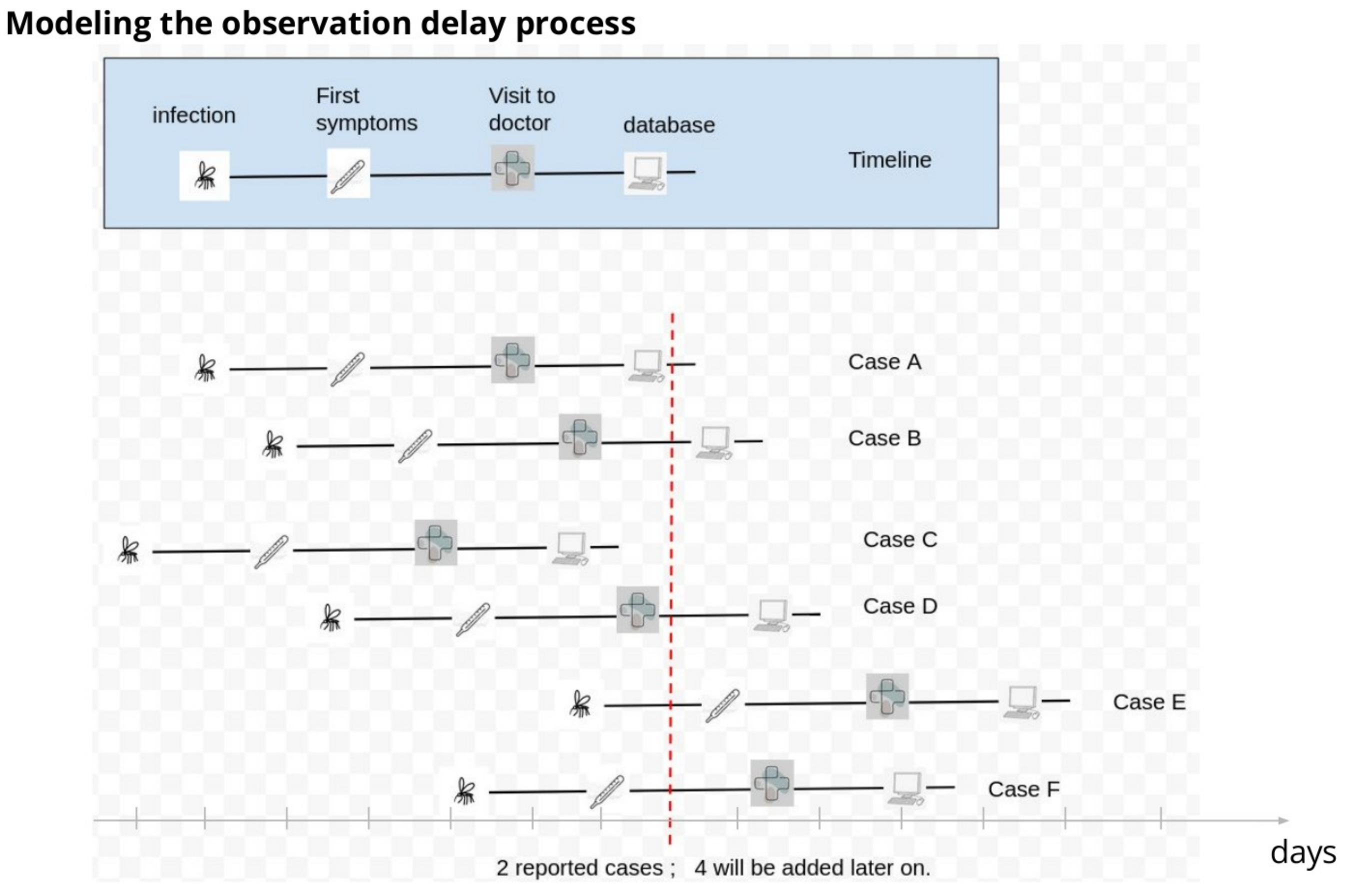
Dengue in Brazil (2010-2024)



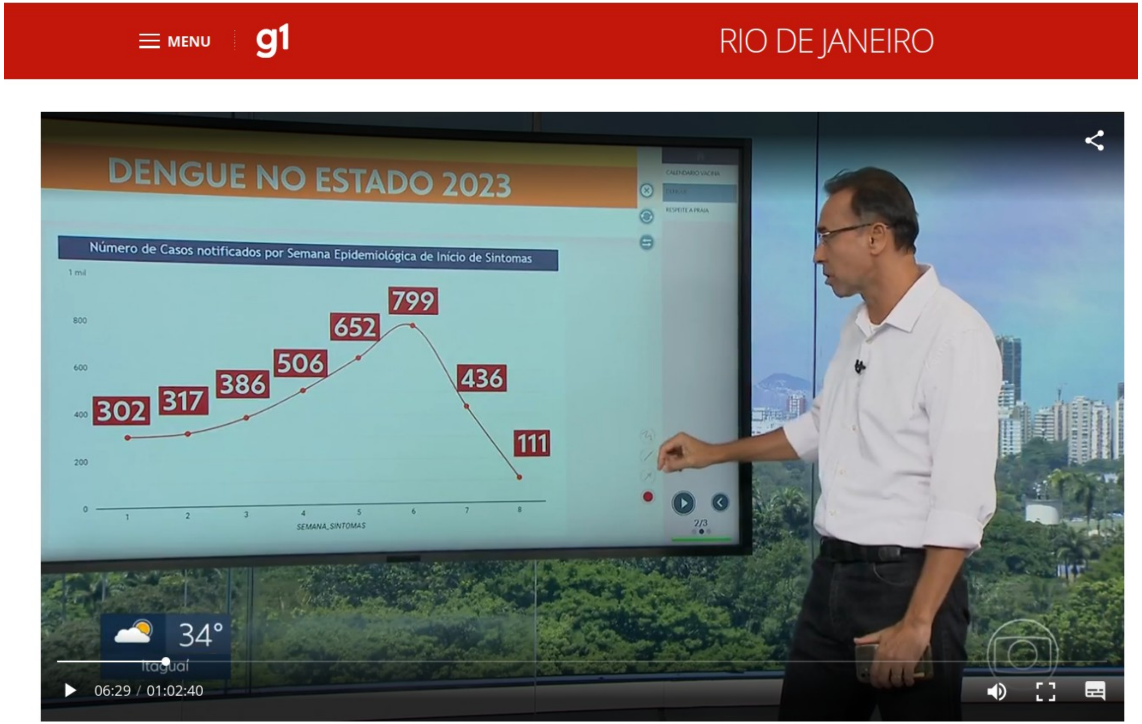
Case definitions (in Brazil)

- **Any suspected case must be reported**
  - It is possible a non dengue case being reported as dengue!
  - e.g. chikungunya, zika, oropouche,…
- **A notified case is not discarted is called probable case.**
- **If the case is tested, it is then called confirmed case.**
- **Serotype or genotyped could be know from a confirmed case**
  - A tiny proportion of the suspected cases would be sequenced.

