Descriptive and Predictive models of dengue epidemiology: an overview

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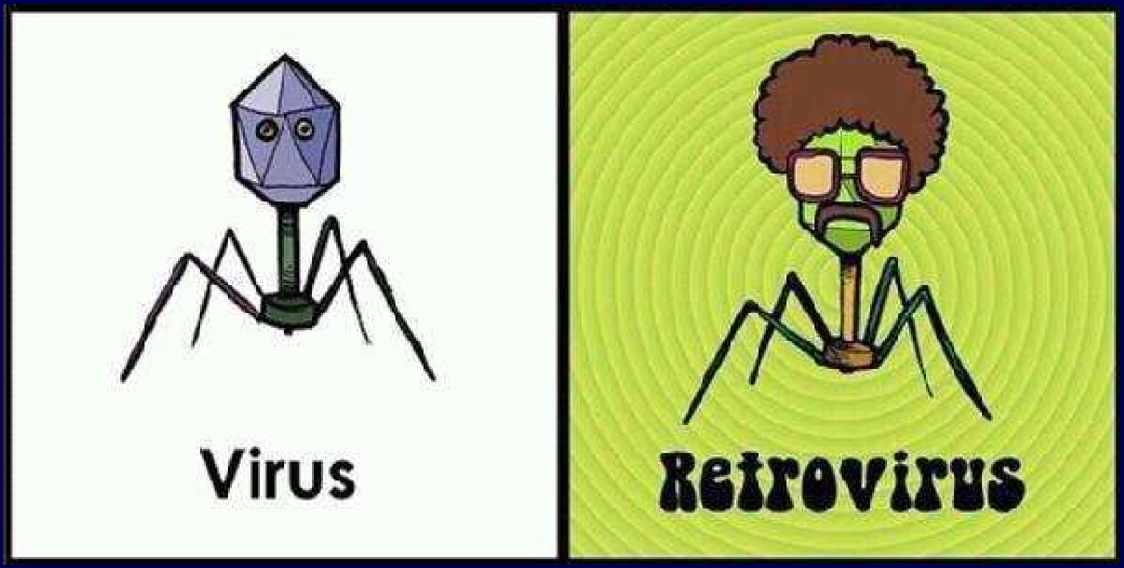
Talk Outline

- *Dengue cases in the Autonomous Region of Madeira, Portugal.*
- *Dengue fever epidemiology.*



- *Epidemiological models that captures the essential differences between primary and secondary infections.*
- *Qualitative study in order to show how much complexity we need to describe the fluctuations observed in empirical dengue hemorrhagic fever incidence data.*

Madeira: Autochthonous Dengue Cases in Portugal

October 2005:

"MADEIRA: Praga de mosquitos no Funchal."
in Diário de Notícias.

"Mosquito da febre amarela e do dengue em Santa Luzia."
in Madeira On-line.

"Insecto identificado por Rúben Capela, entomologist UMa."
in Madeira On-line.

" O mosquito foi detectado em 2005 na freguesia de Santa Luzia, no Funchal, e ter-se-á registrado após a importação de palmeiras para um jardim público.", in Madeira On-line.

Madeira: Autochthonous Dengue Cases in Portugal

November 2007:

“Vector monitoring of Aedes aegypti in the Autonomous Region of Madeira, Portugal.”, in Eurosurveillance.org.

April 2008:

“Portugal montará rede para enfrentar doenças tropicais.”, in BBC.

May 2008:

“Mosquito da dengue se espalha por países não-tropicais.”, in BBC.

“Aedes albopictus agora prolifera no sul da Europa e até na França e na Suíça.”, in BBC.

Madeira: Autochthonous Dengue Cases in Portugal

July 2008:

“Portugal regista cinco casos de dengue.”, in RTP Notícias.

“Doença contraída por cidadãos portugueses quando estes viajavam pela América do Sul.”, in RTP Notícias.

August 2008:

“ Mais mosquitos do dengue na Madeira ”, in Revista Visão .

“O tempo quente está a favorecer o aumento do número de mosquitos que transmitem a doença.”, in Madeira On-line.

October 2008:

“ Dengue: Madeira toma medidas de prevenção. Todos os aviões e navios com origem na Madeira serão analisados e desinfectados. Medidas entram em vigor no dia 1 de Novembro”, in Diário de Notícias.

Madeira: Autochthonous Dengue Cases in Portugal

Outbreak Assessment in Autonomous Region of Madeira:

Onset on 3 October 2012: *2 confirmed cases.*

10 October 2012: *18 confirmed cases, 191 probable cases, 26 hospitalized.*

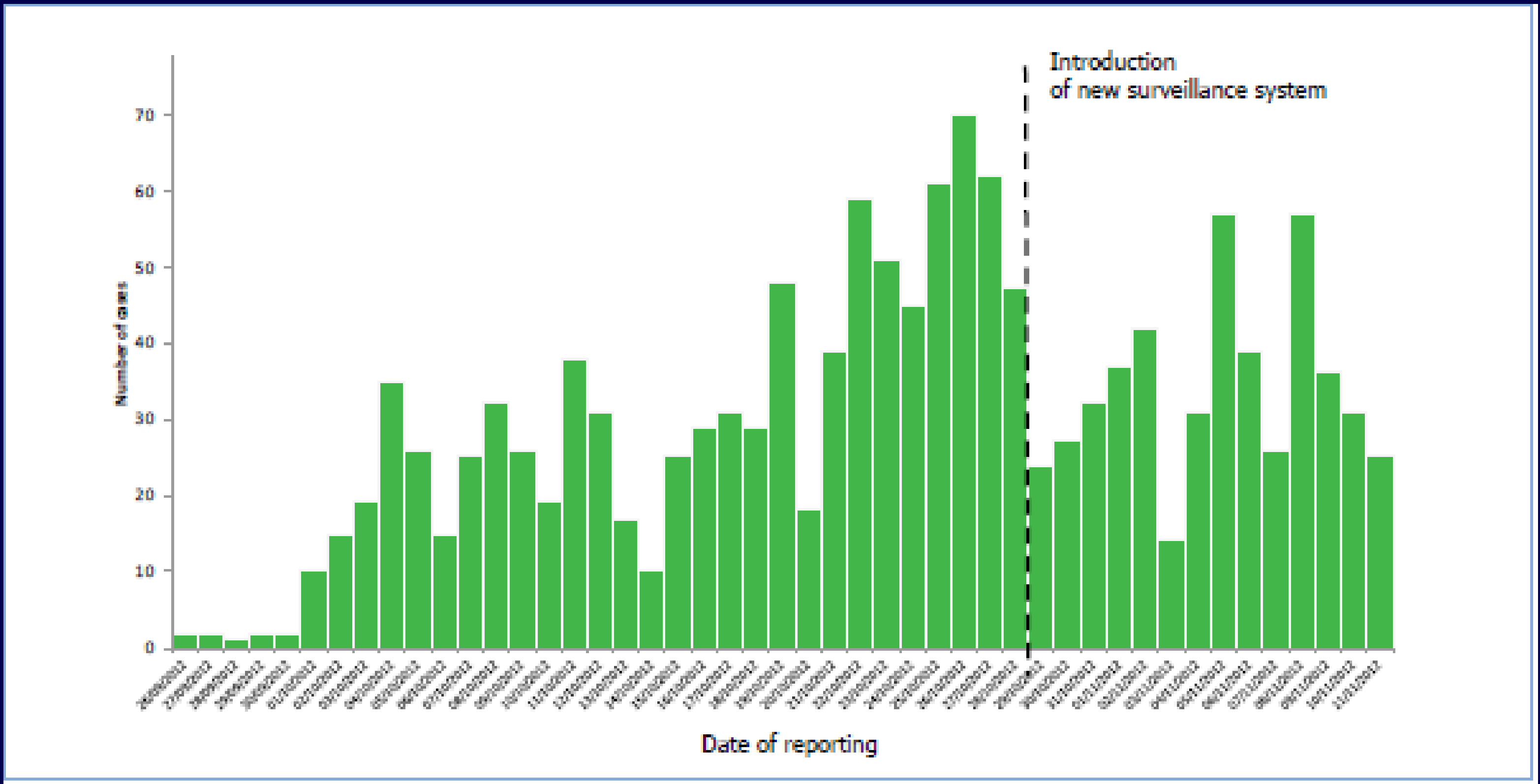
24 October 2012: *52 confirmed cases, 404 probable cases, 5 hospitalized.*

28 October 2012: *62 confirmed cases, 463 probable cases, 6 hospitalized.*

07 November 2012: *537 confirmed cases, 631 probable cases, 57 hospitalized.*

Madeira: Autochthonous Dengue Cases in Portugal

Outbreak Assessment in Autonomous Region of Madeira:



*28 November 2012: 1891 confirmed cases, 111 hospitalized,
32 imported cases in Continental Europe.*

Madeira: Autochthonous Dengue Cases in Portugal

05 Dezember 2012: 1993 confirmed cases, 118 hospitalized, 42 imported cases in Continental Europe.

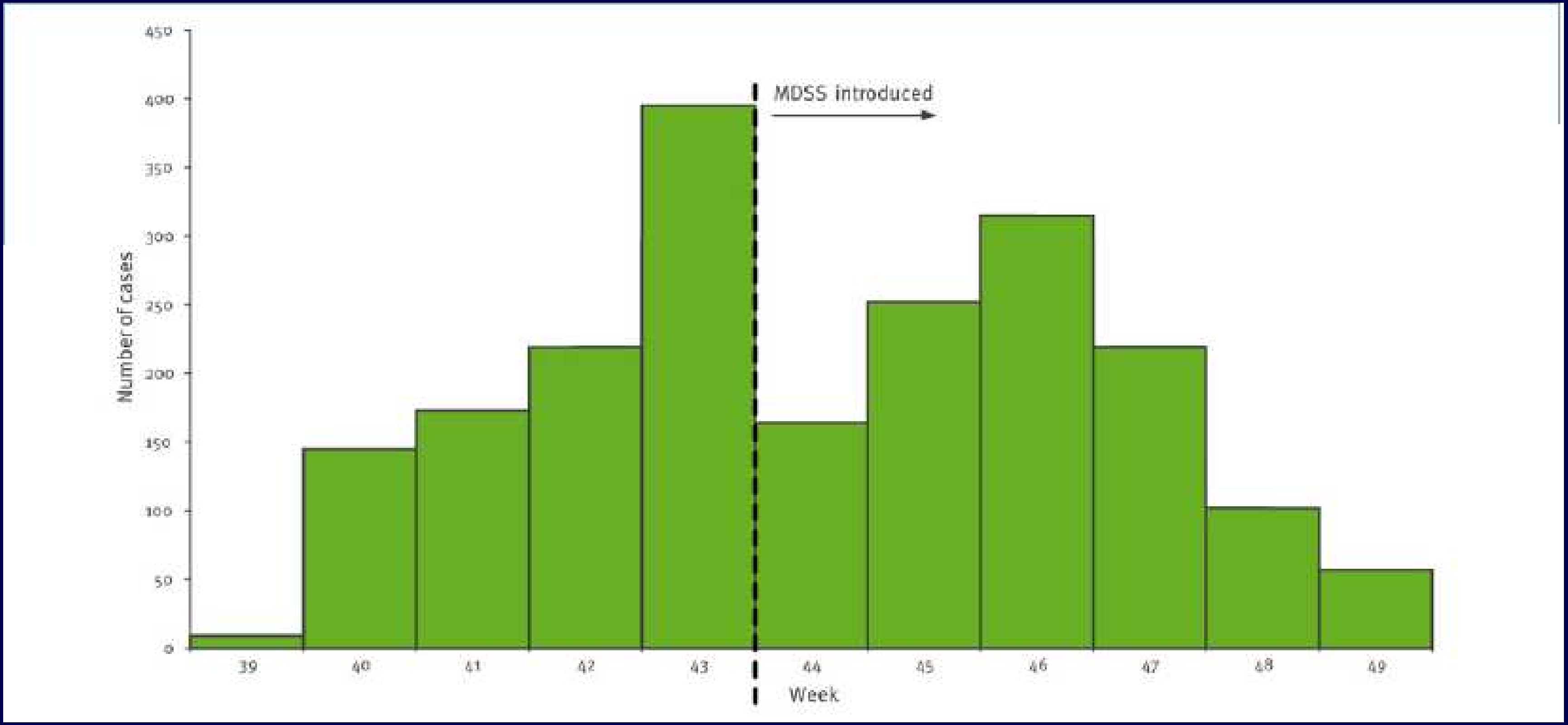
9 Dezember 2012: 2050 confirmed cases, 122 hospitalized, 58 imported cases in Continental Europe.

16 Dezember 2012: 2103 confirmed cases, 122 hospitalized, 72 imported cases in Continental Europe.

Madeira: Autochthonous Dengue Cases in Portugal

Rapid Risk Assessment ECDC: European Center for Disease Control

From September to December 2012



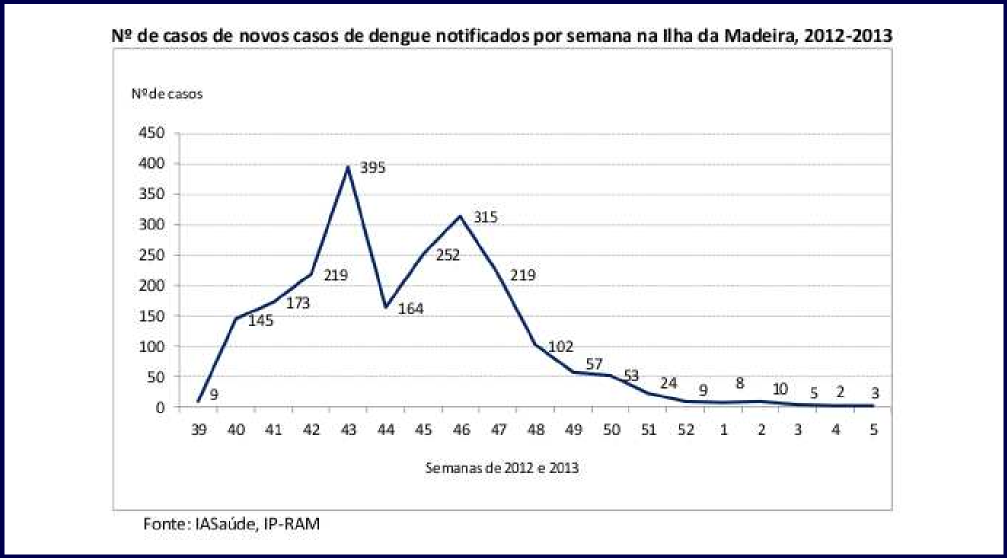
"The LARGEST outbreak in Europe since the 1920th."

Madeira: Autochthonous Dengue Cases in Portugal

21 January 2013: *2144 confirmed cases, 122 hospitalized, 74 imported cases in Continental Europe.*

28 January 2013: *Communicable Disease Threats Report (CDTR): Sporadic cases are still being reported in Madeira.*

3 February 2013: *2164 confirmed cases, 78 imported cases in Continental Europe (11 in Main Land Portugal and 66 in 12 European Countries).*



Nº de casos de novos casos de dengue notificados por semana na Ilha da Madeira, 2012-2013

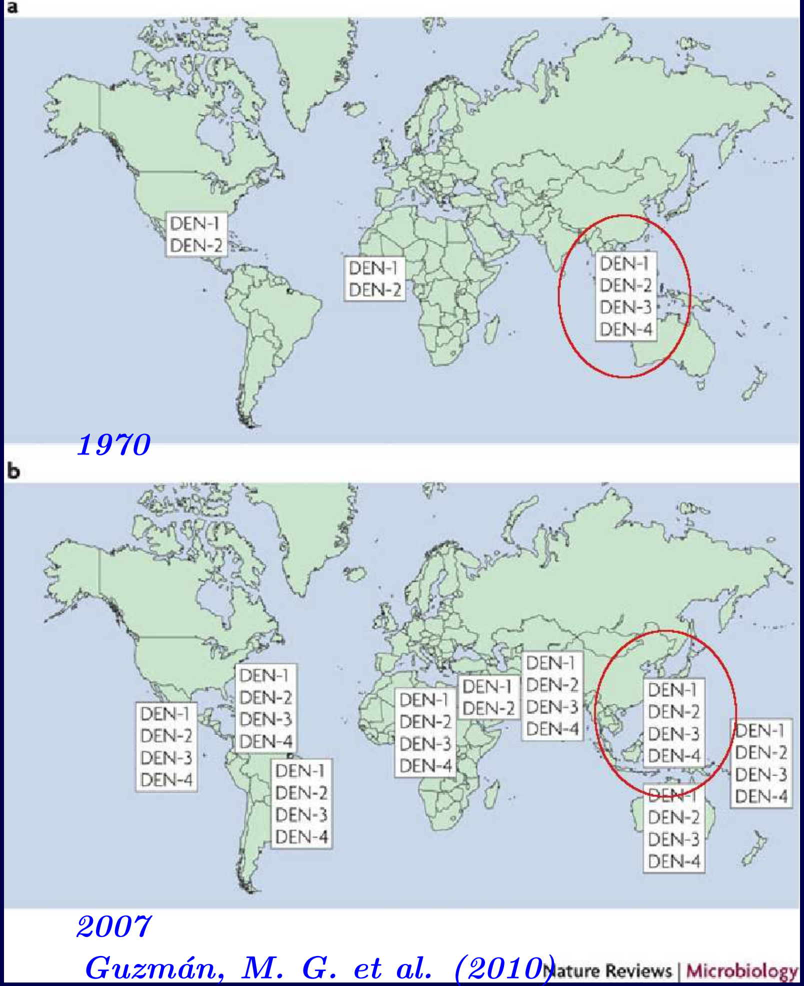
Fonte: IASaúde, IP-RAM

Dengue fever epidemiology

- ⁎ Dengue is a viral mosquito-borne infection, a leading cause of illness and death in the tropics and subtropics.
- ⁎ More than one-third of the world's population are living in areas at risk of acquiring dengue infection.

Worldwide dengue distribution 2008 - Source: WHO (2007) & CDC (2008)

Dengue fever epidemiology



1970

2007

Guzmán, M. G. et al. (2010) Nature Reviews | Microbiology

- ※ *Four antigenically distinct but closely related dengue viruses: DEN-1, DEN-2, DEN-3, DEN-4.*

Dengue fever epidemiology

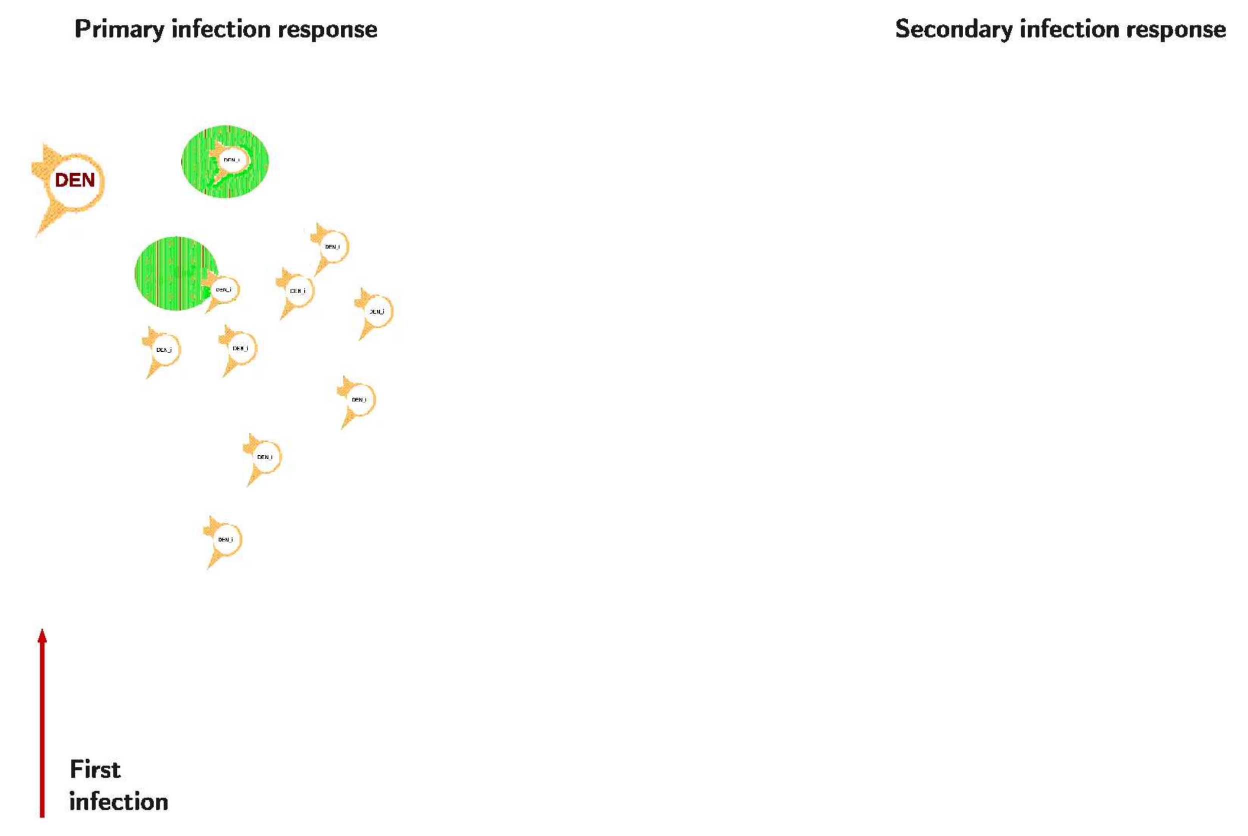
- *Infection by one serotype confers life-long immunity to that serotype and a short period of temporary cross-immunity to other serotypes (3-9 months).*

- *Two forms of the disease exist: dengue fever (DF), and dengue hemorrhagic fever (DHF).*

- *Epidemiological studies support the association of DHF with secondary dengue infection, due to the antibody-dependent enhancement (ADE) process.*