The notification process



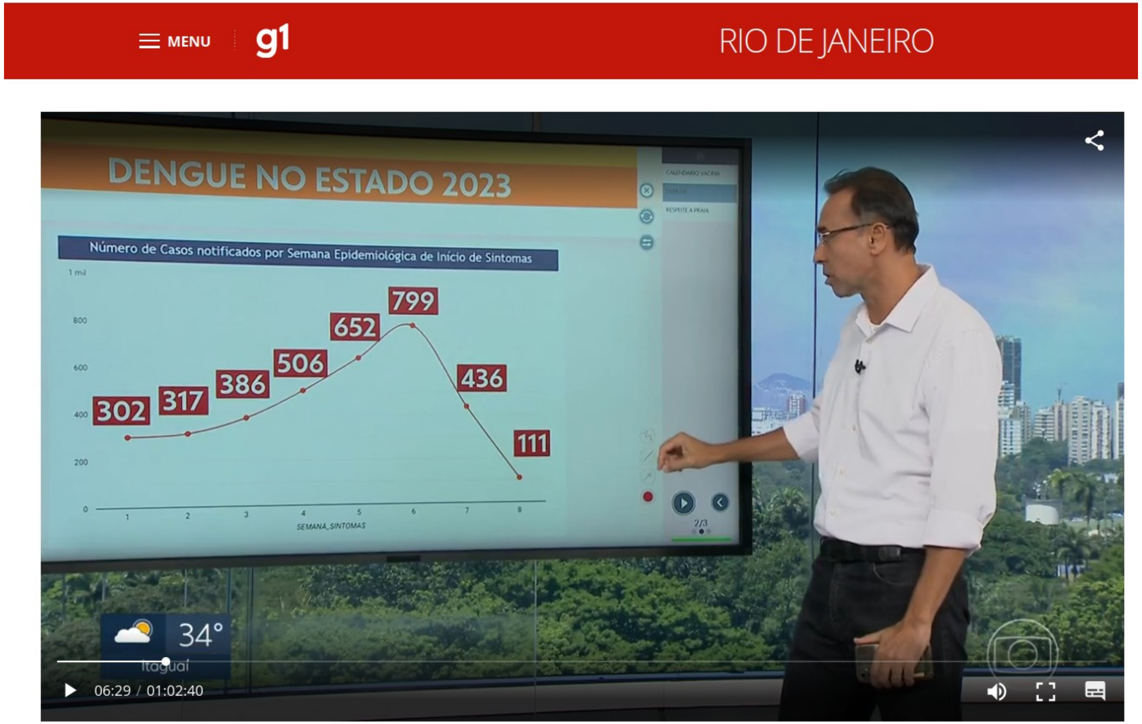
Notification delay problem

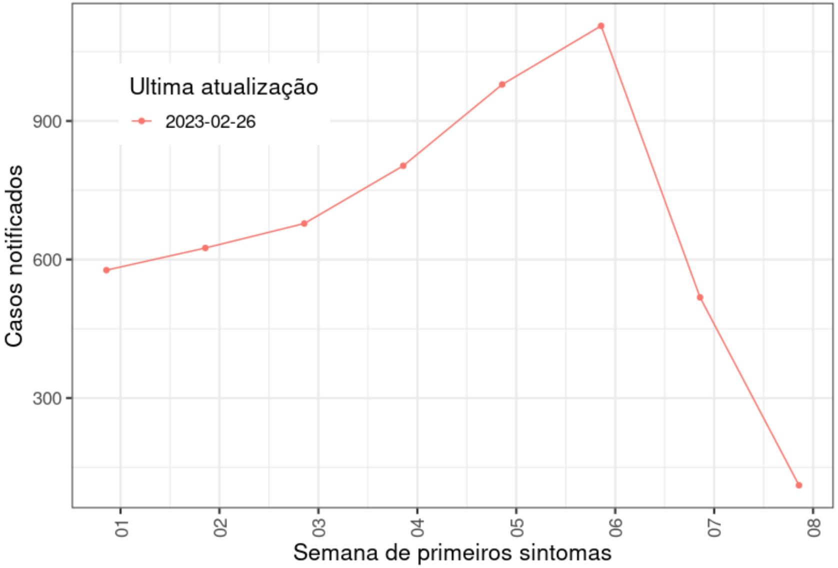


Rio, 2023-03-04

- **Dengue in Rio de Janeiro, 2023**
- End of week 9 (First week of March)
- The TV presenter emphasizes
  - that the **peak occurred** on week 6
  - the “good news” cases are **dropping**

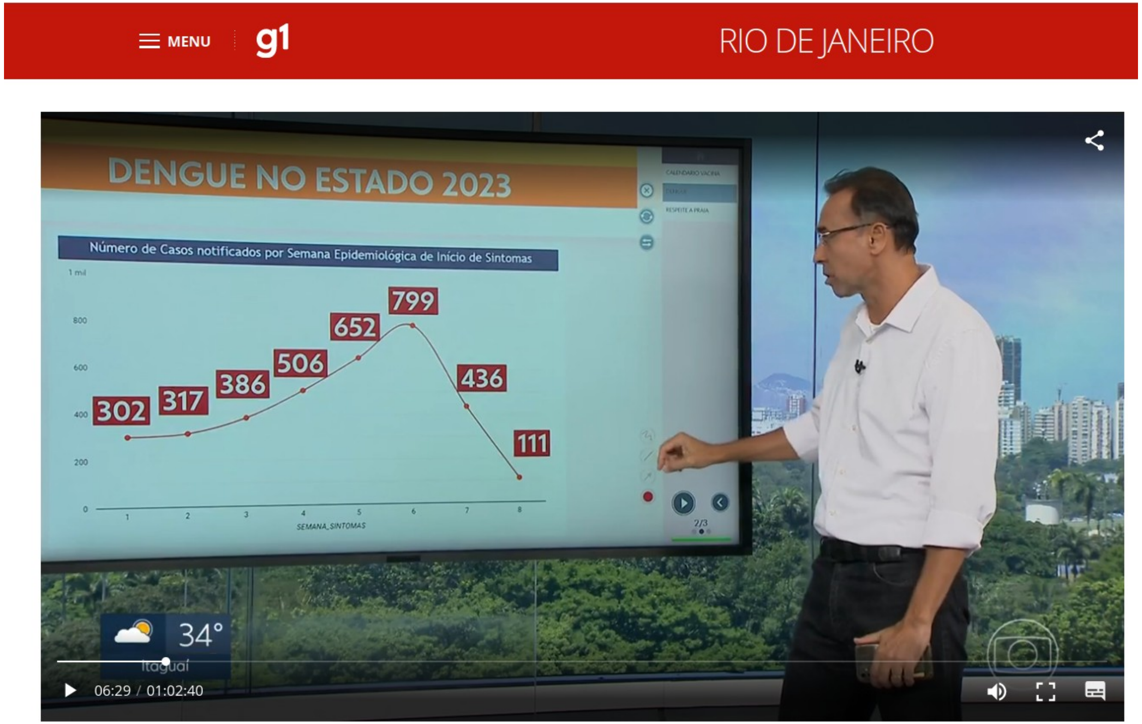
Notification delay problem



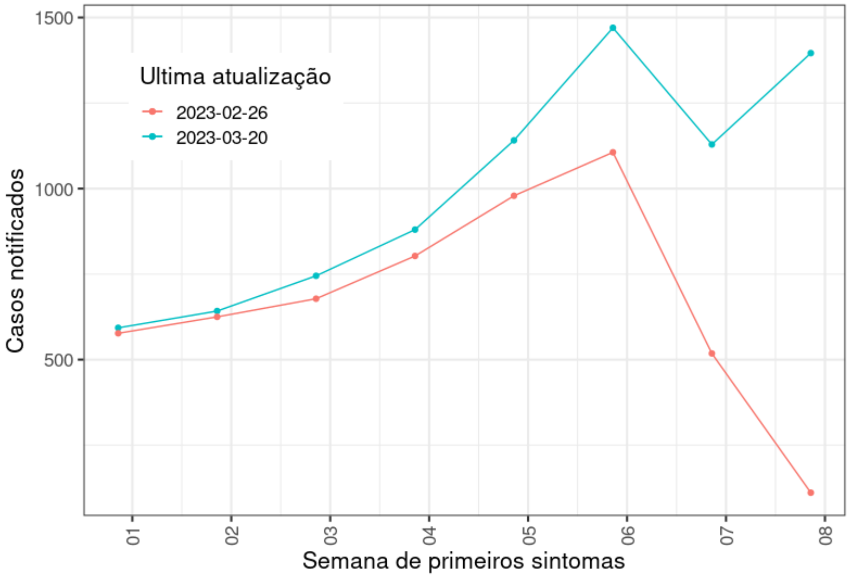


Rio, 2023-03-04

Notification delay problem



Rio, 2023-03-04



Bayesian chain-ladder model

$$n_{t,d} \sim NegBin(\lambda_{t,d}, \phi)$$

- Bastos et al. (2019) (INLA)

$$\log(\lambda_{t,d}) = \alpha + \beta_t + \gamma_d$$

- McGough et al. (2020) (MCMC)