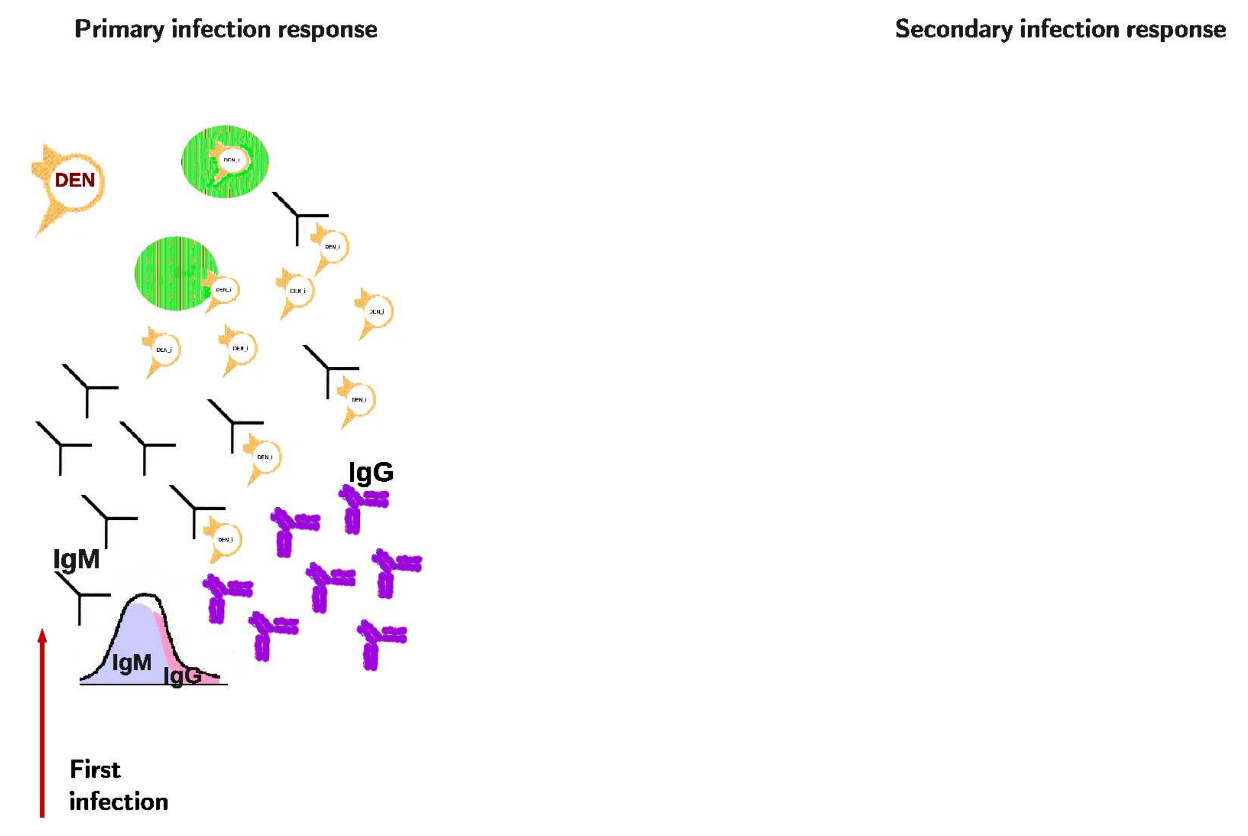
Dengue fever epidemiology

ADE in recurrent infections



Dengue fever epidemiology

ADE in recurrent infections

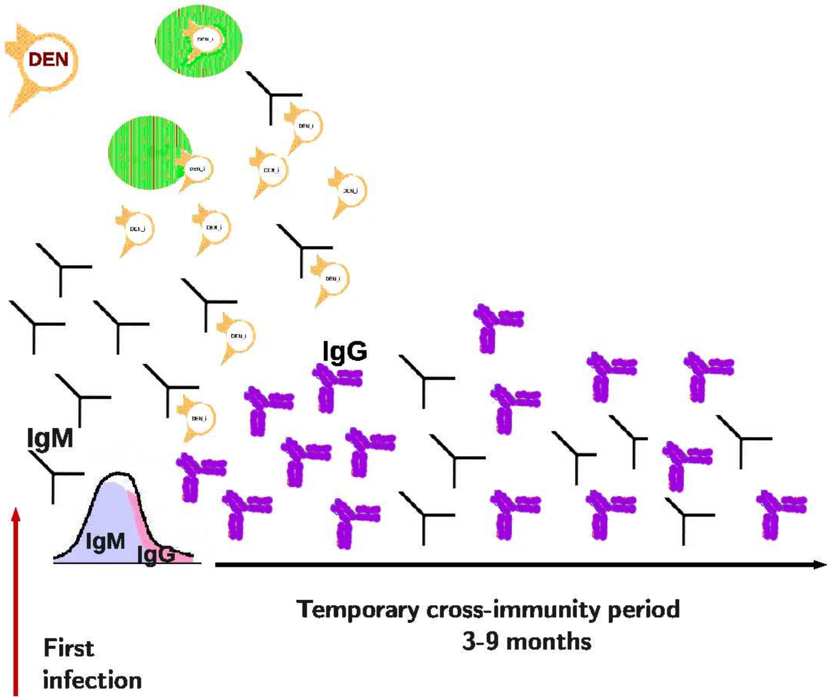


Dengue fever epidemiology

ADE in recurrent infections

Primary infection response

Secondary infection response

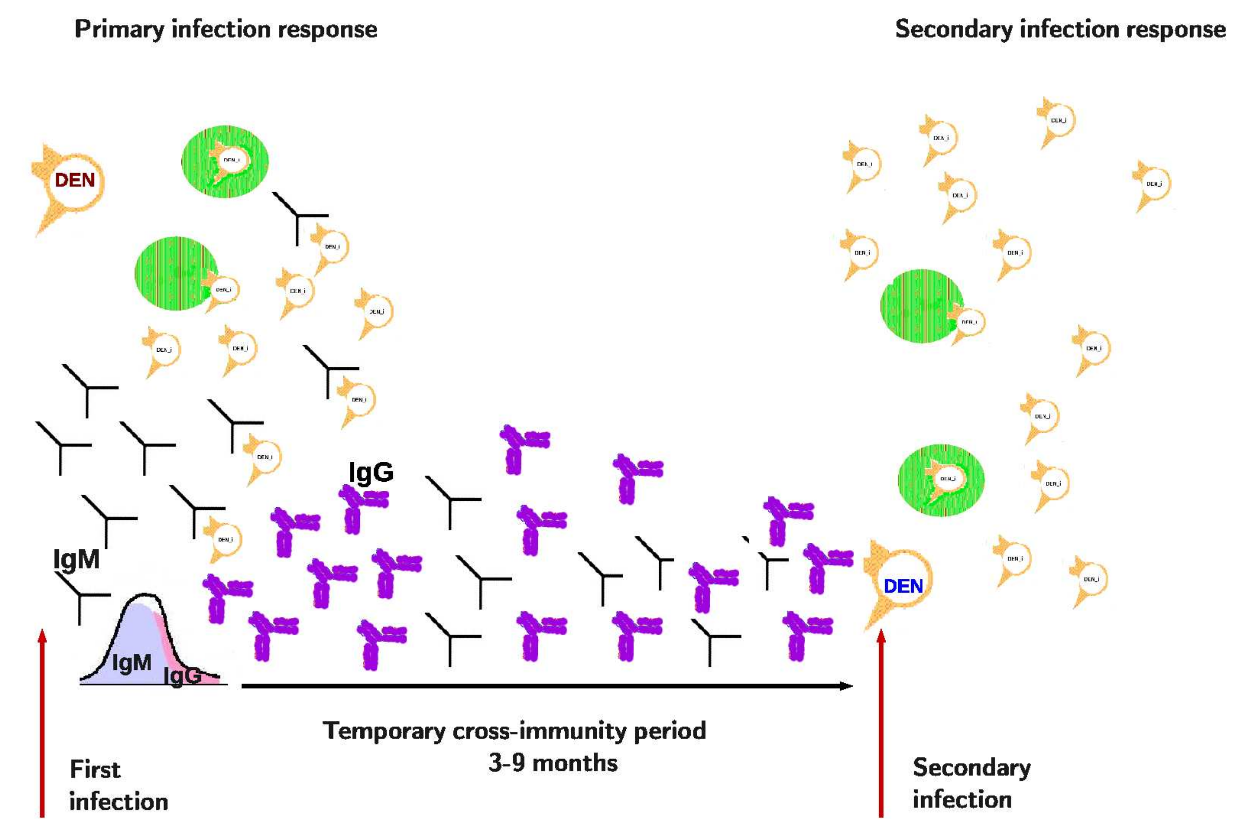


Temporary cross-immunity period
3-9 months

First
infection

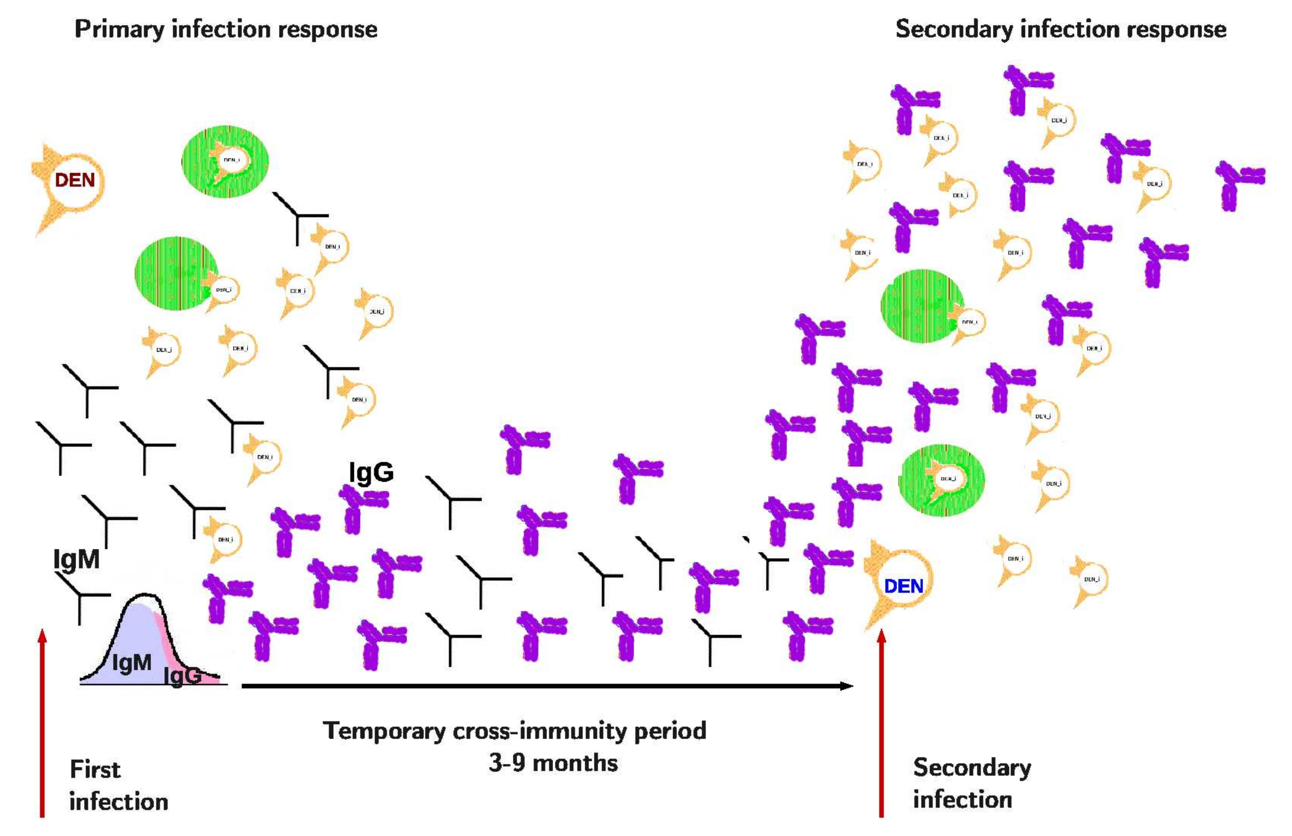
Dengue fever epidemiology

ADE in recurrent infections



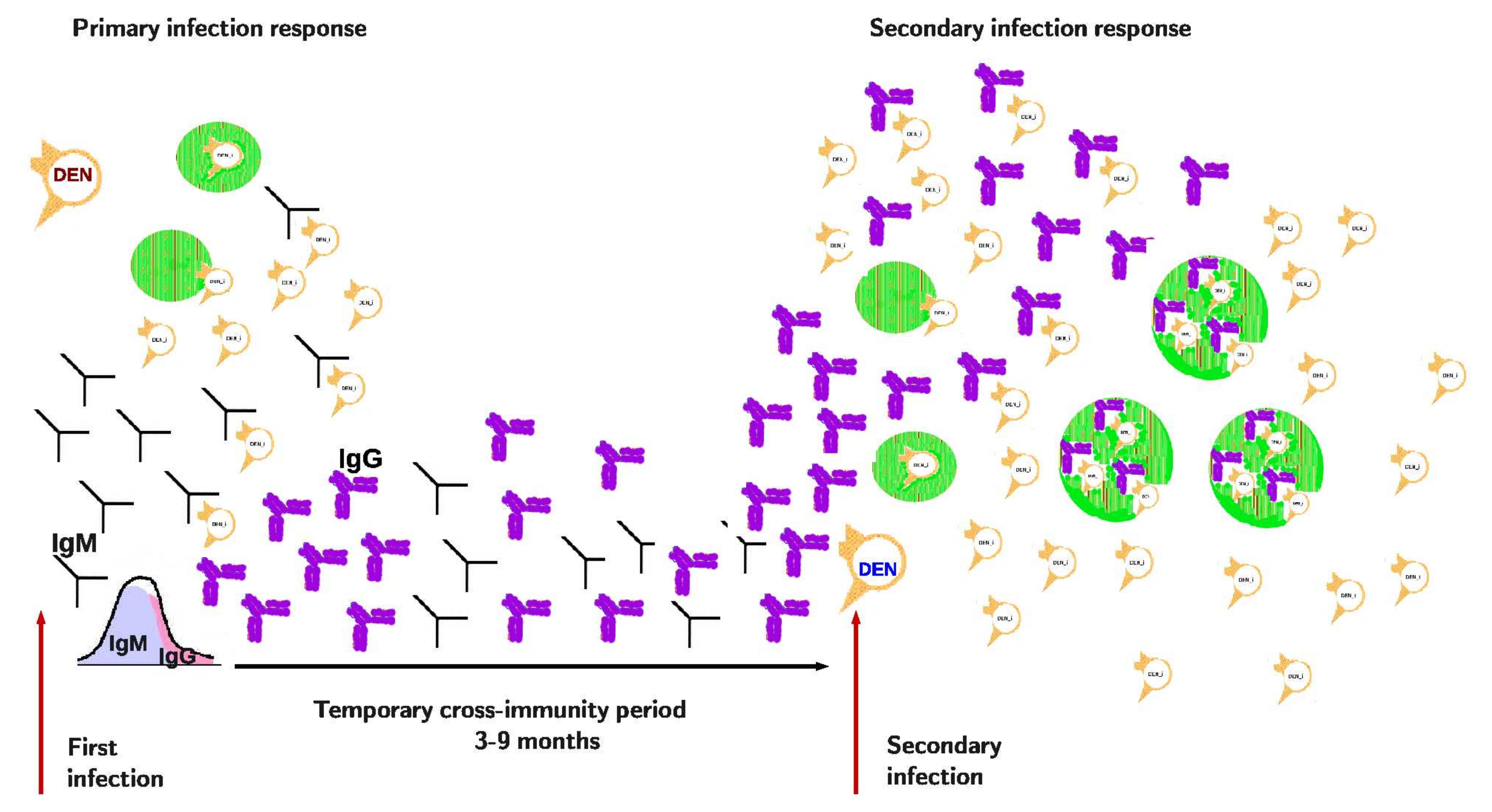
Dengue fever epidemiology

ADE in recurrent infections



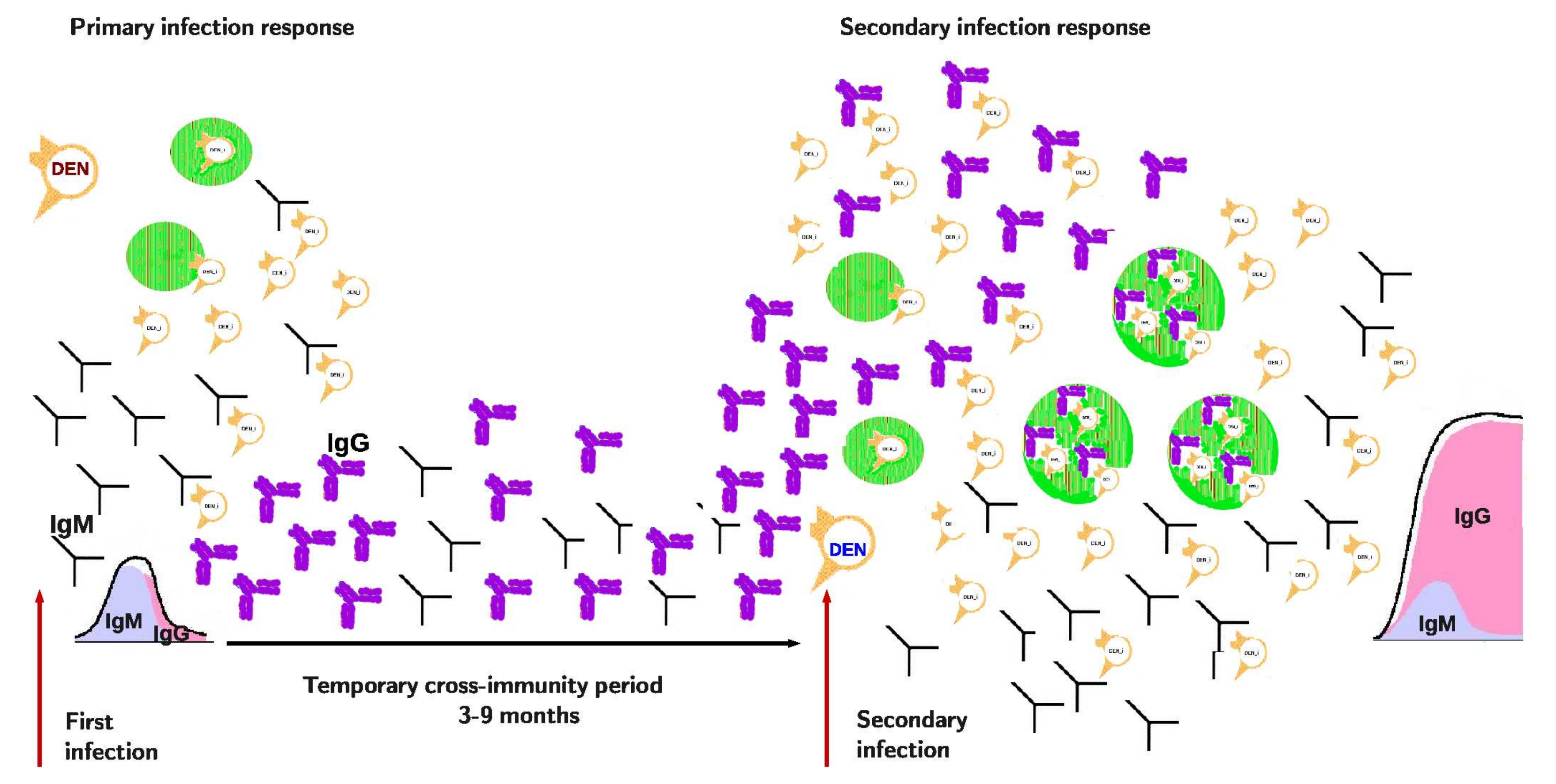
Dengue fever epidemiology

ADE in recurrent infections



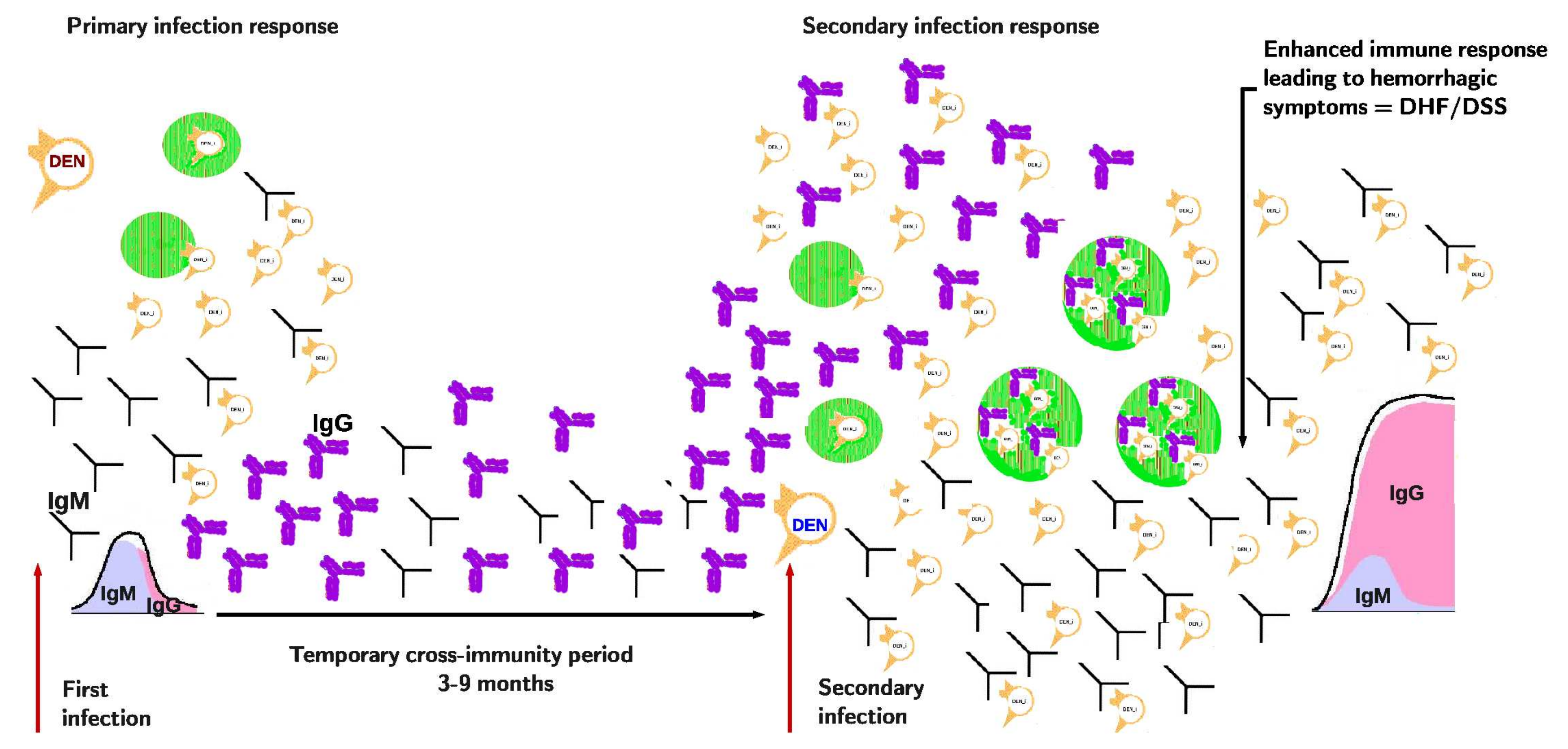
Dengue fever epidemiology

ADE in recurrent infections



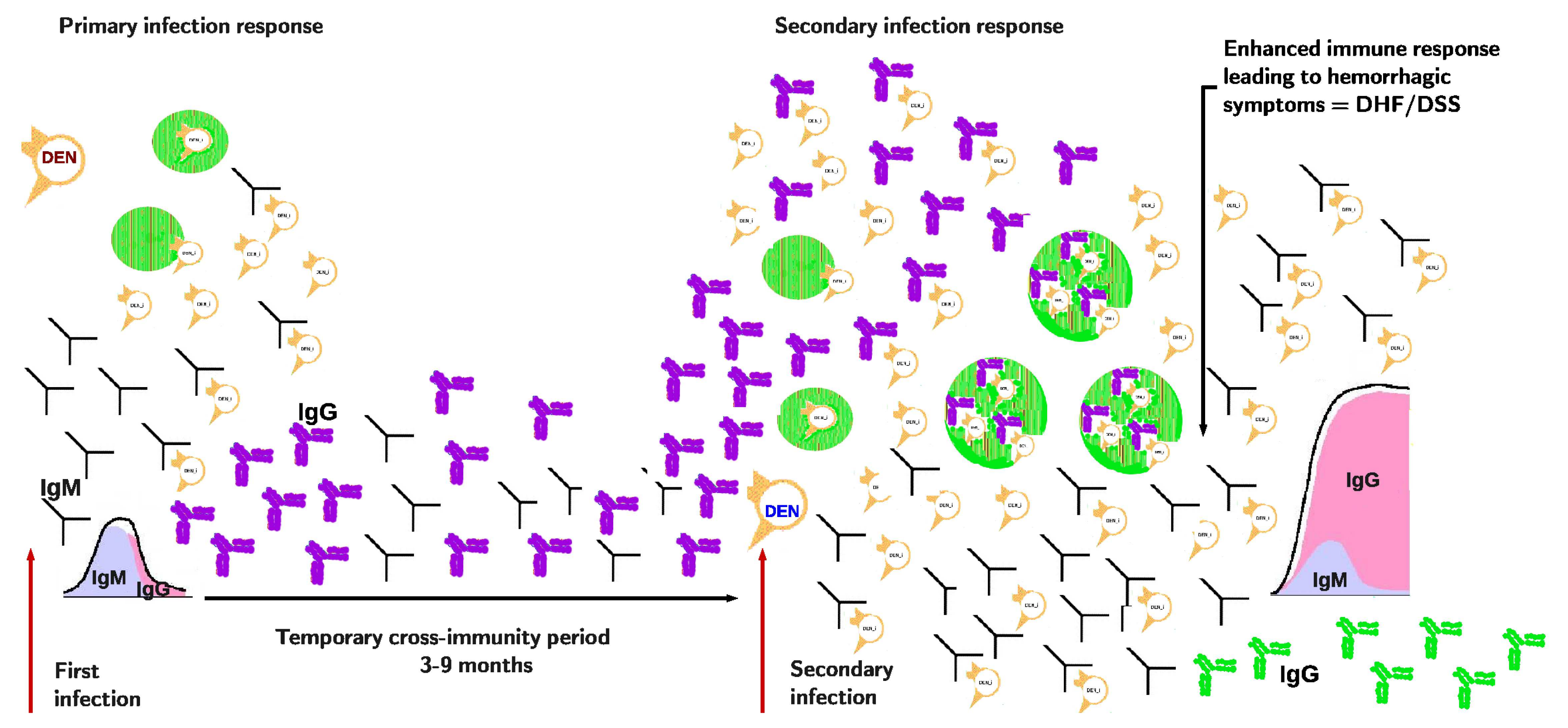
Dengue fever epidemiology

ADE in recurrent infections



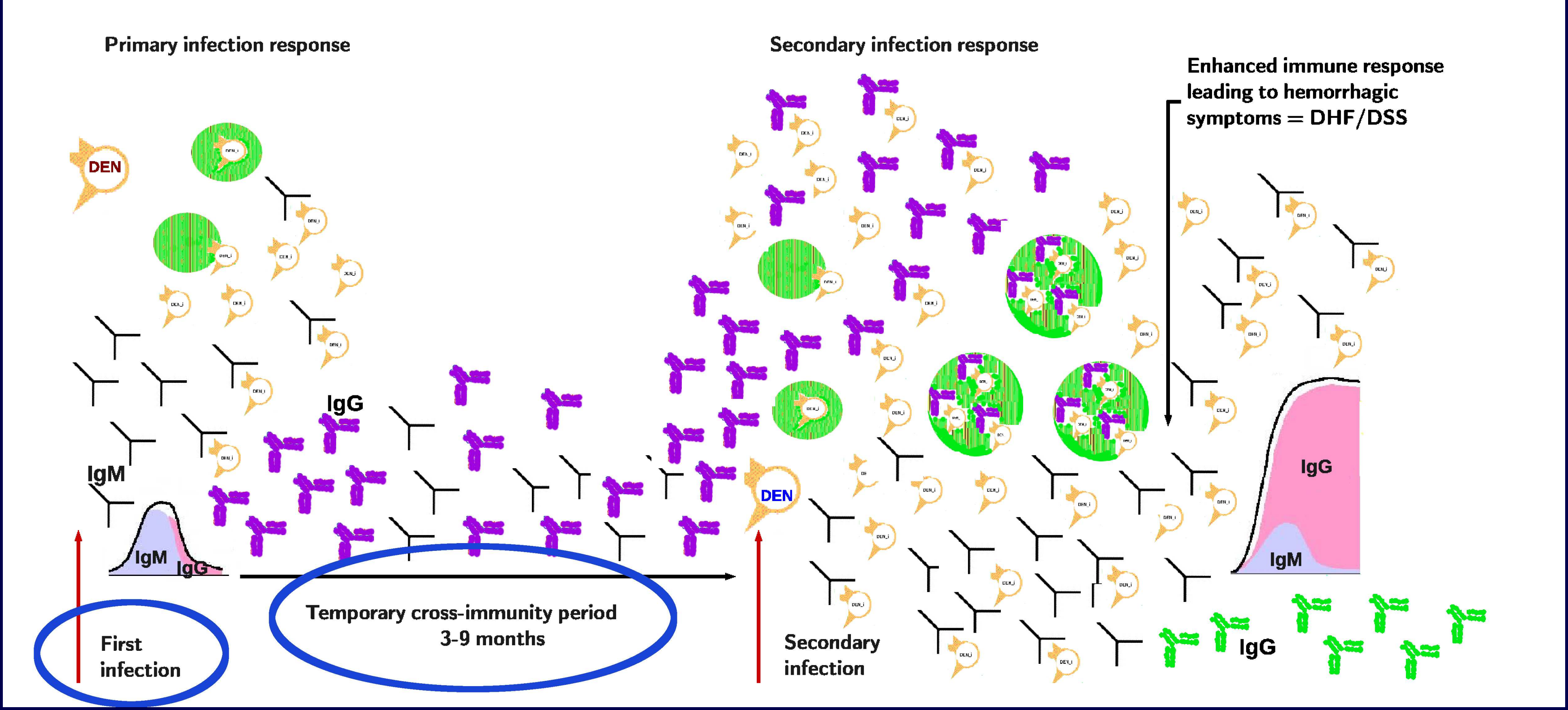
Dengue fever epidemiology

ADE in recurrent infections



Dengue fever epidemiology

ADE in recurrent infections



Primary infection response

Secondary infection response

Enhanced immune response
leading to hemorrhagic
symptoms = DHF/DSS

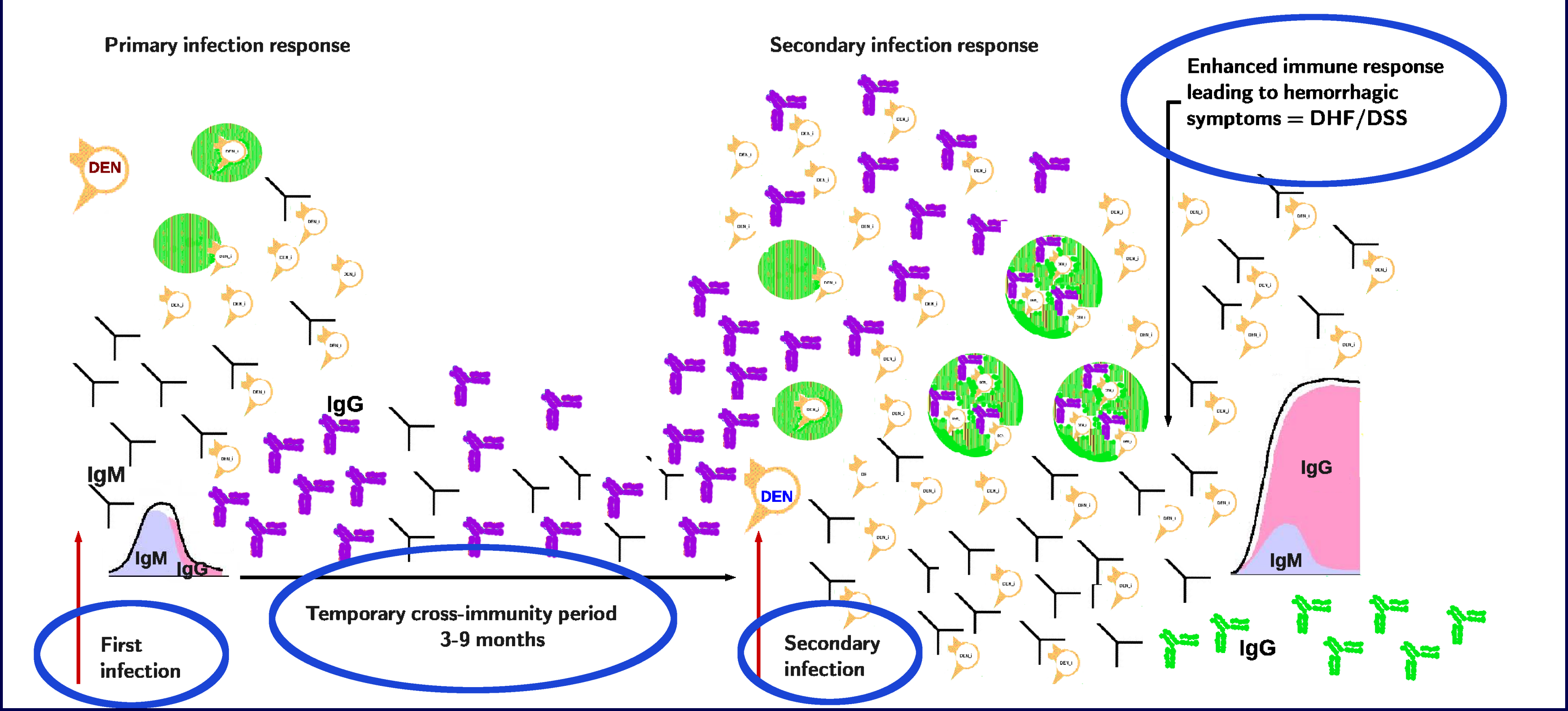
Temporary cross-immunity period
3-9 months

First
infection

Secondary
infection

Dengue fever epidemiology

ADE in recurrent infections



Primary infection response

Secondary infection response

Enhanced immune response leading to hemorrhagic symptoms = DHF/DSS

First infection

Temporary cross-immunity period
3-9 months

Secondary infection

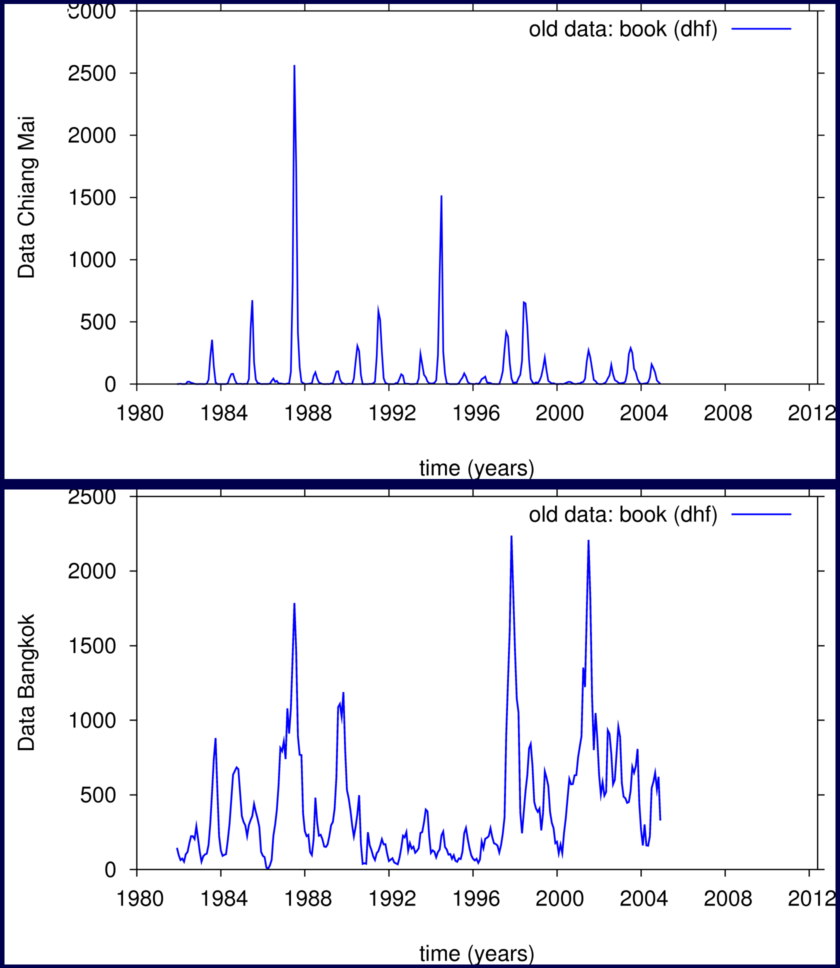
Dengue fever epidemiology

- *It is suggested that the majority of secondary dengue infections occur at a spacing of more than 6 month.*