$$\lambda_{t,d} = \delta_d e^{\beta_t}$$

$$\{n_{t,d}\} = \{n_{t,d} : T \leq t + d\}$$

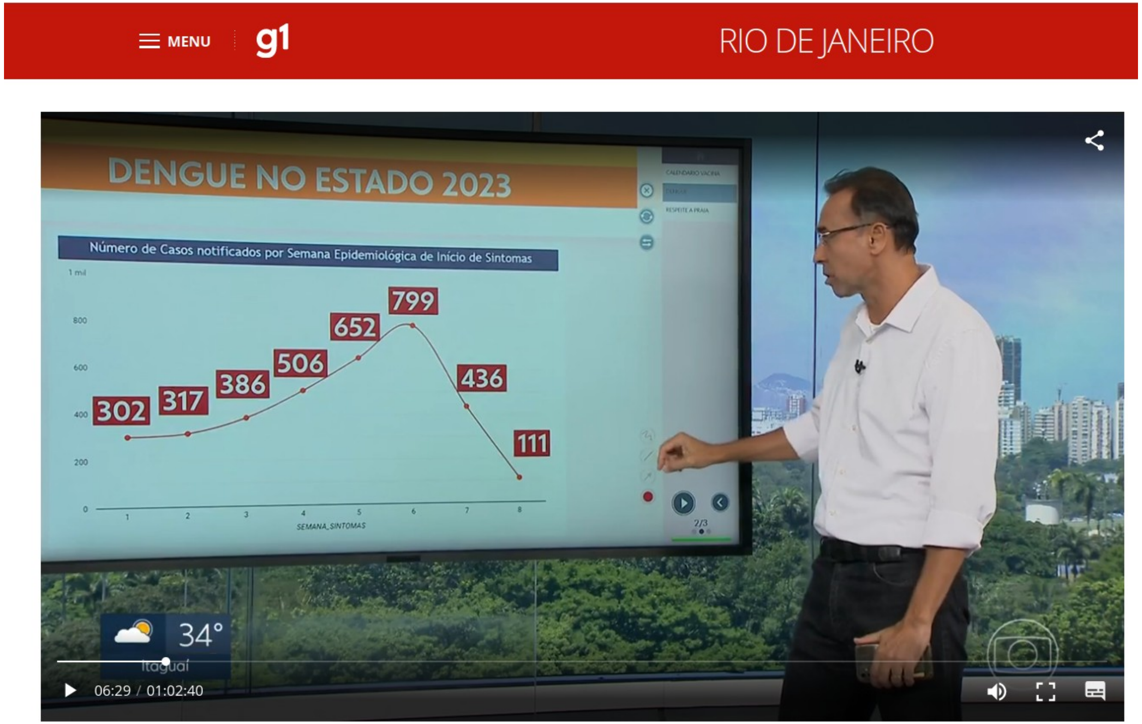
Time	0	1	2	⋯	D-2	D-1	D	N	
1	$n_{1,0}$	$n_{1,1}$	$n_{1,2}$		$n_{1,D-2}$	$n_{1,D-1}$	$n_{1,D}$	N_1	Observations
2	$n_{2,0}$	$n_{2,1}$	$n_{2,2}$	⋯	$n_{2,D-2}$	$n_{2,D-1}$	$n_{2,D}$	N_2	
3	$n_{3,0}$	$n_{3,1}$	$n_{3,2}$		$n_{3,D-2}$	$n_{3,D-1}$	$n_{3,D}$	N_3	
⋮		⋮				⋮			
T-D	$n_{T-D,0}$	$n_{T-D,1}$	$n_{T-D,2}$		$n_{T-D,D-2}$	$n_{T-D,D-1}$	$n_{T-D,D}$	N_{T-D}	
T-D+1	$n_{T-D+1,0}$	$n_{T-D+1,1}$	$n_{T-D+1,2}$		$n_{T-D+1,D-2}$	$n_{T-D+1,D-1}$	$n_{T-D+1,D}$	N_{T-D+1}	Nowcasting
T-D+2	$n_{T-D+2,0}$	$n_{T-D+2,1}$	$n_{T-D+2,2}$		$n_{T-D+2,D-2}$	$n_{T-D+2,D-1}$	$n_{T-D+2,D}$	N_{T-D+2}	
T-2	$n_{T-2,0}$	$n_{T-2,1}$	$n_{T-2,2}$		$n_{T-2,D-2}$	$n_{T-2,D-1}$	$n_{T-2,D}$	N_{T-2}	
T-1	$n_{T-1,0}$	$n_{T-1,1}$	$n_{T-1,2}$		$n_{T-1,D-2}$	$n_{T-1,D-1}$	$n_{T-1,D}$	N_{T-1}	
T	$n_{T,0}$	$n_{T,1}$	$n_{T,2}$	⋯	$n_{T,D-2}$	$n_{T,D-1}$	$n_{T,D}$	N_T	
T+1	$n_{T+1,0}$	$n_{T+1,1}$	$n_{T+1,2}$		$n_{T+1,D-2}$	$n_{T+1,D-1}$	$n_{T+1,D}$	N_{T+1}	Forecasting
T+2	$n_{T+2,0}$	$n_{T+2,1}$	$n_{T+2,2}$		$n_{T+2,D-2}$	$n_{T+2,D-1}$	$n_{T+2,D}$	N_{T+2}	
⋮		⋮		⋯		⋮			
T+K	$n_{T+K,0}$	$n_{T+K,1}$	$n_{T+K,2}$		$n_{T+K,D-2}$	$n_{T+K,D-1}$	$n_{T+K,D}$	N_{T+K}	

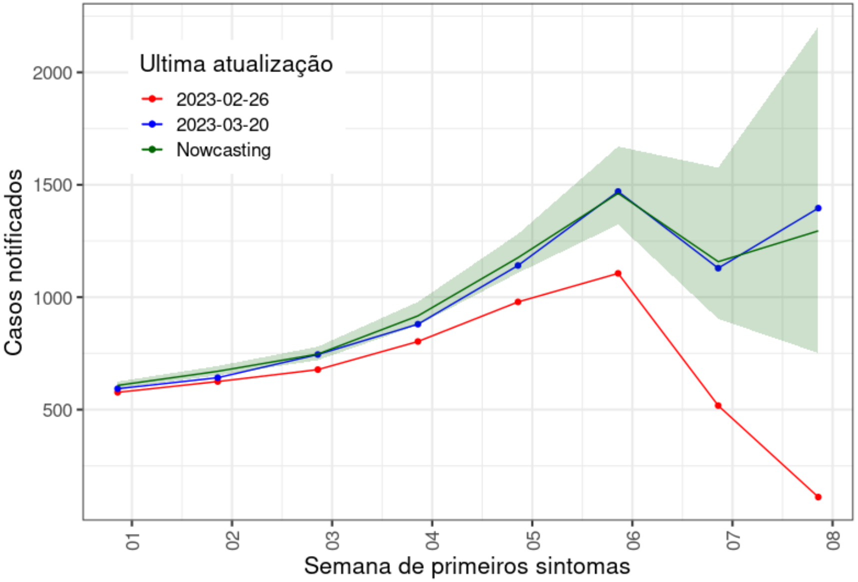
$$\{n^*_{t,d}\} = \{n_{t,d} : T > t + d\}$$

$$P(\{n^*_{t,d}\} \mid \{n_{t,d}\}) = \int_{\theta \in \Theta} p(\theta, \{n^*_{t,d}\} \mid \{n_{t,d}\}) d\theta$$

$$= \int_{\theta \in \Theta} p(\theta \mid \{n_{t,d}\}) p(\{n^*_{t,d}\} \mid \theta) d\theta$$

Notification delay problem





Rio, 2023-03-04

Bayesian Nowcasting

- **The Bayesian chain-ladder models is implemented in:**
  - two National level disease surveillance systems
  - R package: *nowcaster*

INFO GRIPE

INFO DENGUE

Nowcaster

nowcaster nowcaster

`nowcaster` is a R package for "nowcasting" epidemiological time-series. Every single system of notification has an intrinsic delay, `nowcaster` can estimate how many counts of any epidemiological data of interest (*i.e.*, daily cases and deaths counts) by fitting a negative binomial model to the time steps of delay between onset date of the event, (*i.e.*, date of first symptoms for cases or date of occurrence of death) and the date of report (*i.e.*, date of notification of the case or death).

`nowcaster` is based on the `R-INLA` and `INLA` packages for "**I**ntegrated **N**ested **La**place **A**pproximation" algorithm to Bayesian inference. `INLA` is a fast alternative to others methods for Bayesian inference like **MCMC**. An introduction to `INLA` can be found here.

`nowcaster` is build for epidemiological emergency use, it was constructed for the Brazilian Severe Acute Respiratory Illness (SARI) surveillance database (SIVEP-Gripe).