- *There is no specific treatment for DF, and DHF cases require hospitalization.*

- *A vaccine is not yet available. Some of the candidates are in different stages of trials but so far, prevention of exposure remains the only alternative to prevent dengue transmission.*

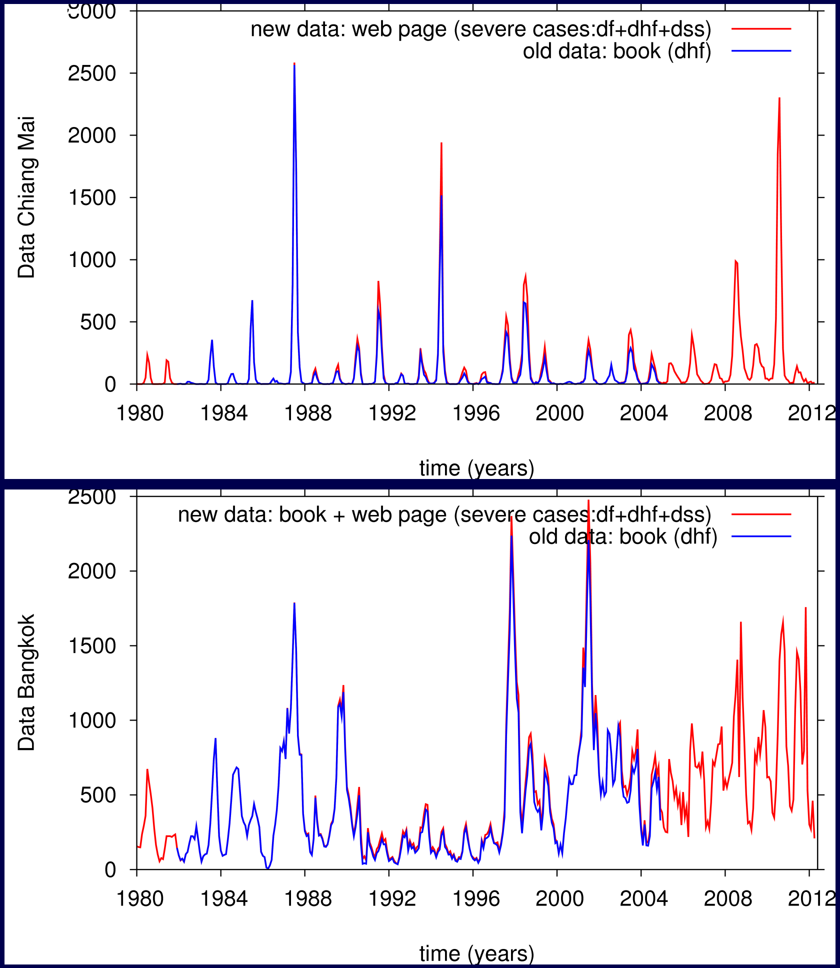
Dengue fever notification data in Thailand



Source: Ministry of Public Health, Thailand. Bureau of Epidemiology (2012)

Note the yearly fluctuations.

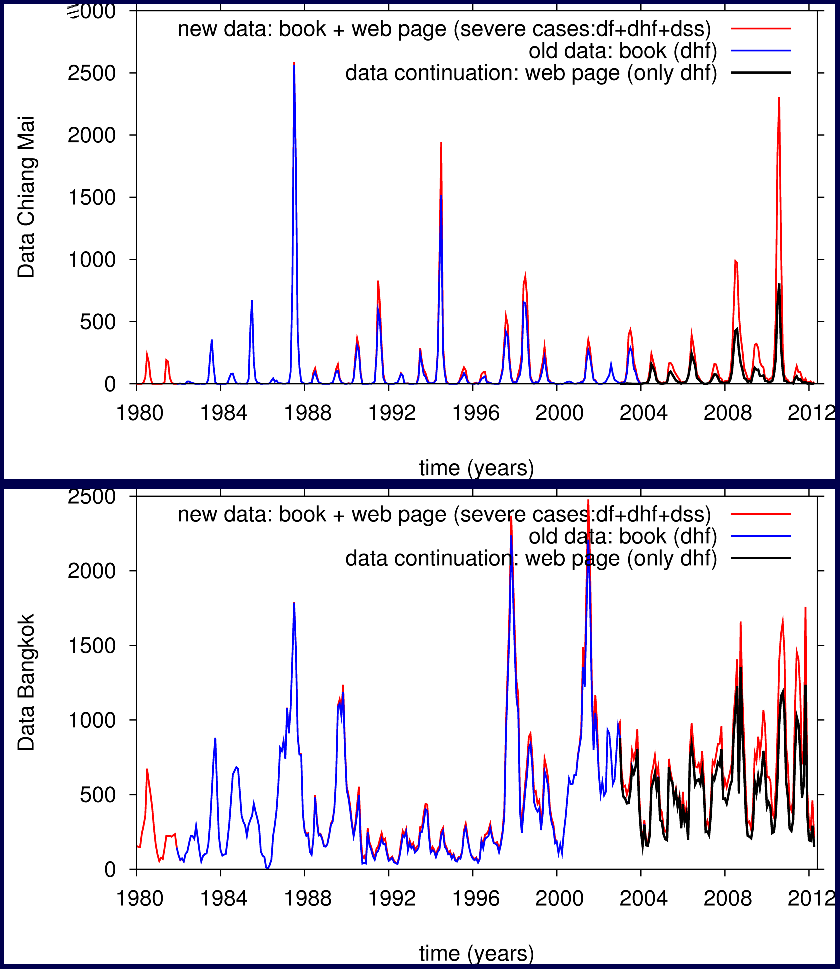
Dengue fever notification data in Thailand



DENFREE EU project under FP7:

Dengue Research Framework for Resisting Epidemics in Europe

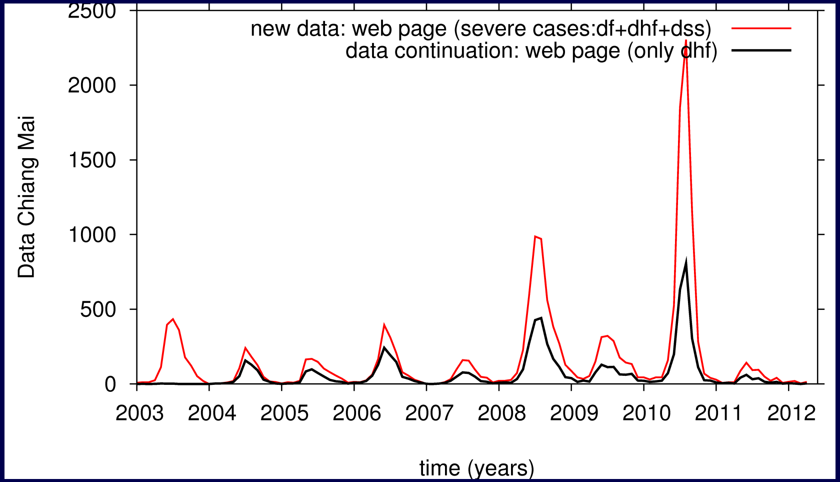
Dengue fever notification data in Thailand

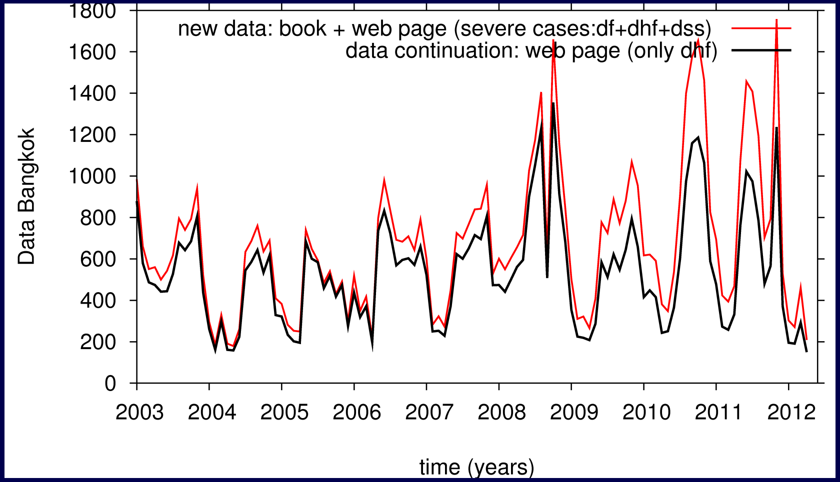


DENFREE EU project under FP7:

The continuation of the data does not match!

Dengue fever notification data in Thailand





DENFREE EU project under FP7:

Official data is the sum up of “severe cases” (DF+DHF+DSS)!

Modeling dengue fever epidemiology

β - *Infection rate*

ϕ- *Second. infection contribution to the force of infection (ADE ratio)*

α- *Cross-immunity period*

γ- *Recovery rate*

μ- *Demographic rate*

Modeling dengue fever epidemiology

The n-strain epidemiological model

$$\dot{S} = \mu\left(N - S\right) - \sum_{i=1}^{n} \frac{\beta}{N} S \left(I_i + \rho \cdot N + \phi \left(\sum_{j=1, j\neq i}^{n} I_{ji} \right) \right)$$

and for $i = 1, ..., n$

$$\dot{I}_i = \frac{\beta}{N} \left(I_i + \rho \cdot N + \phi \left(\sum_{j=1, j\neq i}^{n} I_{ji} \right) \right) - \left(\gamma + \mu\right) I_i$$

$$\dot{R}_i = \gamma I_i - \left(\alpha + \mu\right) R_i$$

$$\dot{S}_i = \alpha R_i - \sum_{j=1, j\neq i}^{n} \frac{\beta}{N} S_i \left(I_j + \rho \cdot N + \phi \left(\sum_{k=1, k\neq j}^{n} I_{kj} \right) \right) - \mu S_i$$

and for $i = 1, ..., n$ and $j = 1, ..., n$ with $j \neq i$

$$\dot{I}_{ij} = \frac{\beta}{N} S_i \left(I_j + \rho \cdot N + \phi \left(\sum_{k=1, k\neq j}^{n} I_{kj} \right) \right) - \left(\gamma + \mu\right) I_{ij}$$

and finally

$$\dot{R} = \gamma \left(\sum_{i=1}^{n} \sum_{j=1, j\neq i}^{n} I_{ij} \right) - \mu R$$

Modeling dengue fever epidemiology

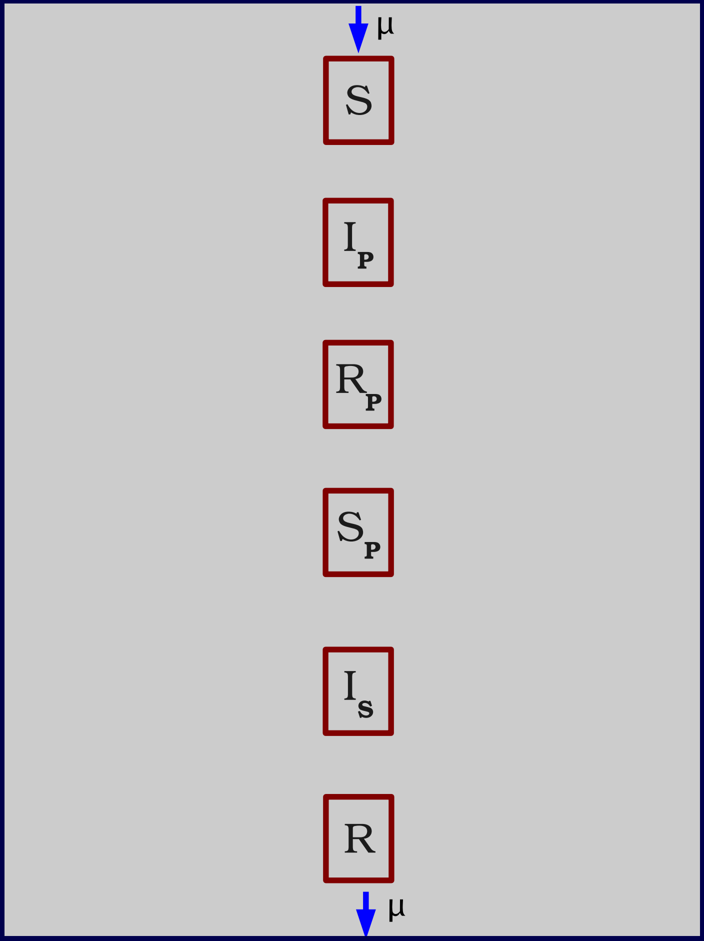
The n-strain epidemiological model can be written as:

- ⋇ *One-strain epidemiological model, an Eq. system with* 6 ***ODE's***
- ⋇ *One-strain epidemiological + vector, an Eq. system with* 8 ***ODE's***
- ⋇ *Two-strain epidemiological model, an Eq. system with* 10 ***ODE's***
- ⋇ *Four-strain epidemiological model, an Eq. system with* 26 ***ODE's***

Modeling dengue fever epidemiology

The two-infections model

without strain structure of the pathogens



Modeling dengue fever epidemiology

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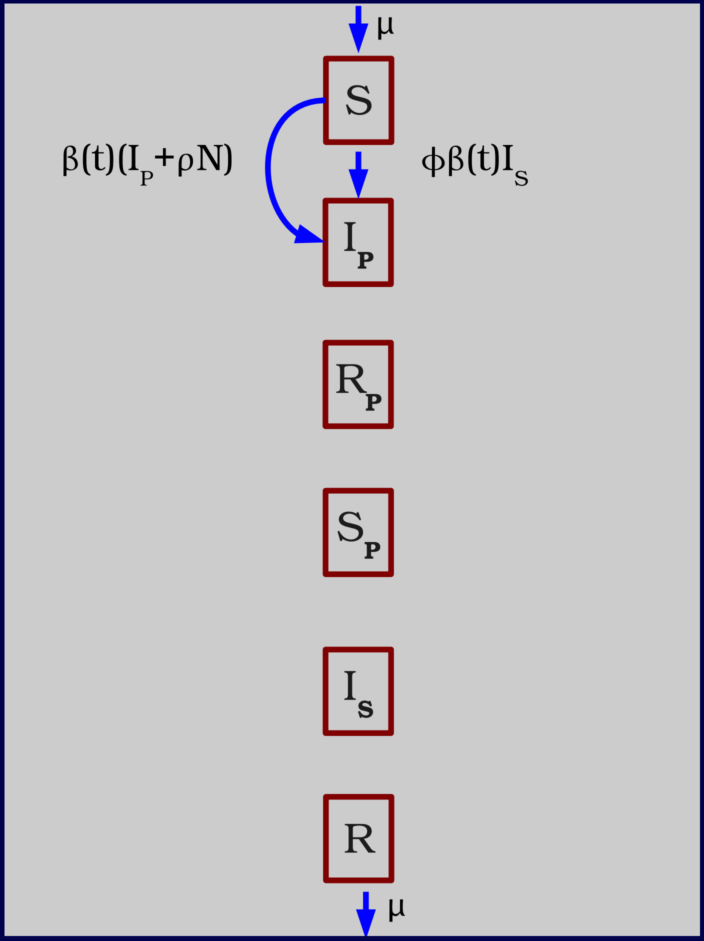

Modeling dengue fever epidemiology

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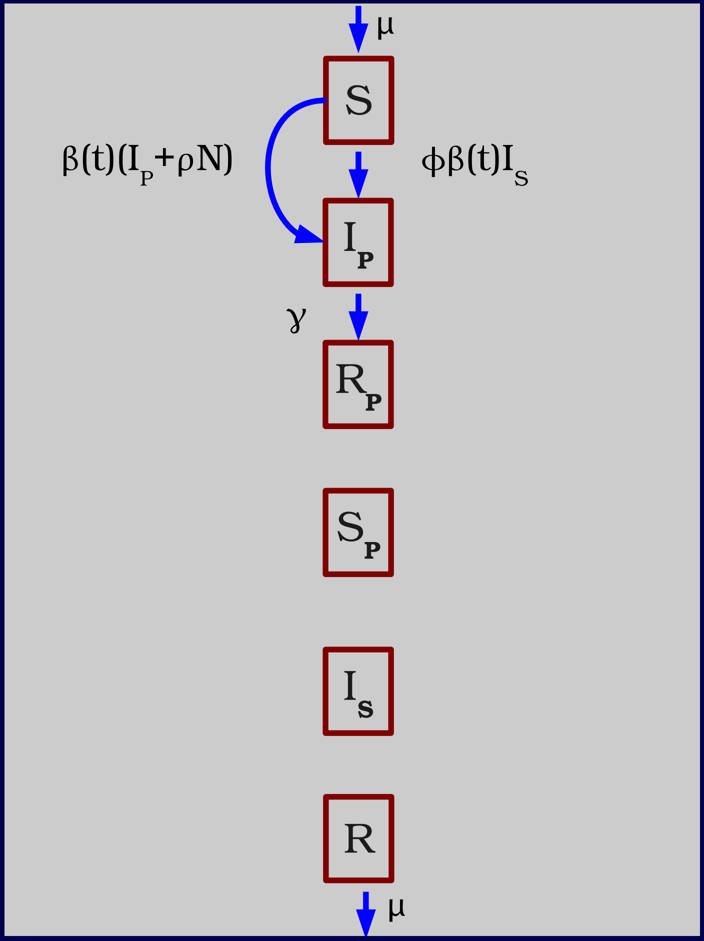

Modeling dengue fever epidemiology

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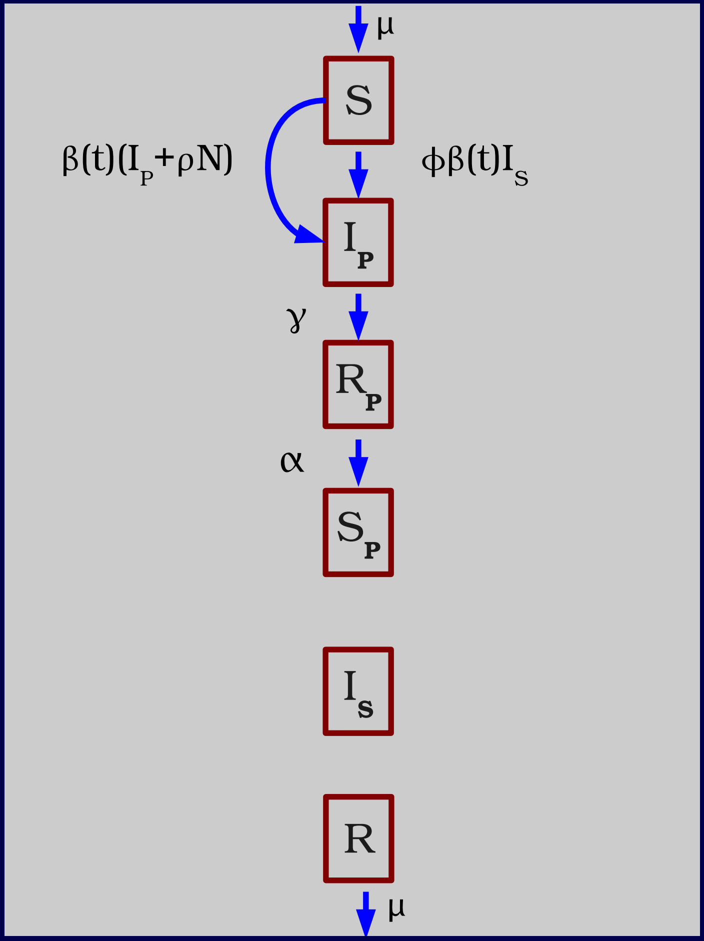