Installing

Before installing the package certify you have an active installation of `INLA`, to do so you can run the follwing code:

```
install.packages("INLA",
                 repos=c(getOption("repos"),
                 INLA="https://inla.r-inla-download.org/R/stable"),
                 dep=TRUE)
```

Links

Browse source code

Report a bug

License

Full license

GPL (>= 3)

Citation

Citing nowcaster

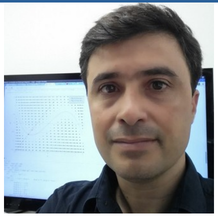
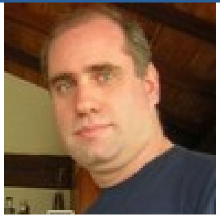
Developers

Rafael Lopes
Author, maintainer

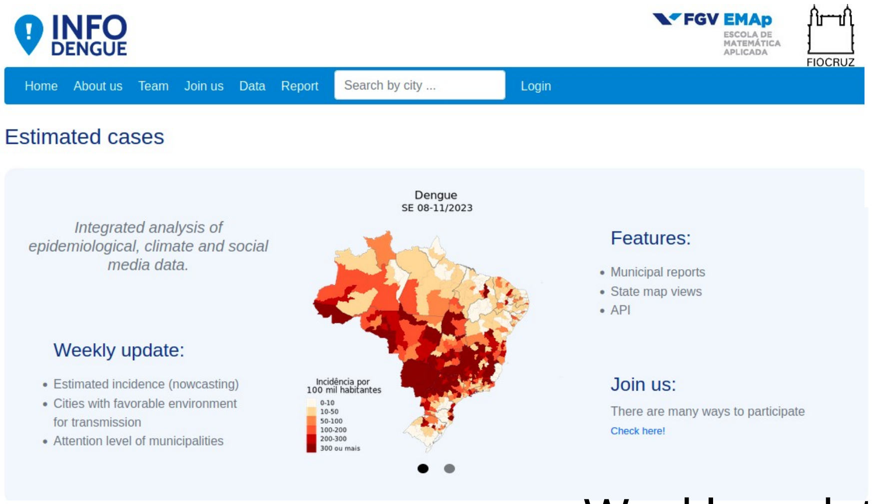
Leonardo Bastos
Author

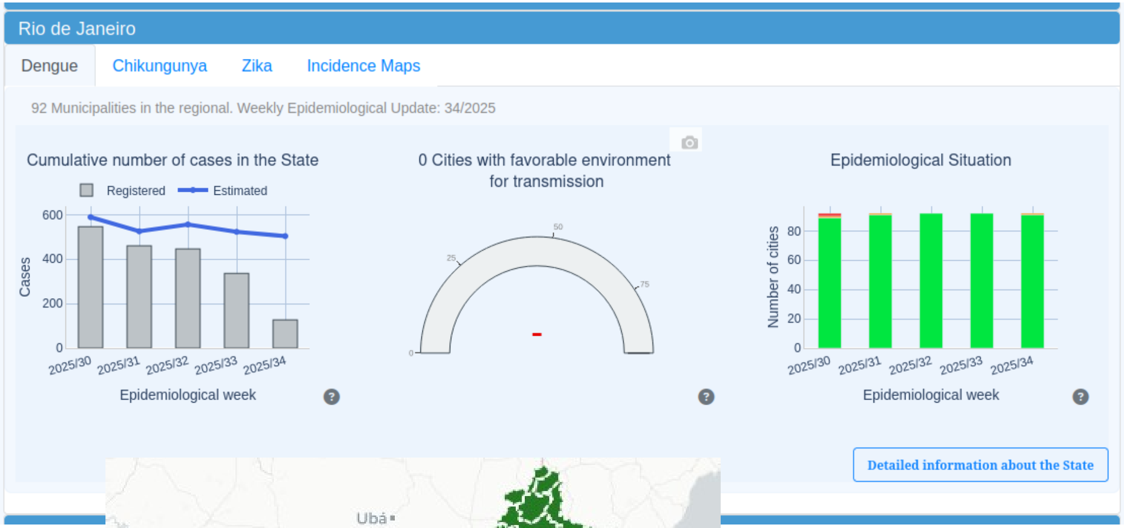
https://covid19br.github.io/nowcaster/

(Nearly) Real-time early warning systems

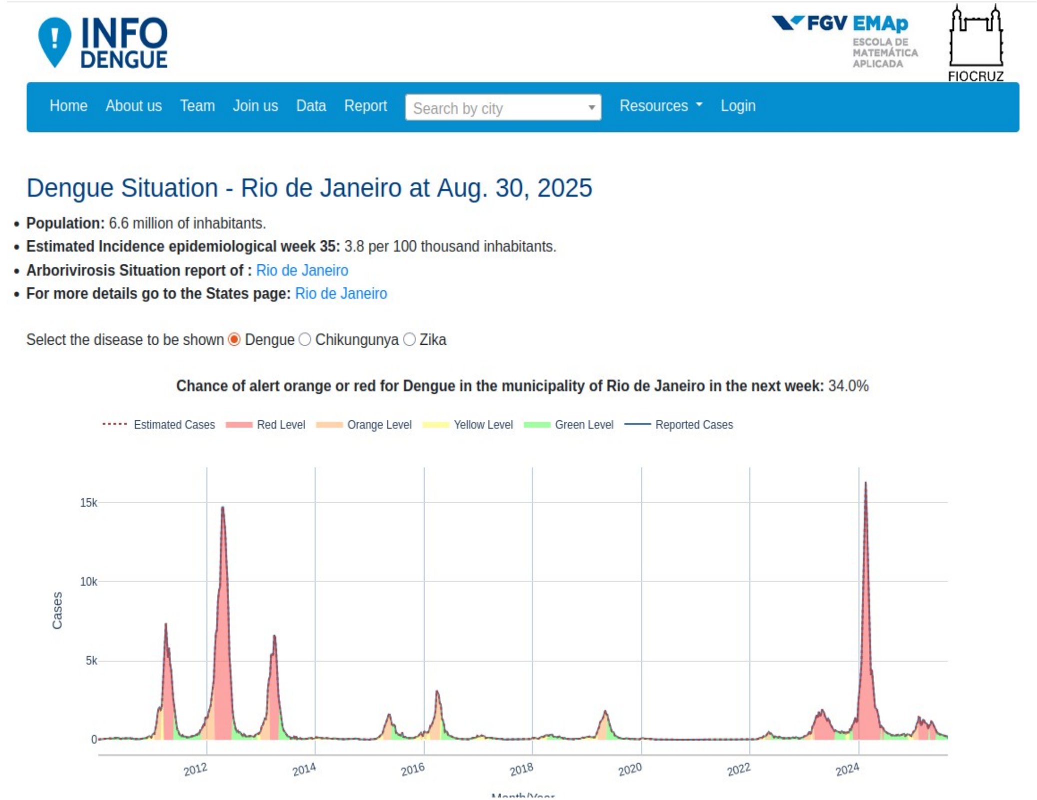
https://info.dengue.mat.br/

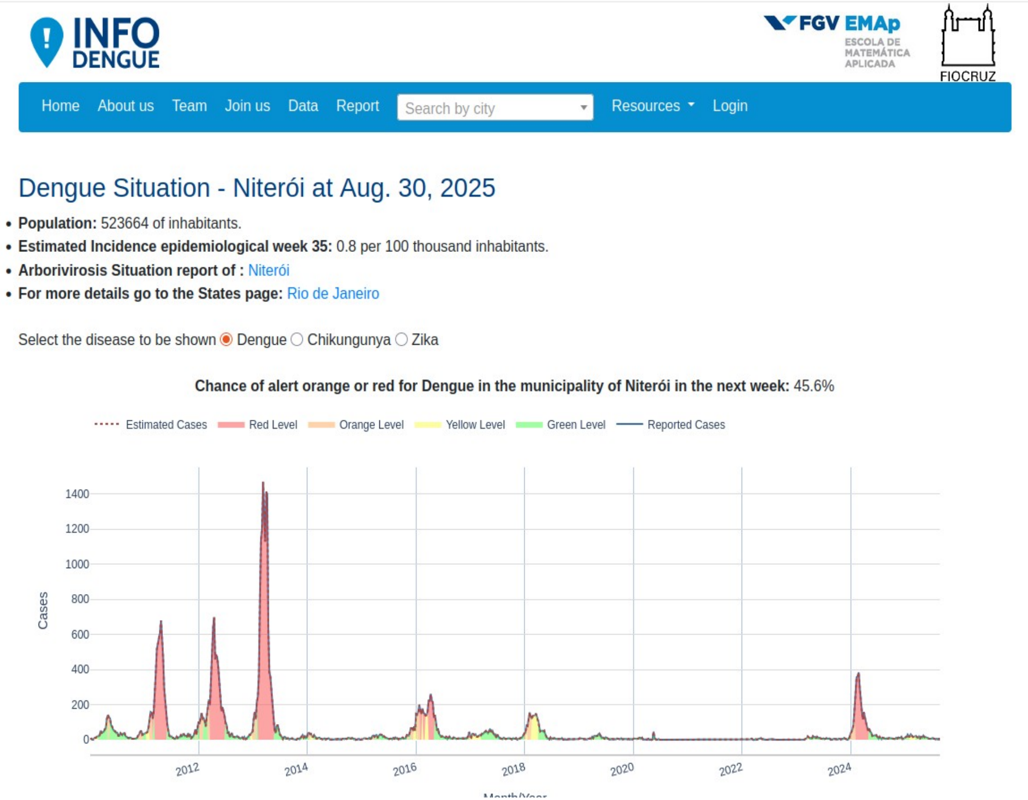




Weekly updated!