Modeling dengue fever epidemiology

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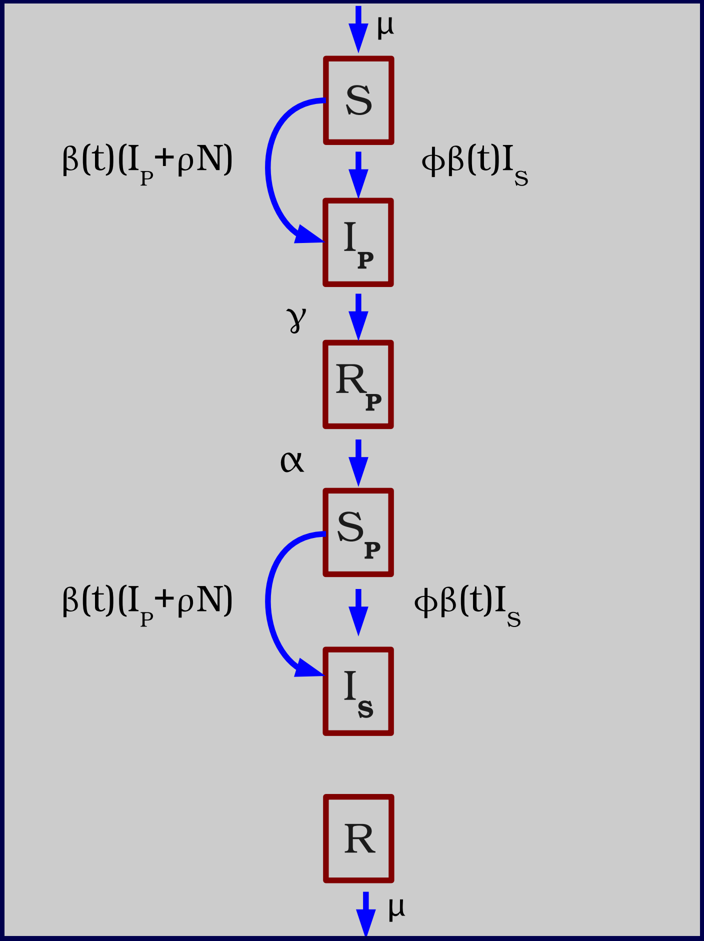

Modeling dengue fever epidemiology

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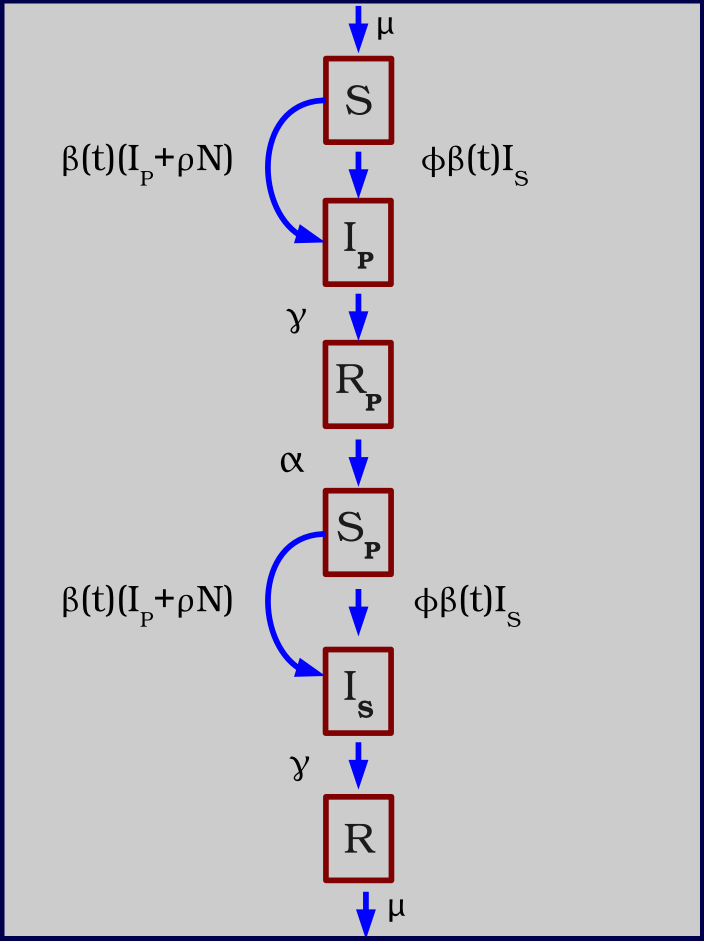


Modeling dengue fever epidemiology

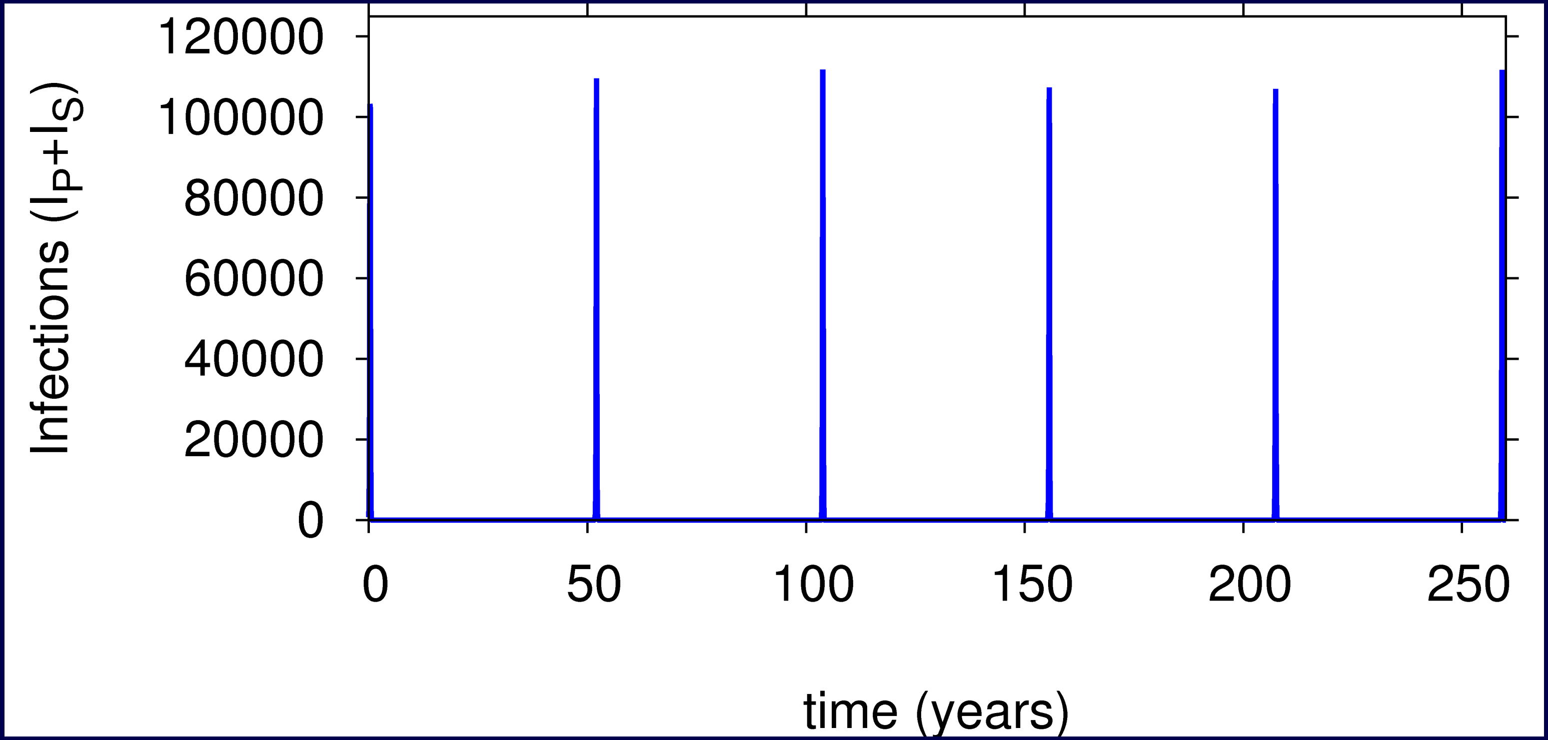
The two-infections model without strain structure of the pathogens

$$
\begin{aligned}
\dot{S} &= -\frac{\beta(t)}{N} S(I_P + \rho \cdot N + \phi I_S) + \mu(N - S) \\
\dot{I}_P &= \frac{\beta(t)}{N} S(I_P + \rho \cdot N + \phi I_S) - (\gamma + \mu) I_P \\
\dot{R}_P &= \gamma I_P - (\alpha + \mu) R_P \\
\dot{S}_P &= -\frac{\beta(t)}{N} S_P(I_P + \rho \cdot N + \phi I_S) + R_P \alpha - S_P \mu \\
\dot{I}_S &= \frac{\beta(t)}{N} S_P(I_P + \rho \cdot N + \phi I_S) - (\gamma + \mu) I_S \\
\dot{R} &= \gamma I_S - \mu R
\end{aligned}
\tag{1}
$$

Modeling dengue fever epidemiology

The two-infections model

without strain structure of the pathogens



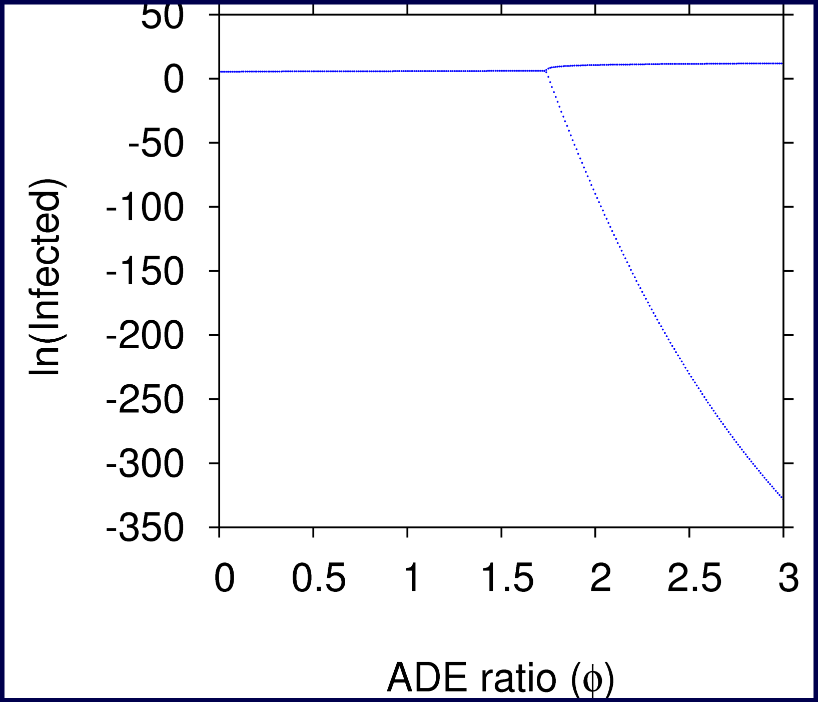
(ϕ=2.6) *Outbreaks every 50 years.*

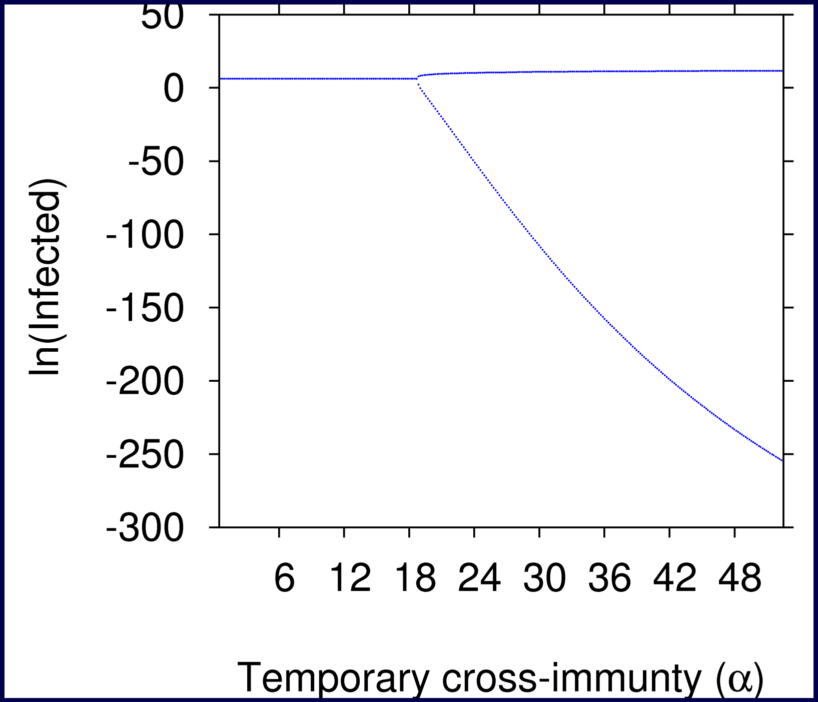
Modeling dengue fever epidemiology

The two-infections model

without strain structure of the pathogens

Bifurcation diagram for α and ϕ





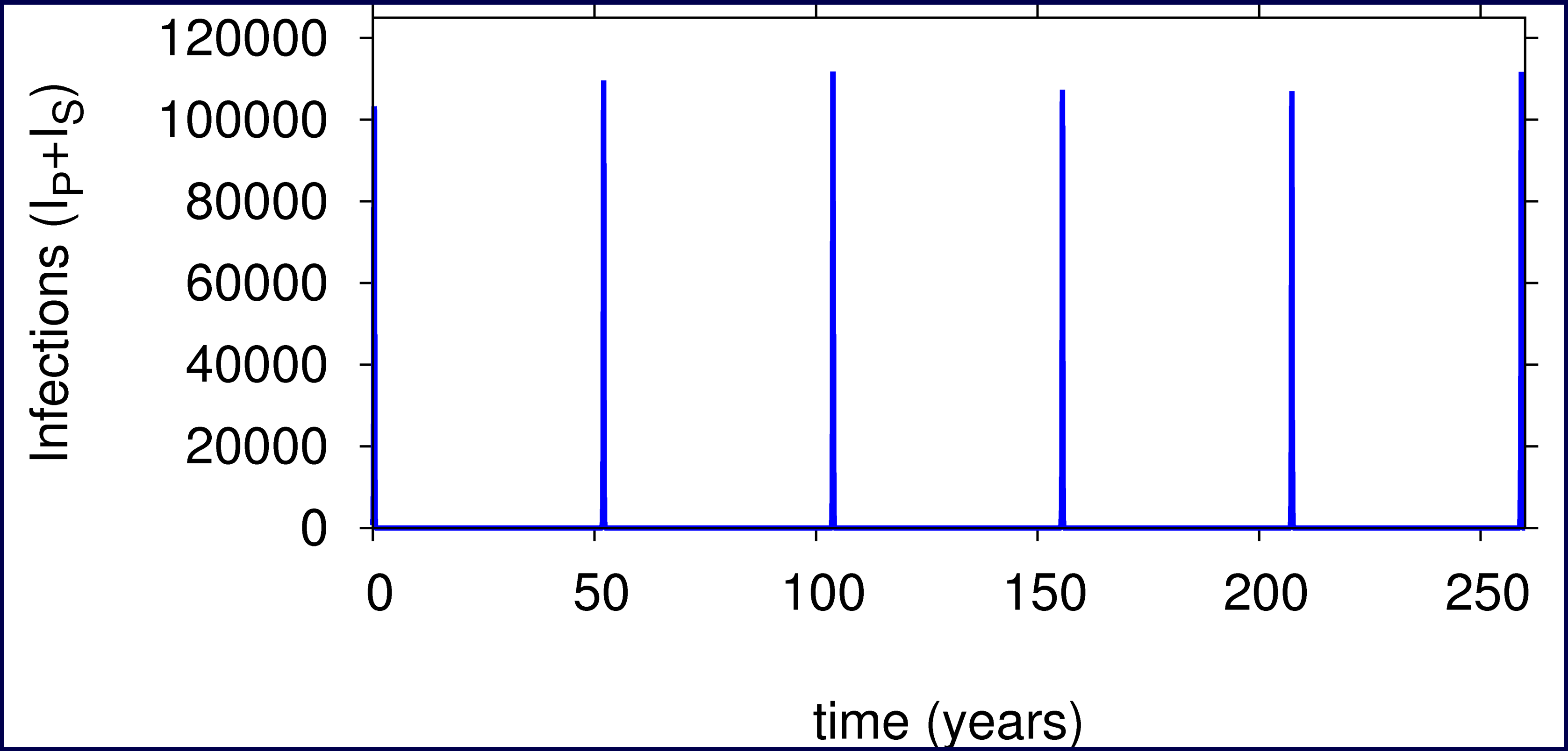
(α=1/one week)

(ϕ=2.6)

Modeling dengue fever epidemiology

The two-infections model

without strain structure of the pathogens



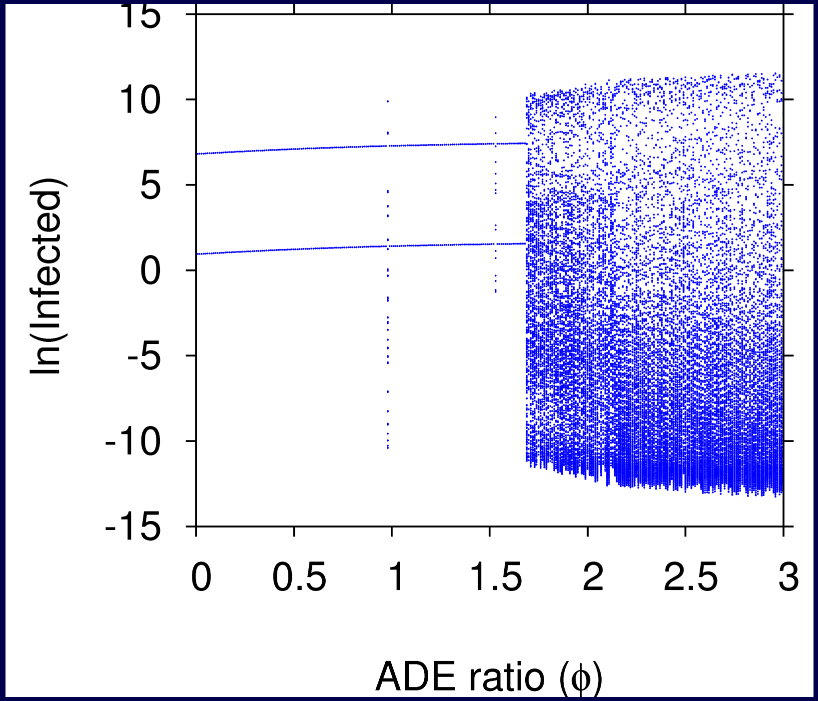
Outbreaks every 50 years.