Infodengue


INFO DENGUE
FGV EMAp
ESCOLA DE MATEMÁTICA APLICADA
FIOCRUZ
Home About us Team Join us Data Report Search by city Resources Login
Dengue Situation - Rio de Janeiro at Aug. 30, 2025
Population: 6.6 million of inhabitants.
Estimated Incidence epidemiological week 35: 3.8 per 100 thousand inhabitants.
Arborivirosis Situation report of : Rio de Janeiro
For more details go to the States page: Rio de Janeiro
Select the disease to be shown Dengue Chikungunya Zika
Chance of alert orange or red for Dengue in the municipality of Rio de Janeiro in the next week: 34.0%
Estimated Cases Red Level Orange Level Yellow Level Green Level Reported Cases
15k
10k
5k
0
Cases
2012 2014 2016 2018 2020 2022 2024


INFO DENGUE
FGV EMAp
ESCOLA DE MATEMÁTICA APLICADA
FIOCRUZ
Home About us Team Join us Data Report Search by city Resources Login
Dengue Situation - Niterói at Aug. 30, 2025
Population: 523664 of inhabitants.
Estimated Incidence epidemiological week 35: 0.8 per 100 thousand inhabitants.
Arborivirosis Situation report of : Niterói
For more details go to the States page: Rio de Janeiro
Select the disease to be shown Dengue Chikungunya Zika
Chance of alert orange or red for Dengue in the municipality of Niterói in the next week: 45.6%
Estimated Cases Red Level Orange Level Yellow Level Green Level Reported Cases
1400
1200
1000
800
600
400
200
0
Cases
2012 2014 2016 2018 2020 2022 2024

Improving the delay correction

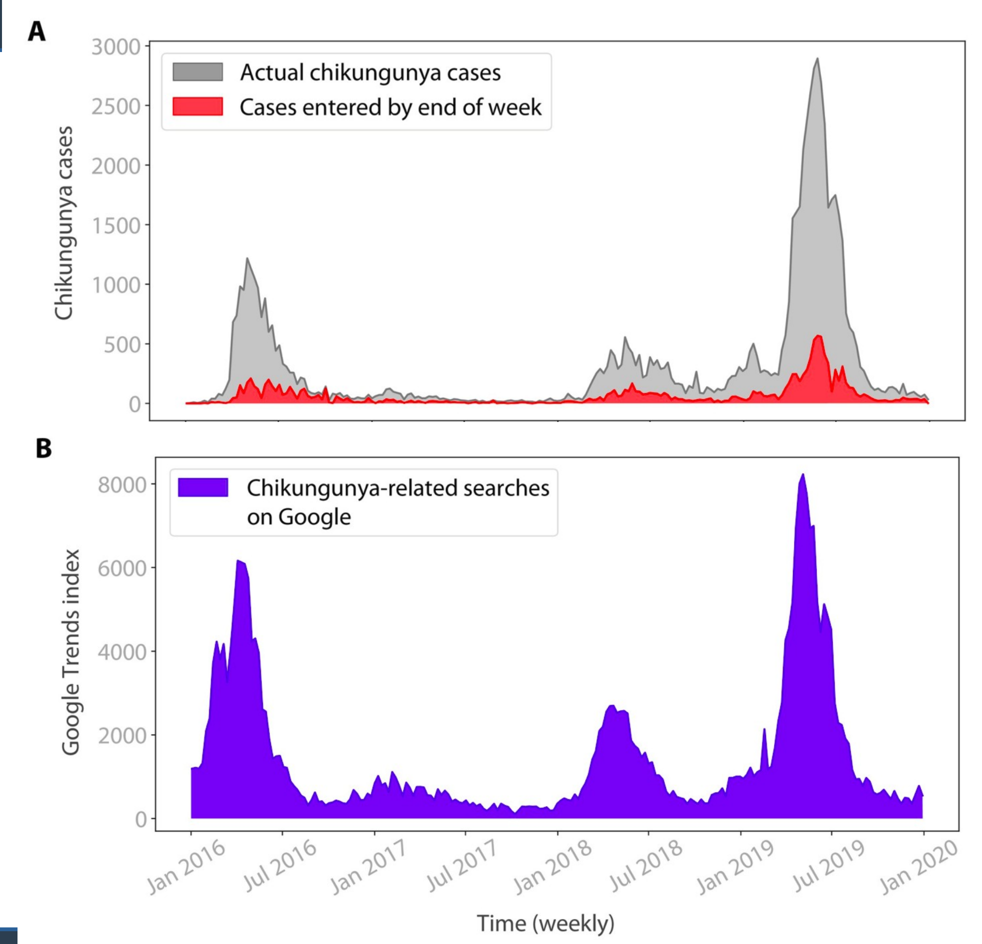
- **Covariates may improve corrections**

$$n_{t,d} \sim NegBin(\lambda_{t,d}, \phi)$$

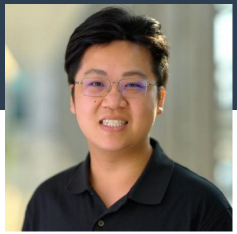
$$\log(\lambda_{t,d}) = \alpha + \beta_t + \gamma_d + \mathbf{x}_{t,d}^T \delta$$

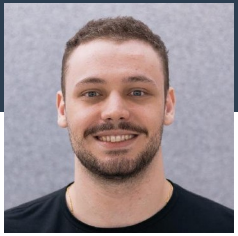
Bastos et al. (2019)

Mizzi (2019, PhD Warwick), Miller et al. (2022)

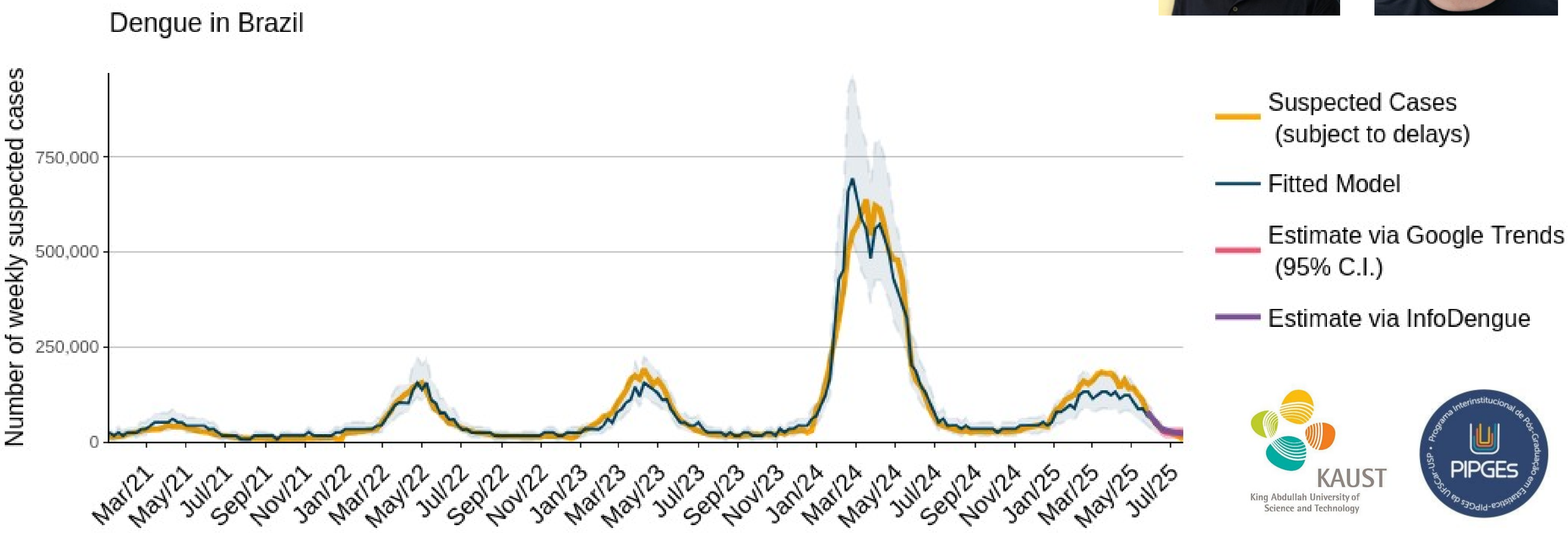


Nowcasting using google searches





Corrected number of suspected dengue cases via Google Trends



KAUST
King Abdullah University of Science and Technology

PIPGEs

Yang Xian, Guilherme Soares, LB, Rafael Izbick, Paula Moraga (2025, PLOS NTD)

Short-term forecasts

Bayesian additive regression trees (BART)

- *BART: R* package
- Msc dissertation (Jo Arruda)
- 4-week ahead forecasts
- Attribute engineering
- 4 Brazilian cities

Data

- **Dengue cases**
- **climate (ERA5)**
  - Temperature, humidity
- **Google trends**

Short-term forecasts for Rio

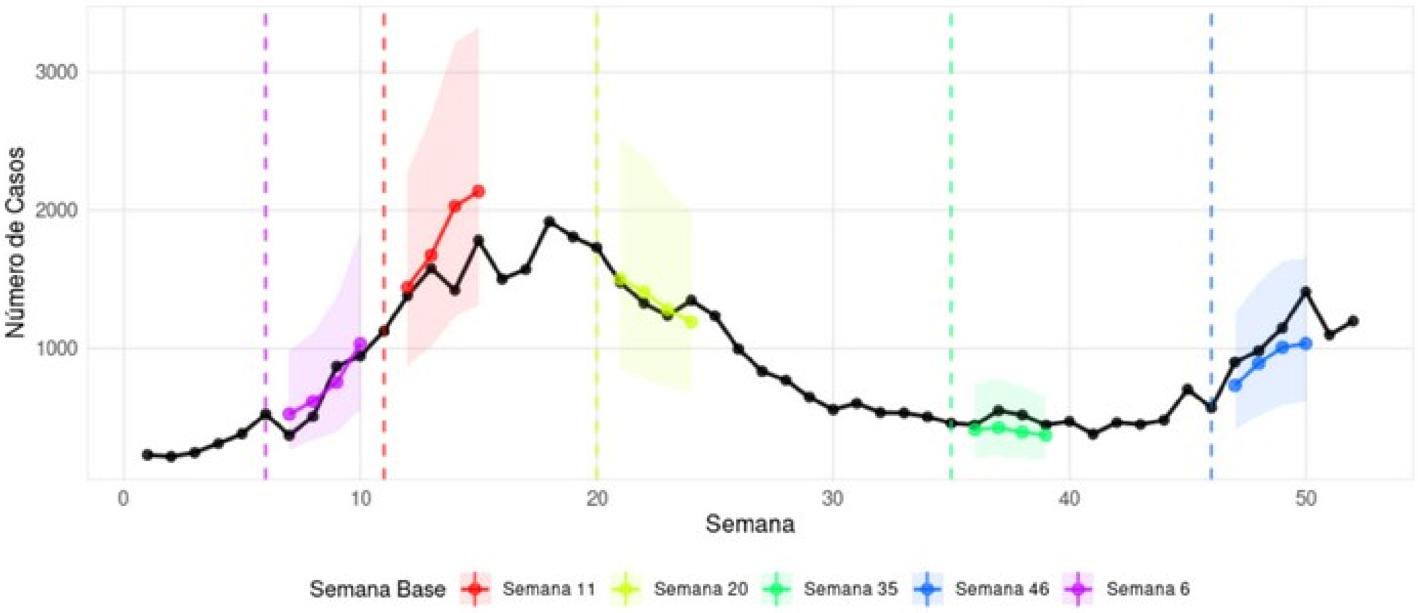


Figura 4.2 – Previsões de casos de dengue originadas de diferentes pontos de partida sobrepostas aos casos reais durante o ano de 2023 - Rio de Janeiro

Arruda (2025)

Multivariate nowcasting

Dengue and Chikungunya joint model

Shared component model

$$n_{t,d}^{(i)} \sim NegBin(\lambda_{t,d}^{(i)}, \phi^{(i)})$$

$$\log(\lambda_{t,d}^{(i)}) = \alpha + \beta_t + \gamma_d + \delta_t^{(i)} + \psi_d^{(i)}$$

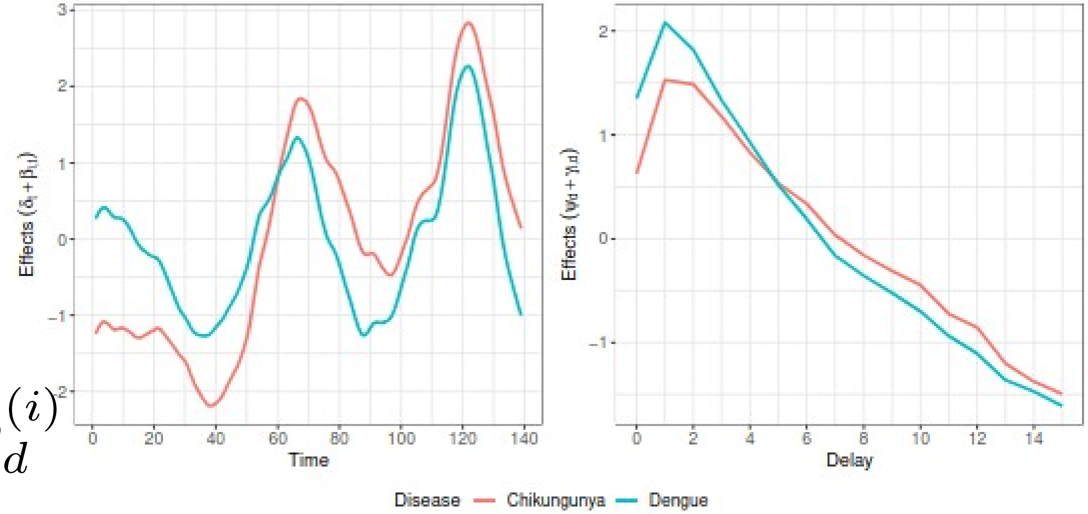
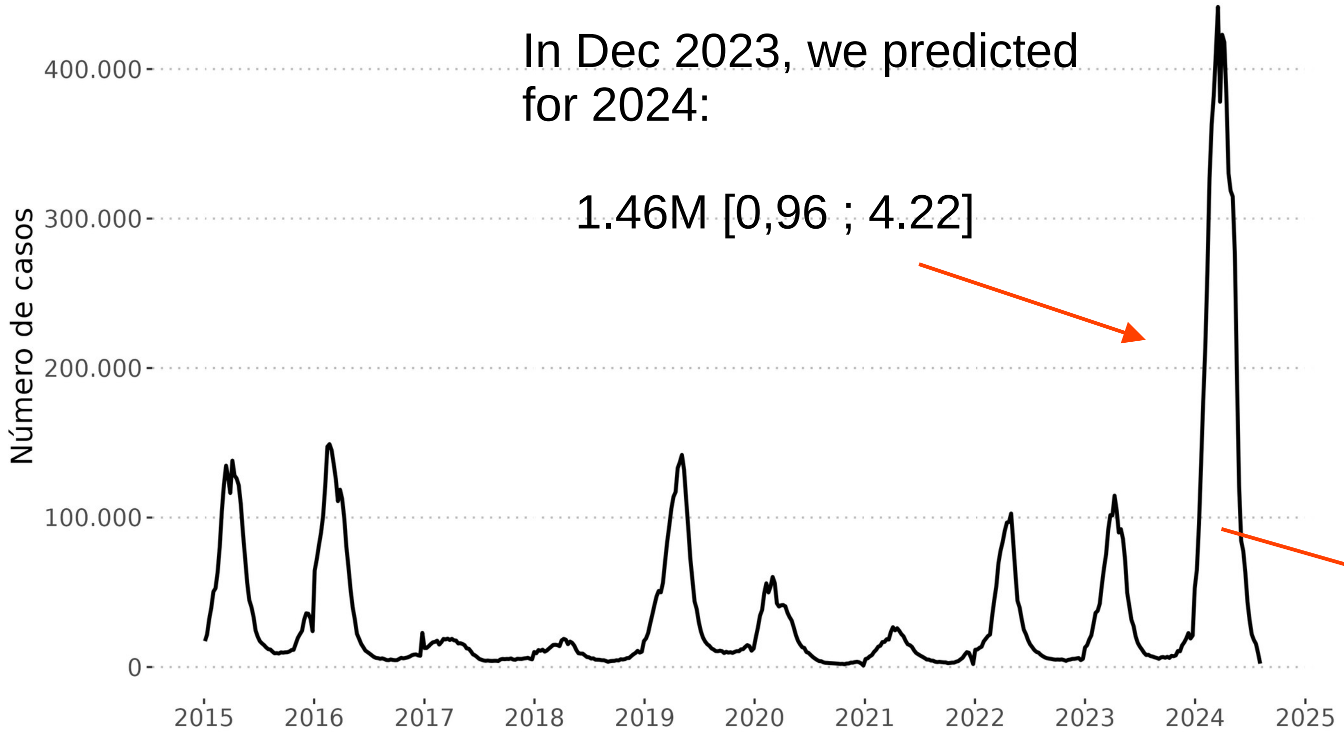


FIGURE 6 Effects of time and delay for dengue (blue) and chikungunya (red).

Dos Santos (2023, Msc, UFRJ)

Dengue in Brazil: Can we predict one-year ahead?