Modeling dengue fever epidemiology

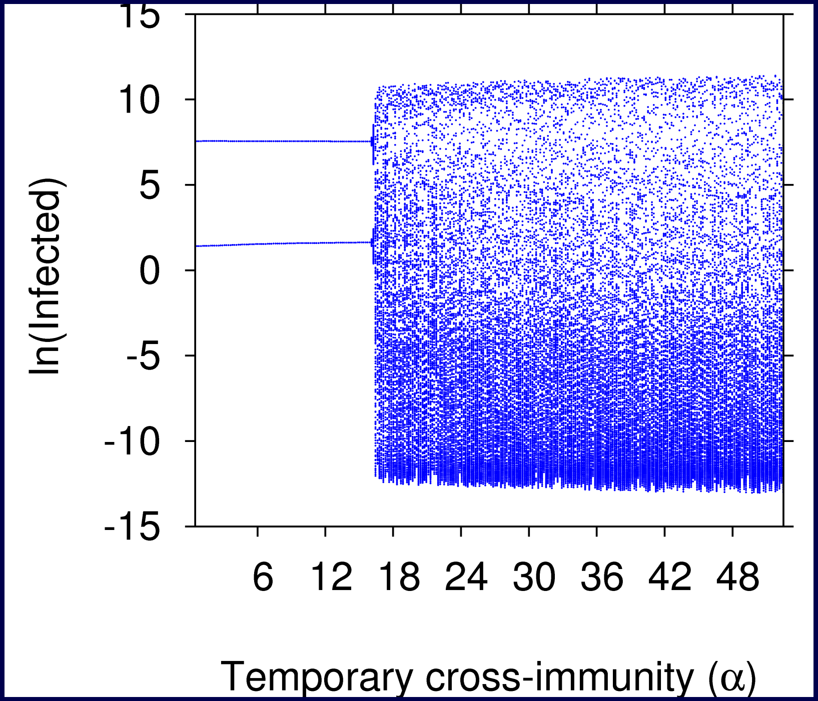
The two-infections model

without strain structure of the pathogens

Bifurcation diagram for α and ϕ



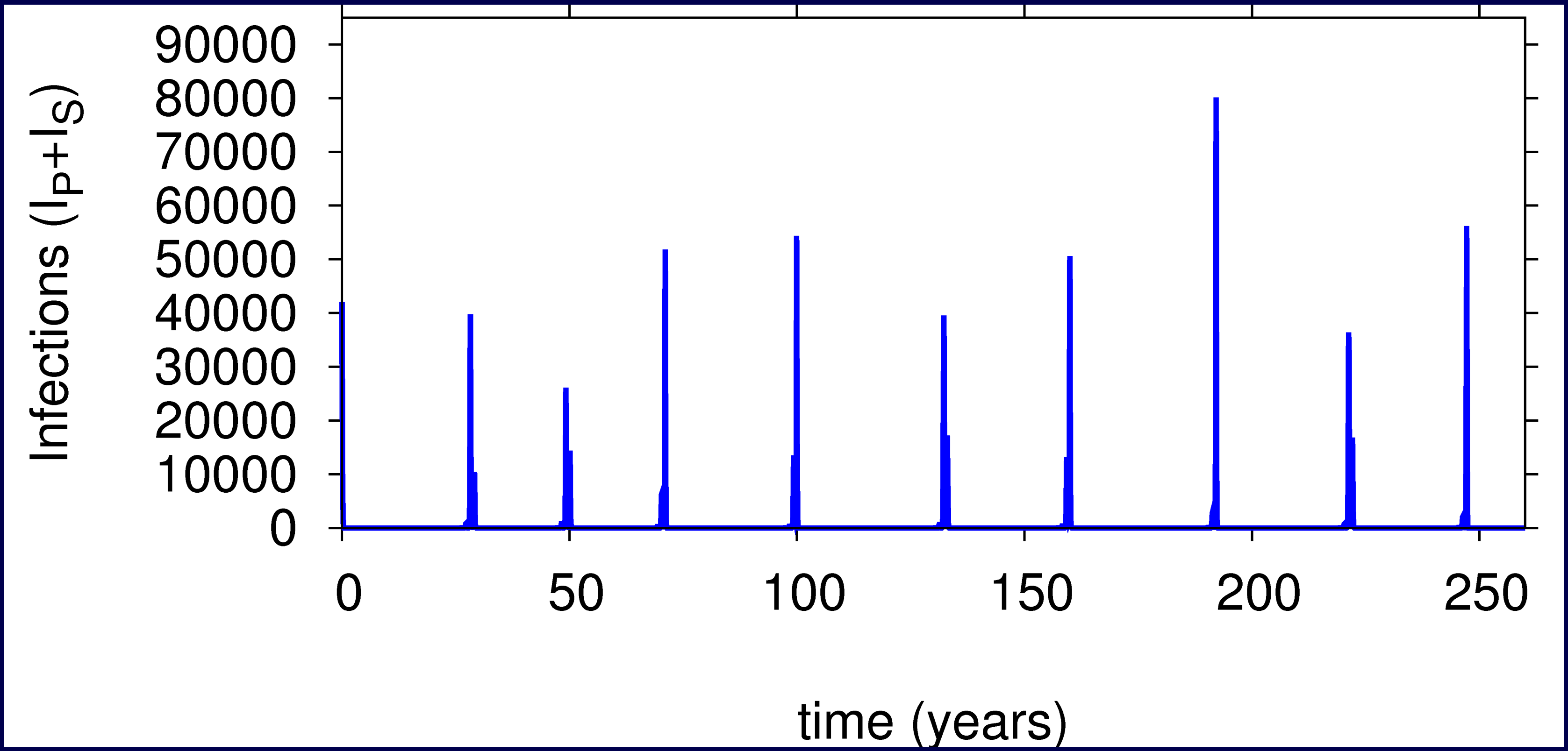
$(\alpha = 1/\text{one week})$



$(\phi = 2.6\ )$

Modeling dengue fever epidemiology

The two-infections model
without strain structure of the pathogens

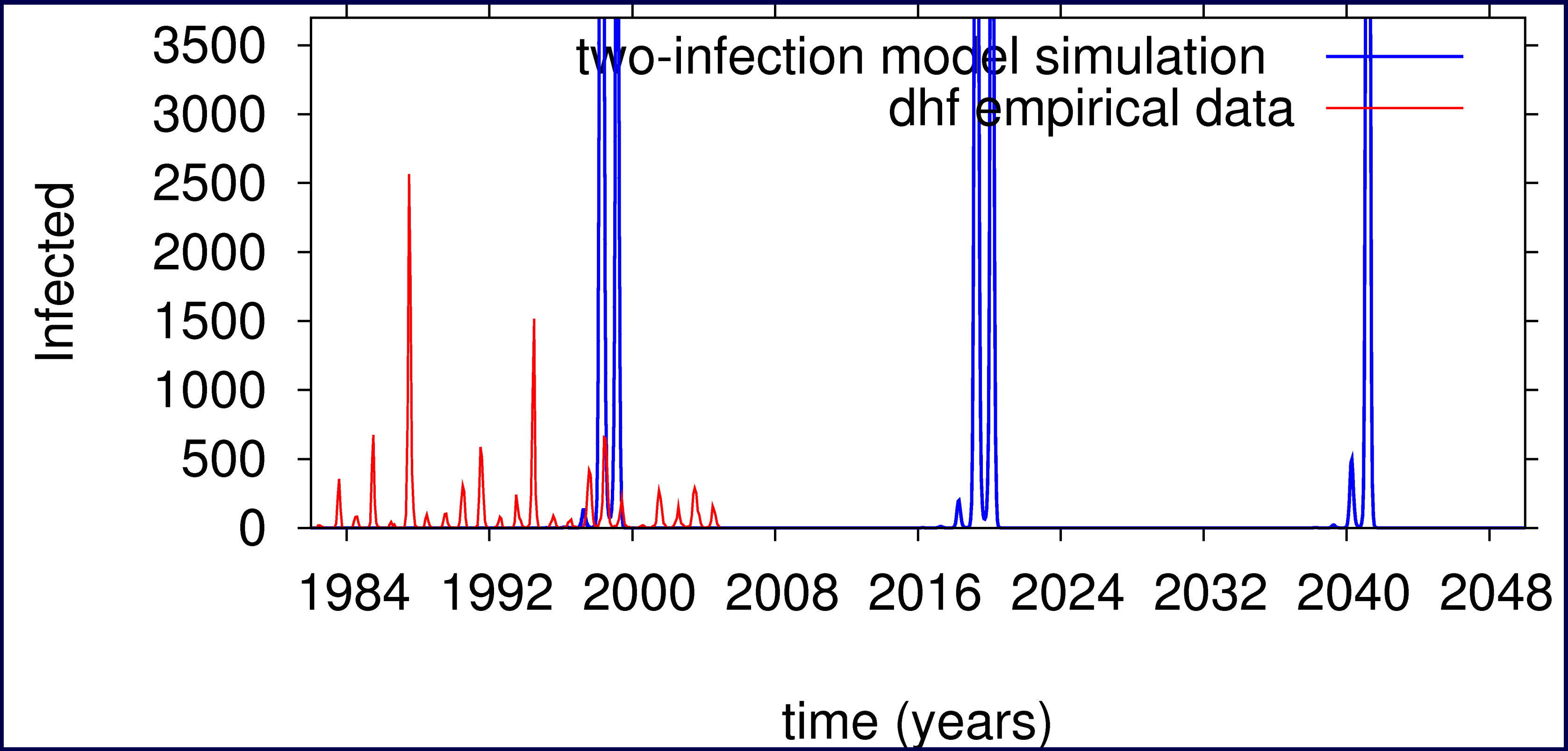


Irregular outbreaks every 25 years...

Modeling dengue fever epidemiology

The two-infections model

without strain structure of the pathogens

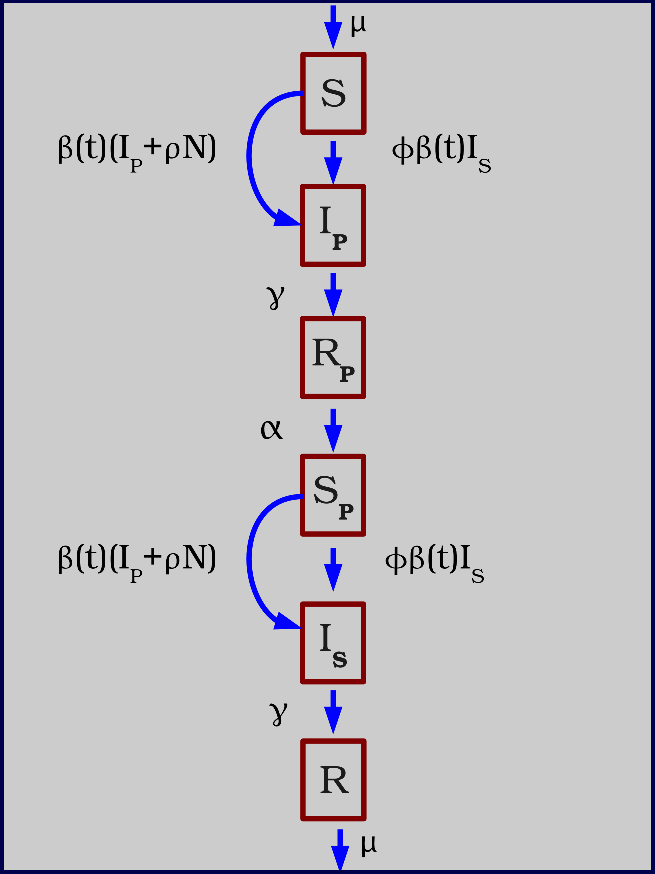


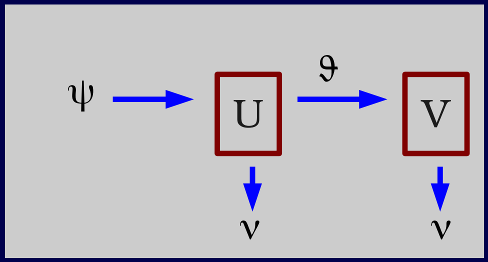
... and not data alike.

Modeling dengue fever epidemiology

The two-infections model

without strain structure of the pathogens





Modeling dengue fever epidemiology

The two-infections model
without strain structure of the pathogens

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\begin{aligned}
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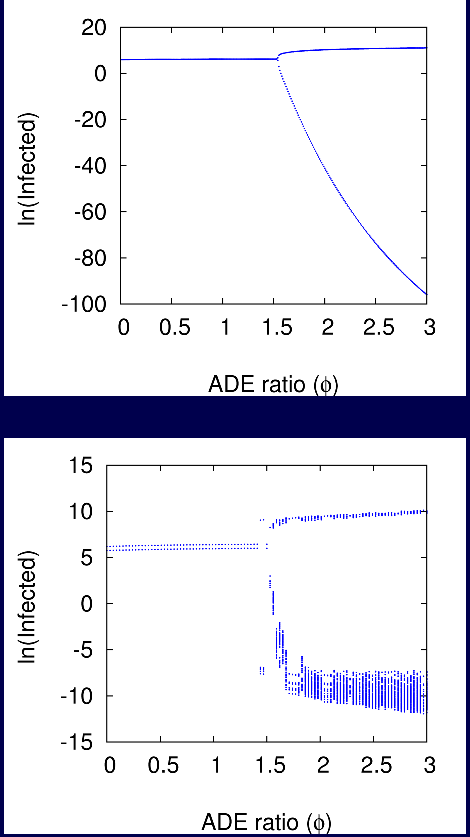
\dot{I}_P &= \frac{\beta}{M_0} S V - (\gamma + \mu) I_P \\
\dot{R}_P &= \gamma I_P - (\alpha + \mu) R_P \\
\dot{S}_P &= -\frac{\beta}{M_0} S_P V + R_P \alpha - S_P \mu \\
\dot{I}_S &= \frac{\beta}{M_0} S_P V - (\gamma + \mu) I_S \\
\dot{R} &= \gamma I_S - \mu R \\
\dot{U} &= \psi - \frac{\theta}{N} (M(t) - V)(I_P + \rho \cdot N + \phi I_S) - \nu U \\
\dot{V} &= \frac{\theta}{N} (M(t) - V)(I_P + \rho \cdot N + \phi I_S) - \nu V
\end{aligned}
\tag{2}
$$

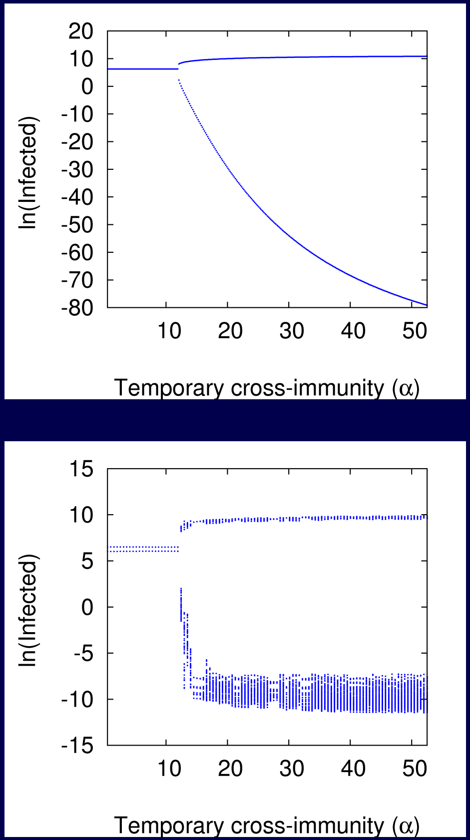
Modeling dengue fever epidemiology

The two-infections model
without strain structure of the pathogens

Bifurcation diagram for α and ϕ



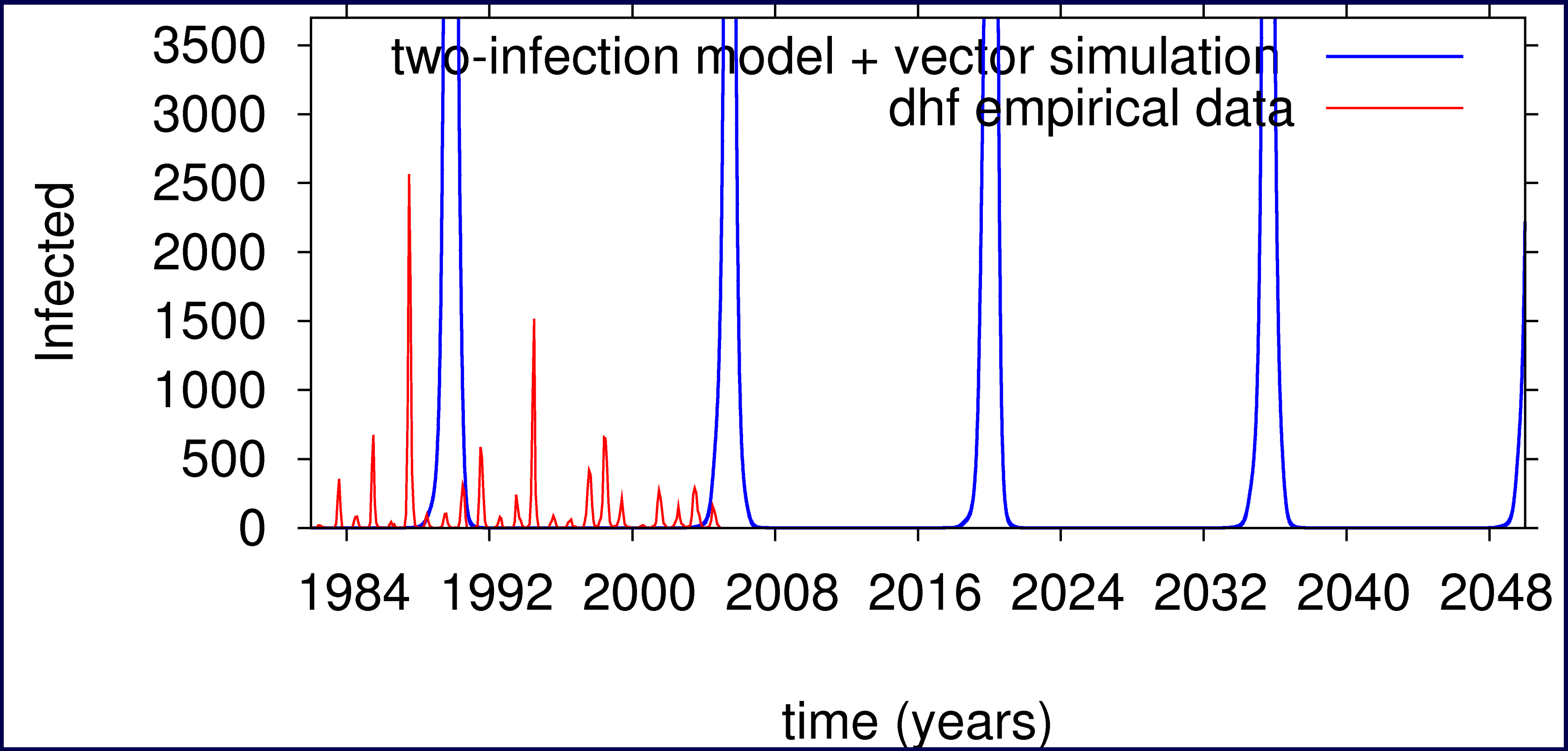
(α=1/one week)



(ϕ=2.6)

Modeling dengue fever epidemiology

The seasonal two-infections model without strain structure of the pathogens

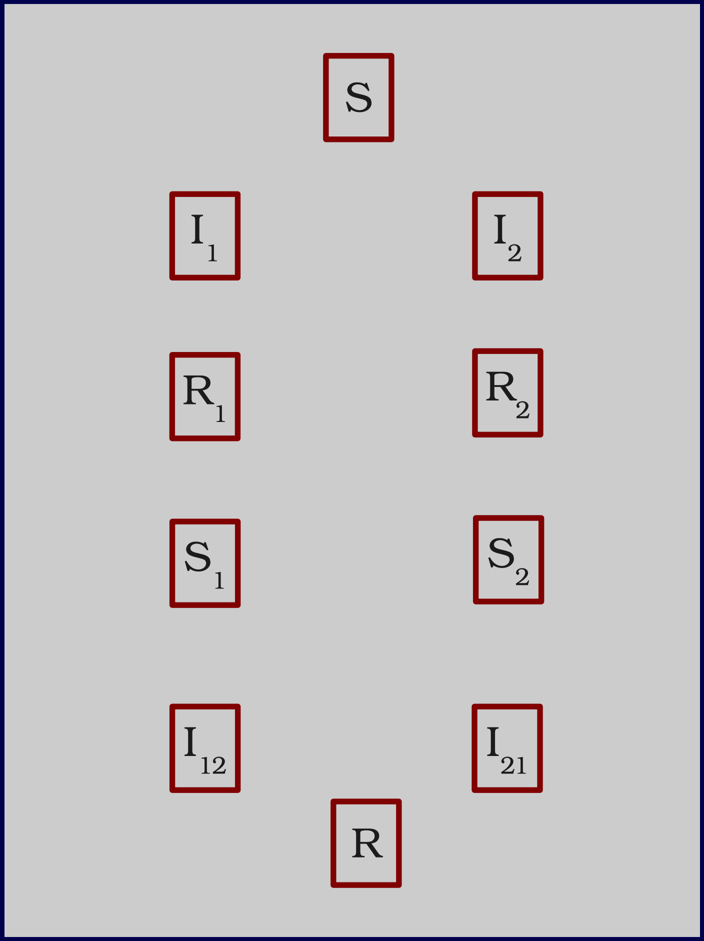


Also not data alike.

Modeling dengue fever epidemiology

The two-strain model

with strain structure of the pathogens



S

I_1 I_2

R_1 R_2

S_1 S_2

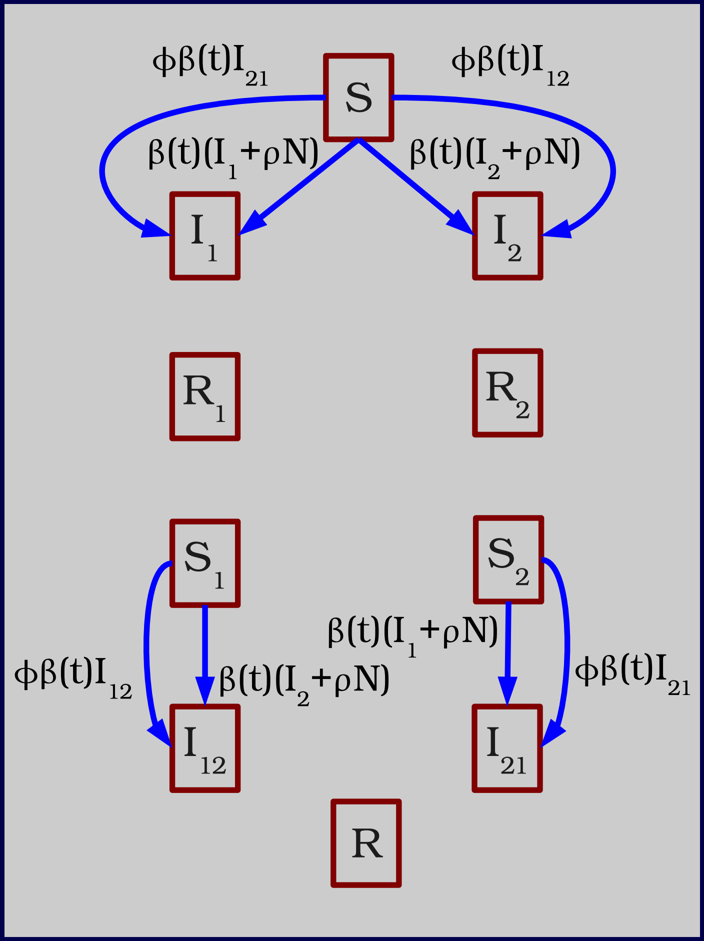
I_{12} I_{21}

R

Modeling dengue fever epidemiology

The two-strain model

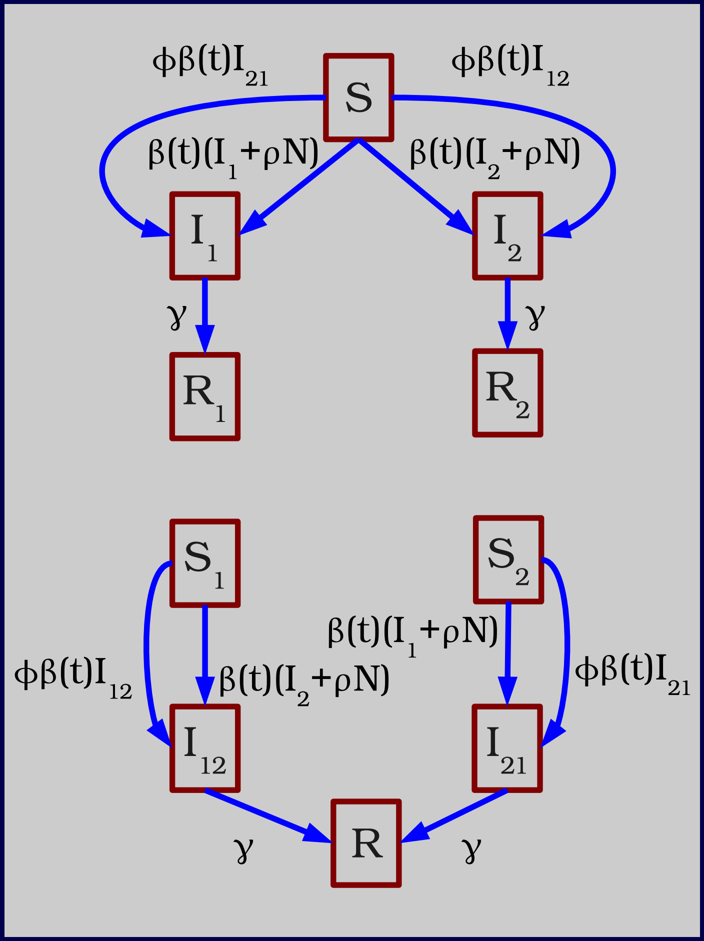
with strain structure of the pathogens



Modeling dengue fever epidemiology

The two-strain model

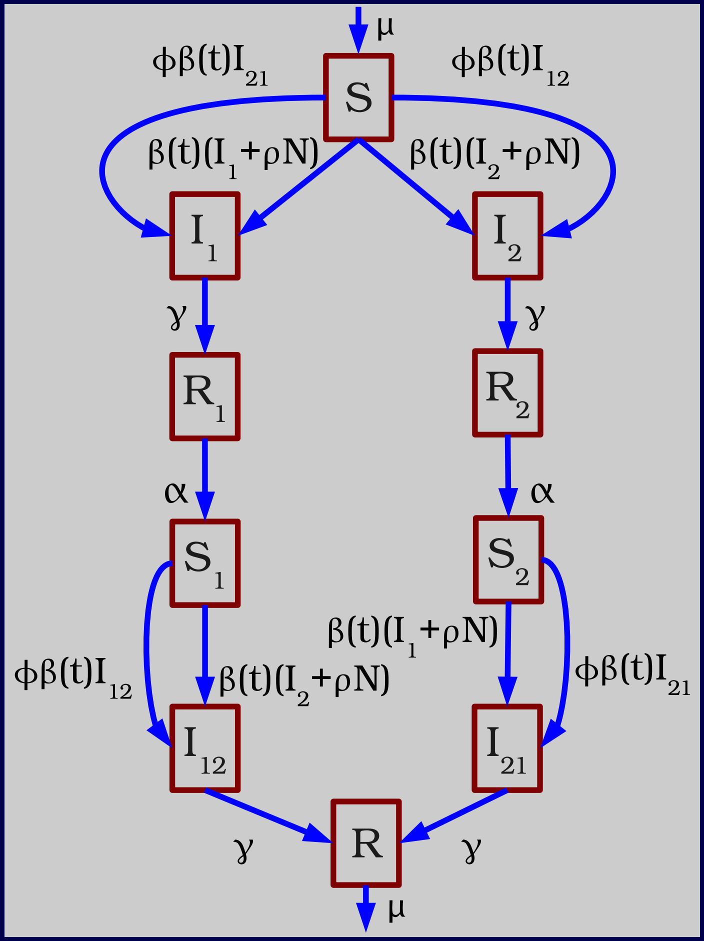
with strain structure of the pathogens



Modeling dengue fever epidemiology

The two-strain model

with strain structure of the pathogens



Modeling dengue fever epidemiology

The two-strain model

with strain structure of the pathogens

$$\dot{S} = -\frac{\beta(t)}{N} S(I_1 + \rho \cdot N + \phi I_{21}) - \frac{\beta(t)}{N} S(I_2 + \rho \cdot N + \phi I_{12}) + \mu(N - S)$$

$$\dot{I}_1 = \frac{\beta(t)}{N} S(I_1 + \rho \cdot N + \phi I_{21}) - (\gamma + \mu) I_1$$

$$\dot{I}_2 = \frac{\beta(t)}{N} S(I_2 + \rho \cdot N + \phi I_{12}) - (\gamma + \mu) I_2$$

$$\dot{R}_1 = \gamma I_1 - (\alpha + \mu) R_1$$

$$\dot{R}_2 = \gamma I_2 - (\alpha + \mu) R_2$$

$$\dot{S}_1 = -\frac{\beta(t)}{N} S_1(I_2 + \rho \cdot N + \phi I_{12}) + \alpha R_1 - \mu S_1$$

$$\dot{S}_2 = -\frac{\beta(t)}{N} S_2(I_1 + \rho \cdot N + \phi I_{21}) + \alpha R_2 - \mu S_2$$

$$\dot{I}_{12} = \frac{\beta(t)}{N} S_1(I_2 + \rho \cdot N + \phi I_{12}) - (\gamma + \mu) I_{12}$$

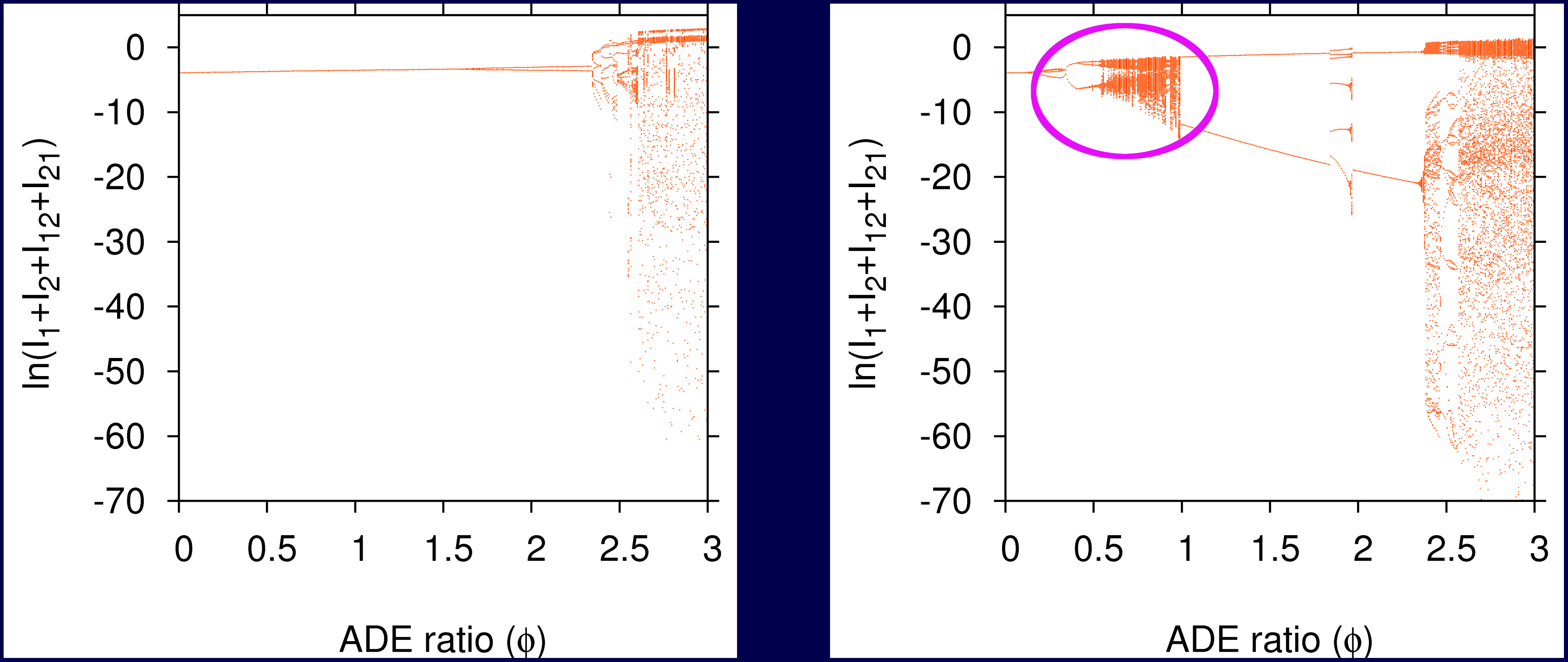
$$\dot{I}_{21} = \frac{\beta(t)}{N} S_2(I_1 + \rho \cdot N + \phi I_{21}) - (\gamma + \mu) I_{21}$$

$$\dot{R} = \gamma(I_{12} + I_{21}) - \mu R$$

Modeling dengue fever epidemiology

The two-strain model

with strain structure of the pathogens



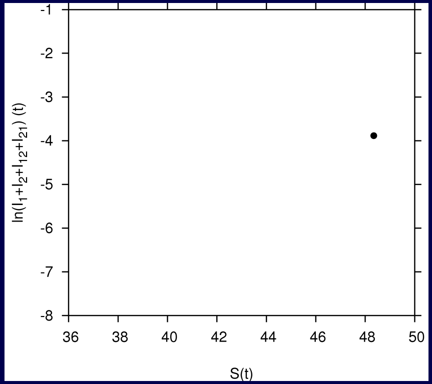
(α=1/one week) *(α=1/6 months)*

New chaotic window for $\phi < 1$!

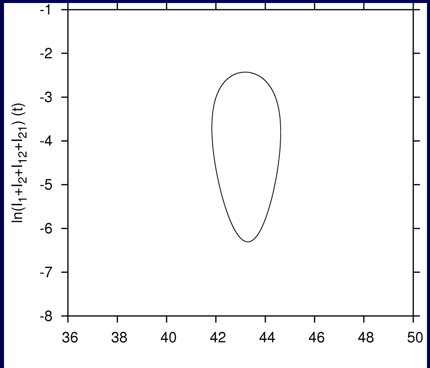
More realistic due to hospitalization of the severe cases.

Modeling dengue fever epidemiology

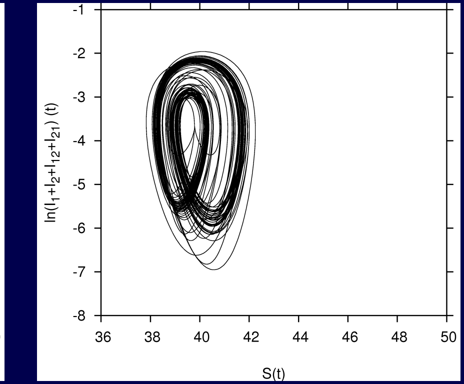
The two-strain model
with strain structure of the pathogens