In Dec 2023, we predicted for 2024:

1.46M [0,96 ; 4.22]

g1 SAÚDE

Brasil pode chegar a 4,2 milhões de casos de dengue em 2024, diz Ministério da Saúde

Os primeiros 521 municípios a receberem a vacina contra a doença devem ser cobertos até o final de março. Crianças de 10 a 11 anos serão primeiro grupo a receber o imunizante.

Por Paloma Rodrigues, TV Globo

09/02/2024 08h34 · Atualizado há um ano

ISTOÉ

Início > Notícias

Brasil pode registrar até 4,2 milhões de casos de dengue em 2024

Agência Brasil – 30/01/24 - 12h24min Em Notícias

> 6 million cases!

Dengue forecasting challenge

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2025 Sprint: 2nd Infodengue-Mosqlimate Dengue Challenge (IMDC)

Welcome to the dengue forecast sprint page

Sprint 2025 webinar

Webinar – 2nd Infodengue-Mosqlimate Dengue Challenge (IMDC)

Attention, scientific community and public health professionals! On Wednesday, Sep 3, 2025 · 2pm – 3pm (Central European Time), join the virtual meeting of the 2nd Infodengue-Mosqlimate Dengue Challenge (IMDC). We will present the results of the validation round. This webinar will bring together researchers, health professionals, data scientists, and forecasters who have submitted predictive models to address a major global health challenge: predicting the burden of dengue, in the context of current global climate transformations.

read more

https://sprint.mosqlimate.org/

- “1 team in 2023”
- 6 teams in 2024
- 16 teams in 2025

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Leveraging probabilistic forecasts for dengue preparedness and control: the 2024 Dengue Forecasting Sprint in Brazil

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This article is a preprint and has not been peer-reviewed [what does this mean?]. It reports new medical research that has yet to be evaluated and so should *not* be used to guide clinical practice.

Abstract Full Text Info/History Metrics Preview PDF

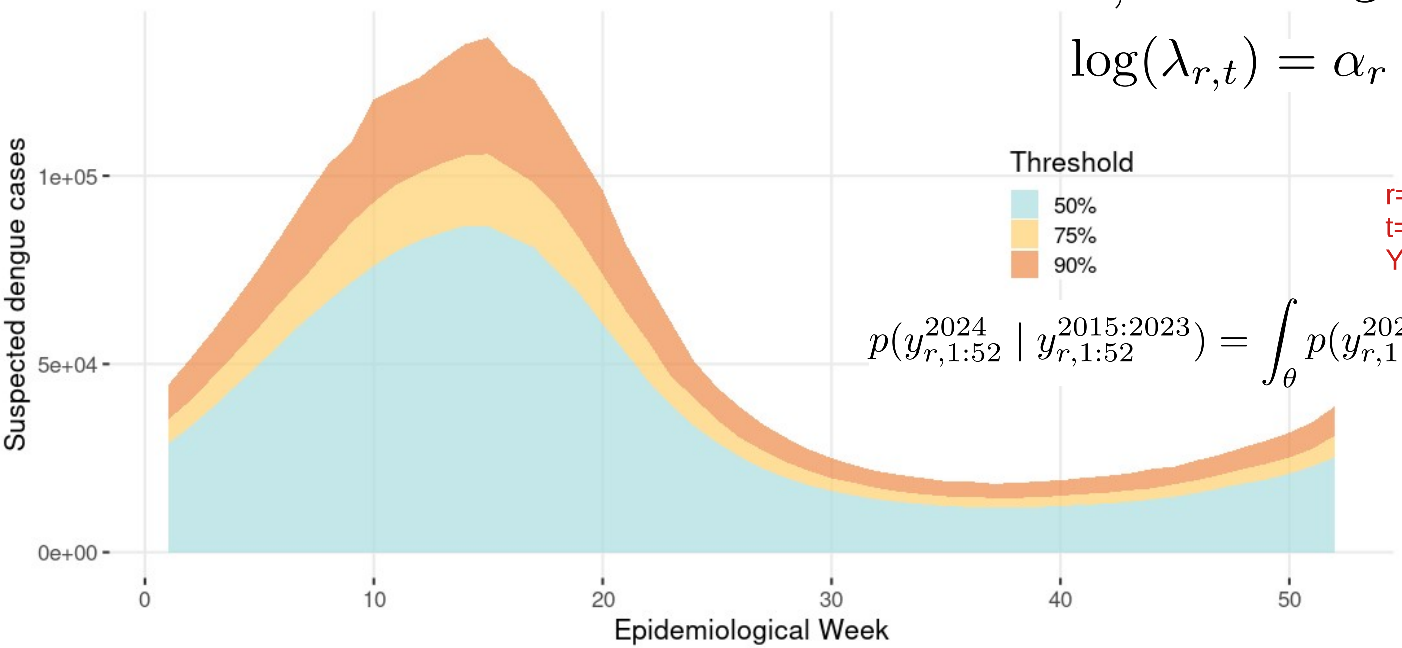
Forecasting probabilistic epidemic bands for dengue

$$Y_{r,t} \sim NegBin(\lambda_{r,t}, \phi_r)$$

$$\log(\lambda_{r,t}) = \alpha_r + \beta_{r,W[t]} + \gamma_{r,Y[t]}$$

r=1,…,108 macro de saude ;
t=1,2,3,… ; W=1,2,..,52 ;
Y=2015,2016,...

$$p(y_{r,1:52}^{2024} \mid y_{r,1:52}^{2015:2023}) = \int_\theta p(y_{r,1:52}^{2024} \mid \theta) p(\theta \mid y_{r,1:52}^{2015:2023}) d\theta$$



Freitas et al. (2025)

Probabilistic epidemic bands

Table 1
Proposed classification of predicted cases level with the interpretation.

Band	Predicted cases level	Interpretation
$\leq 50\%$	Below the median, typical	Number of cases below the historical median, with a 50% occurrence probability.
50-75%	Moderately high, fairly typical	Number of cases moderately higher than the historical median, with a 25% occurrence probability.
75-90%	Fairly high, atypical	Number of cases fairly higher than the historical median, with a 15% occurrence probability.
>90%	Exceptionally high, very atypical	Number of cases exceptionally higher than the historical median, with a 10% occurrence probability.

Freitas et al. (2025)

Training and predicting the season ahead

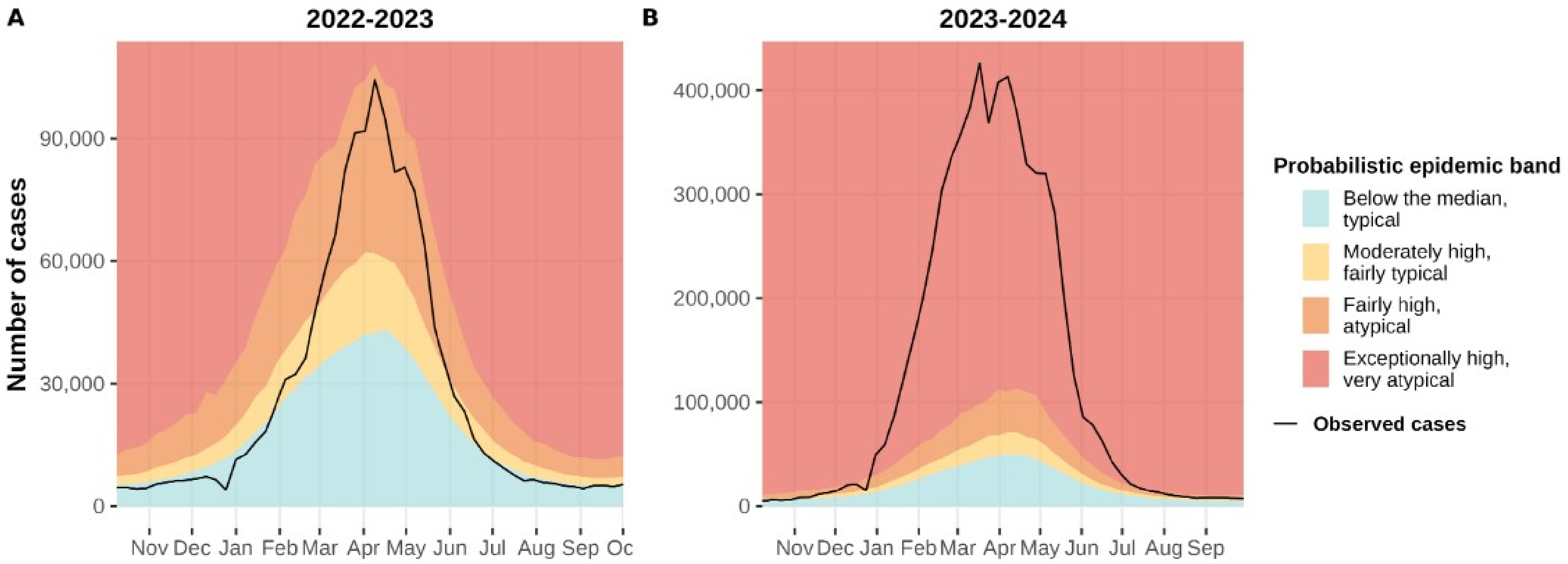


Figure 1: Estimated probabilistic epidemic bands compared with the observed number of dengue cases by week, 2022-2023 (A) and 2023-2024 (B) seasons, Brazil.

2024-2025

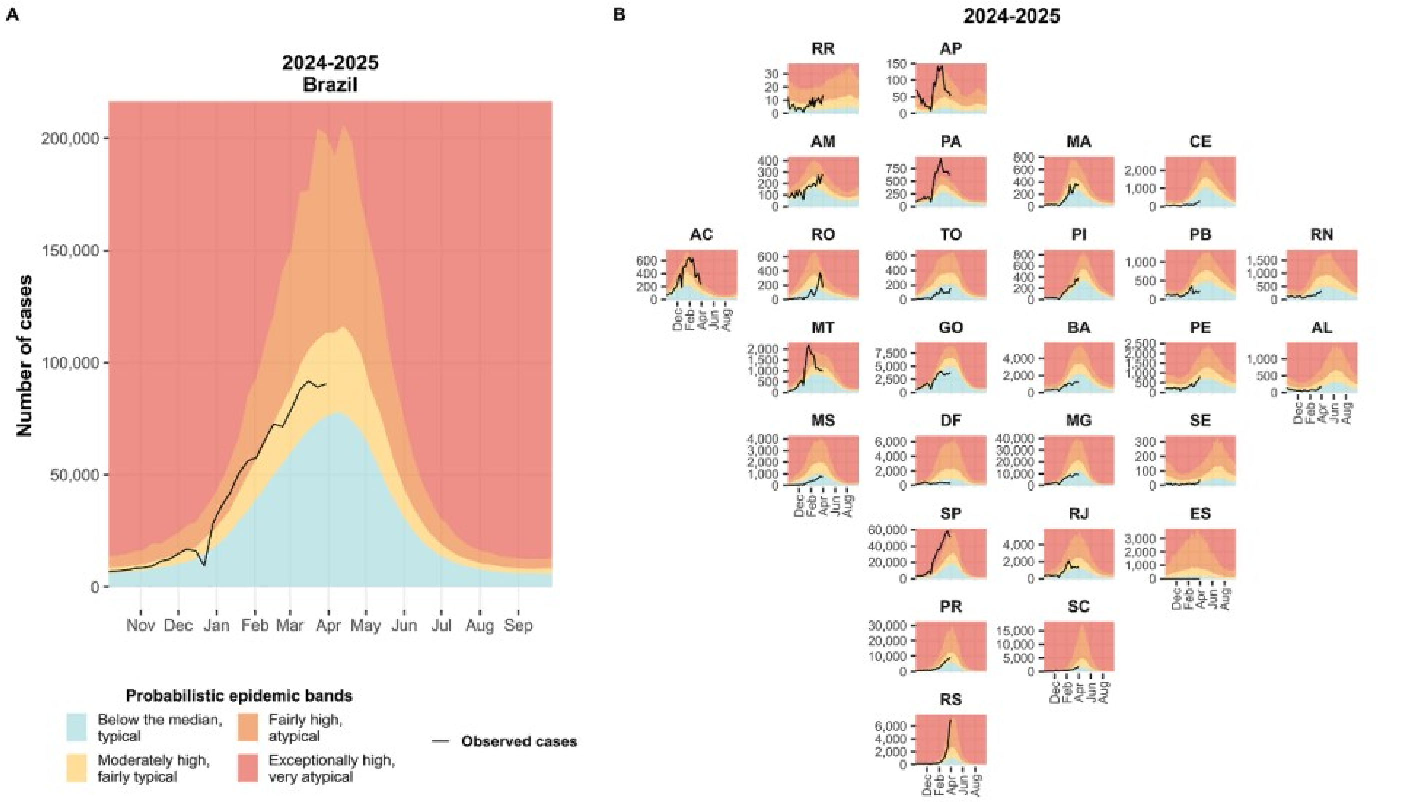


Fig. 4. Forecasted probabilistic epidemic bands of weekly dengue cases for the 2024–2025 season in Brazil (A) and by Federal Unit (B).

Dengue and clima: Predicting dengue in Vietnam

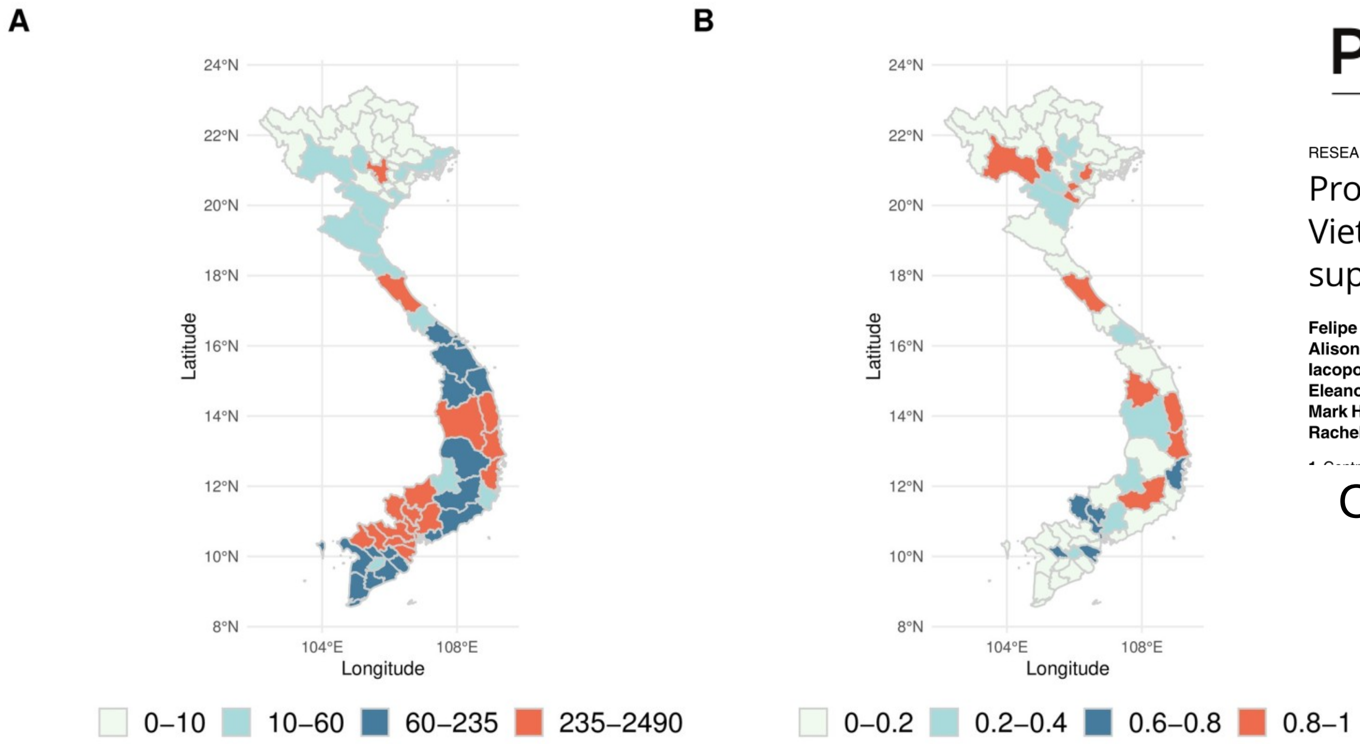


Fig 8. Risk maps. (A) Spatial distribution of the posterior mean of the predicted number of dengue cases 1 month ahead for a forecast initialised on May 10, 2020. (B) Spatial distribution of the probability of exceeding an outbreak threshold based on the 95th percentile. The shapefile used to create this figure was obtained from DIVA-gis (https://www.diva-gis.org).

PLOS MEDICINE

RESEARCH ARTICLE

Probabilistic seasonal dengue forecasting in Vietnam: A modelling study using superensembles

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Colon-Gonzalez et al. (2020)

Challenges and oportunities

- **Climate information**
  - Climate events (El nino, La nina)
  - Climate change (global warming)
  - Forecast weather and propagate uncertainty!
- **Immunity and control measures**
  - Previous epidemics
  - Vaccination
  - Wolbacchia
- **Mobility (How to add it in our models?)**
- **Lagged variables**
  - DLNM
- **Dynamic models**
  - DQM for thresholds?
  - Spatially structured models
- **Statistical learning**
  - Forecasting and/or explain
  - Fast computation

Obrigado!

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