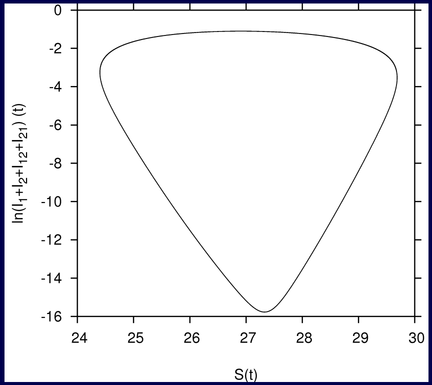
$\phi = 0.1$



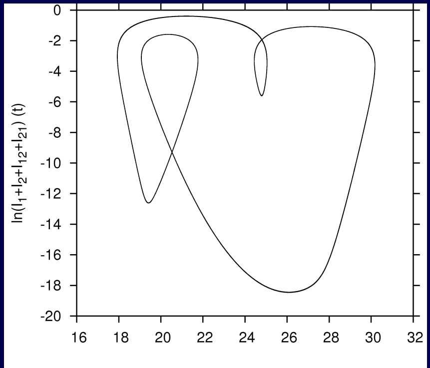
$\phi = 0.4$



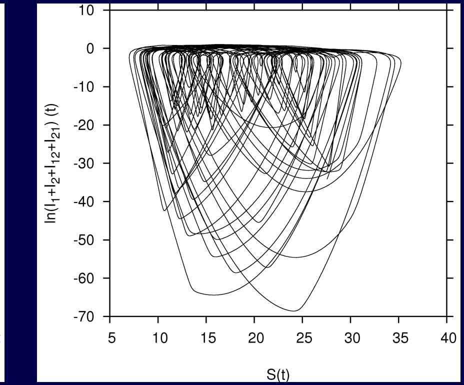
$\phi = 0.6$



$\phi = 1.5$



$\phi = 1.9$

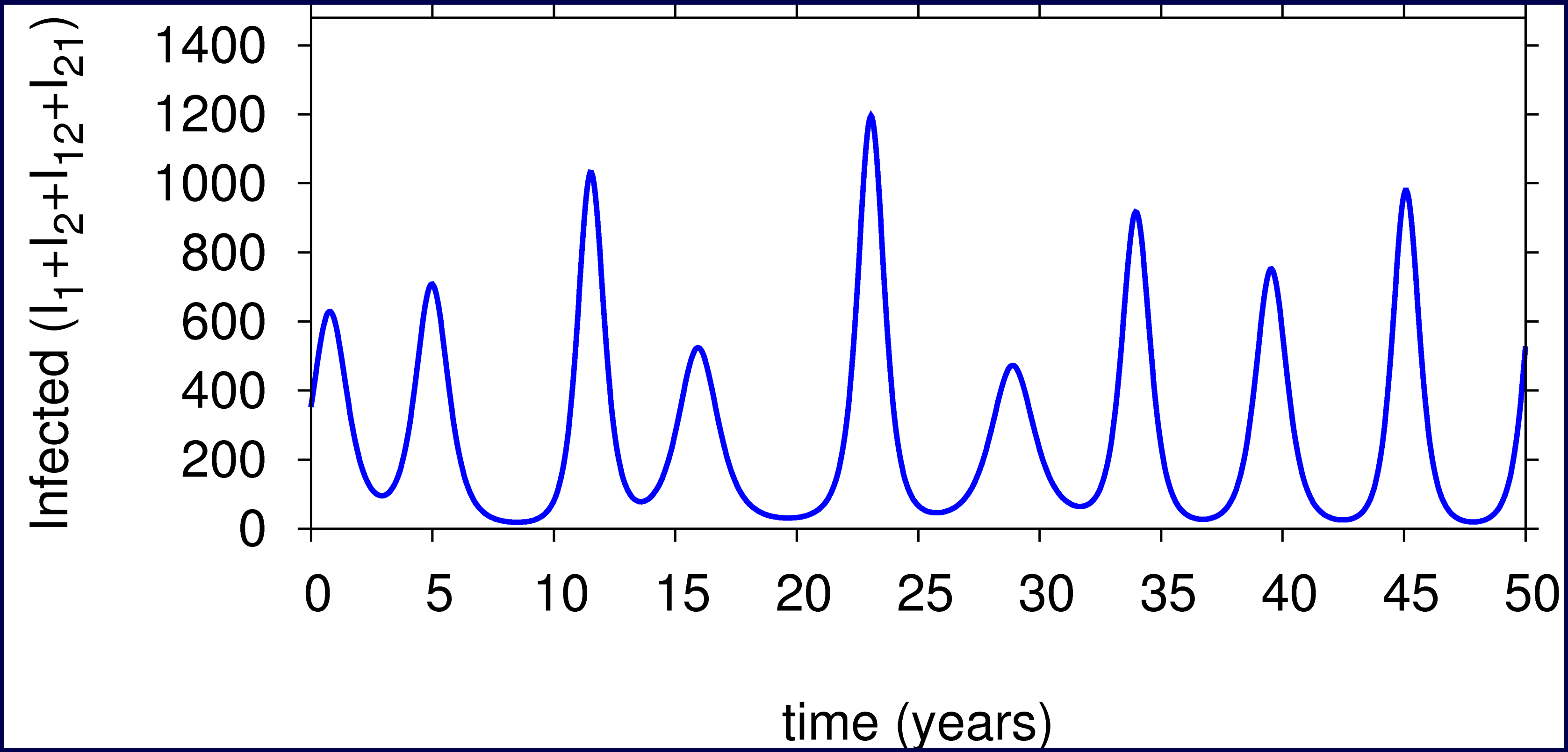


$\phi = 2.7$

Modeling dengue fever epidemiology

The two-strain model

with strain structure of the pathogens

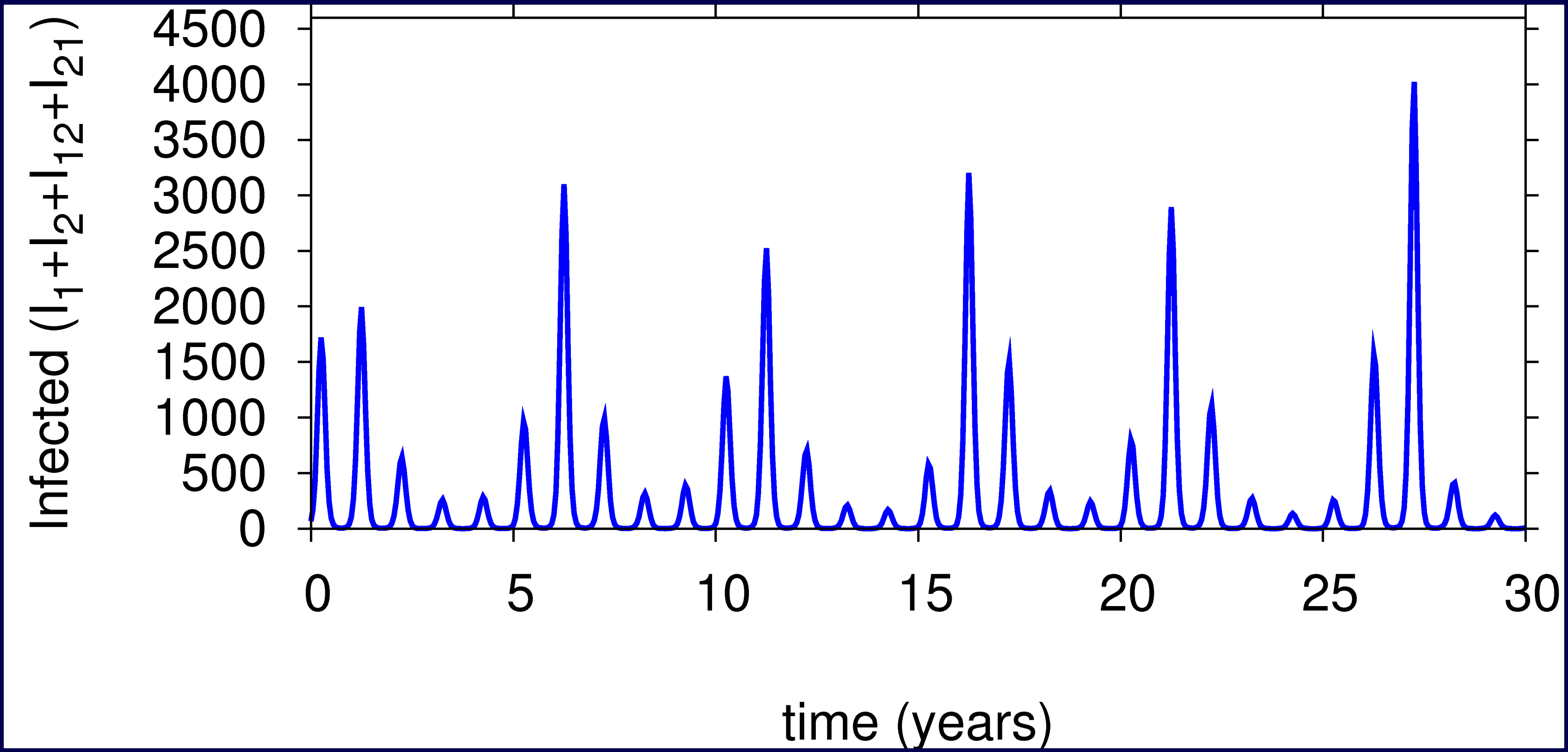


Irregular pattern every 5 years.

Modeling dengue fever epidemiology

The seasonal two-strain model

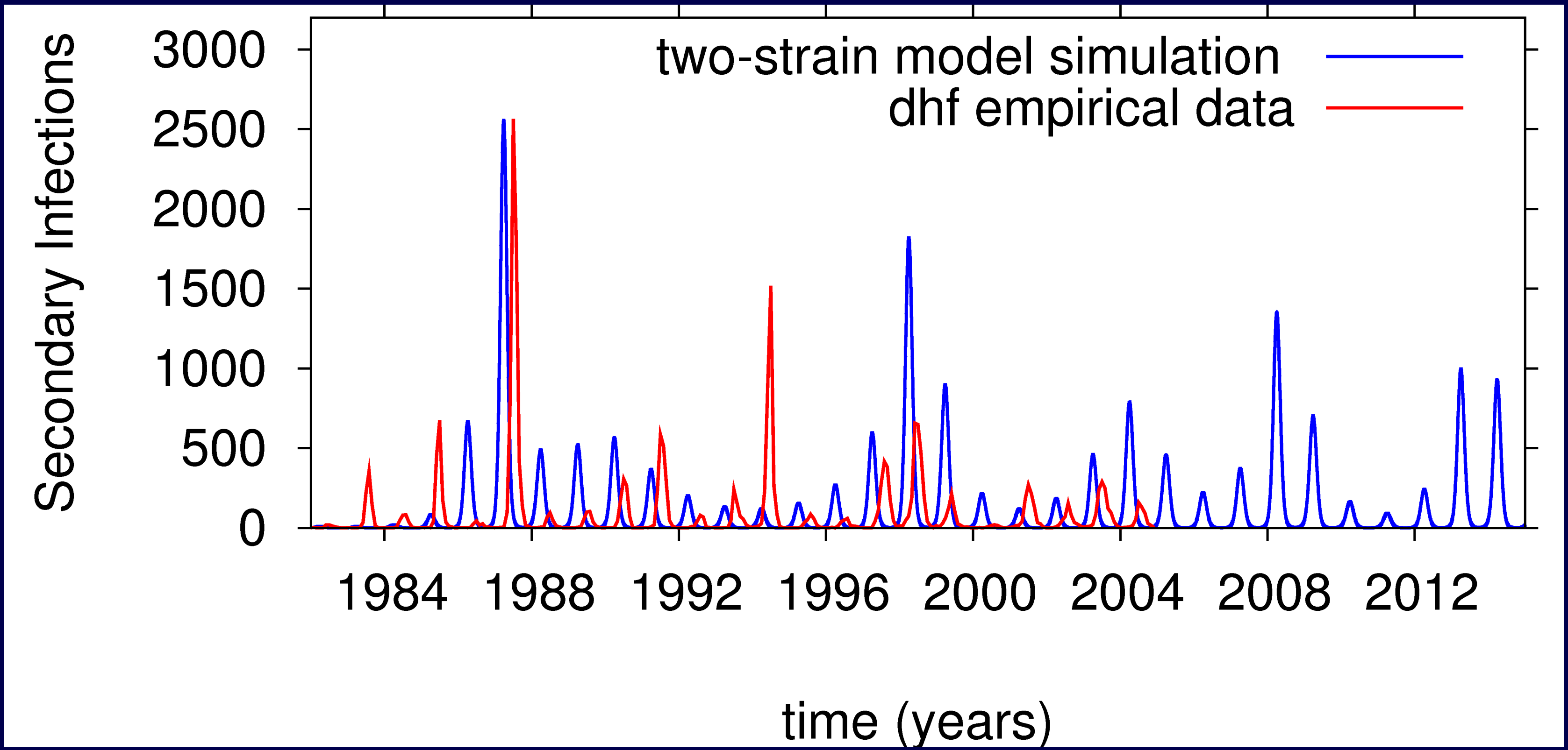
with strain structure of the pathogens



Realistic pattern with irregular, yearly and smooth outbreaks.

Modeling dengue fever epidemiology

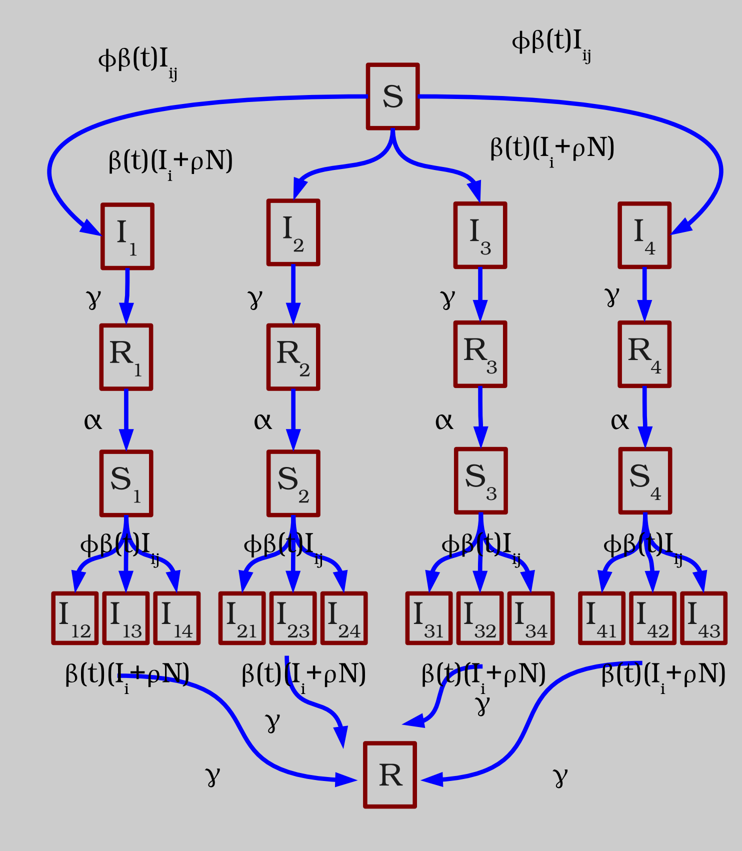
Implications for data analysis



Qualitatively a very good result when comparing empirical DHF data and model simulation.

Modeling dengue fever epidemiology

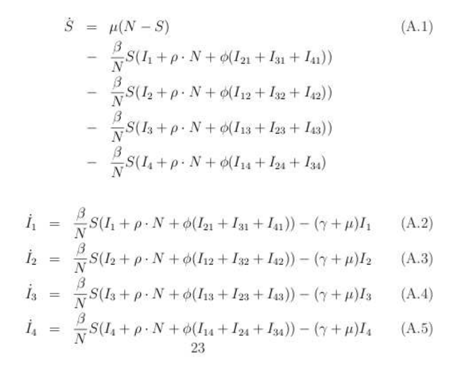
The four-strain model
with strain structure of the pathogens



Modeling dengue fever epidemiology

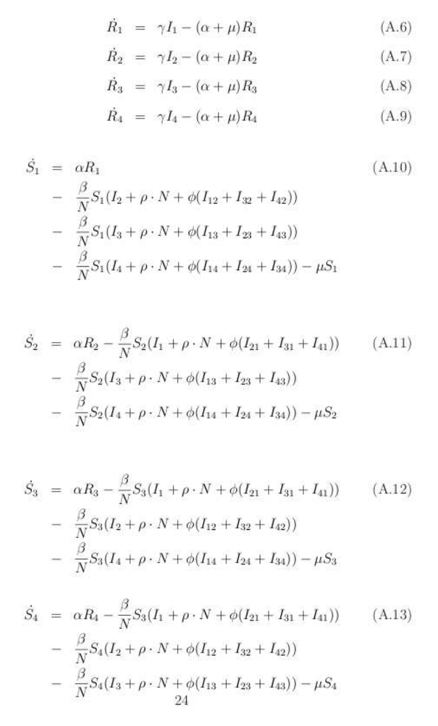
The four-strain model

with strain structure of the pathogens



$$
\begin{aligned}
\dot{S} &= \mu(N-S) \qquad \text{(A.1)}\\
&- \frac{\beta}{N}S(I_1+\rho\cdot N+\phi(I_{21}+I_{31}+I_{41}))\\
&- \frac{\beta}{N}S(I_2+\rho\cdot N+\phi(I_{12}+I_{32}+I_{42}))\\
&- \frac{\beta}{N}S(I_3+\rho\cdot N+\phi(I_{13}+I_{23}+I_{43}))\\
&- \frac{\beta}{N}S(I_4+\rho\cdot N+\phi(I_{14}+I_{24}+I_{34})
\end{aligned}
$$

$$
\begin{aligned}
\dot{I}_1 &= \frac{\beta}{N}S(I_1+\rho\cdot N+\phi(I_{21}+I_{31}+I_{41}))-(\gamma+\mu)I_1 && \text{(A.2)}\\
\dot{I}_2 &= \frac{\beta}{N}S(I_2+\rho\cdot N+\phi(I_{12}+I_{32}+I_{42}))-(\gamma+\mu)I_2 && \text{(A.3)}\\
\dot{I}_3 &= \frac{\beta}{N}S(I_3+\rho\cdot N+\phi(I_{13}+I_{23}+I_{43}))-(\gamma+\mu)I_3 && \text{(A.4)}\\
\dot{I}_4 &= \frac{\beta}{N}S(I_4+\rho\cdot N+\phi(I_{14}+I_{24}+I_{34}))-(\gamma+\mu)I_4 && \text{(A.5)}
\end{aligned}
$$



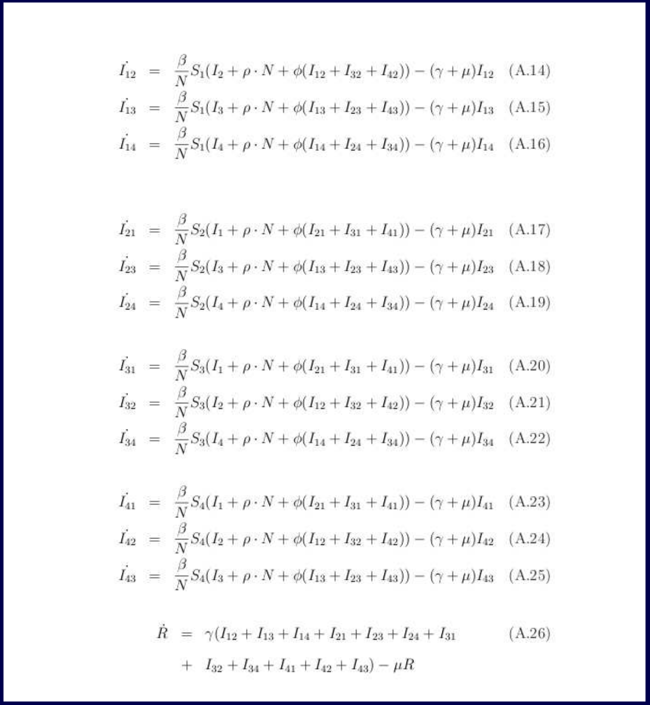
$$
\begin{aligned}
\dot{R}_1 &= \gamma I_1-(\alpha+\mu)R_1 && \text{(A.6)}\\
\dot{R}_2 &= \gamma I_2-(\alpha+\mu)R_2 && \text{(A.7)}\\
\dot{R}_3 &= \gamma I_3-(\alpha+\mu)R_3 && \text{(A.8)}\\
\dot{R}_4 &= \gamma I_4-(\alpha+\mu)R_4 && \text{(A.9)}
\end{aligned}
$$

$$
\begin{aligned}
\dot{S}_1 &= \alpha R_1 && \text{(A.10)}\\
&- \frac{\beta}{N}S_1(I_2+\rho\cdot N+\phi(I_{12}+I_{32}+I_{42}))\\
&- \frac{\beta}{N}S_1(I_3+\rho\cdot N+\phi(I_{13}+I_{23}+I_{43}))\\
&- \frac{\beta}{N}S_1(I_4+\rho\cdot N+\phi(I_{14}+I_{24}+I_{34}))-\mu S_1
\end{aligned}
$$

$$
\begin{aligned}
\dot{S}_2 &= \alpha R_2-\frac{\beta}{N}S_2(I_1+\rho\cdot N+\phi(I_{21}+I_{31}+I_{41})) && \text{(A.11)}\\
&- \frac{\beta}{N}S_2(I_3+\rho\cdot N+\phi(I_{13}+I_{23}+I_{43}))\\
&- \frac{\beta}{N}S_2(I_4+\rho\cdot N+\phi(I_{14}+I_{24}+I_{34}))-\mu S_2
\end{aligned}
$$

$$
\begin{aligned}
\dot{S}_3 &= \alpha R_3-\frac{\beta}{N}S_3(I_1+\rho\cdot N+\phi(I_{21}+I_{31}+I_{41})) && \text{(A.12)}\\
&- \frac{\beta}{N}S_3(I_2+\rho\cdot N+\phi(I_{12}+I_{32}+I_{42}))\\
&- \frac{\beta}{N}S_3(I_4+\rho\cdot N+\phi(I_{14}+I_{24}+I_{34}))-\mu S_3
\end{aligned}
$$

$$
\begin{aligned}
\dot{S}_4 &= \alpha R_4-\frac{\beta}{N}S_3(I_1+\rho\cdot N+\phi(I_{21}+I_{31}+I_{41})) && \text{(A.13)}\\
&- \frac{\beta}{N}S_4(I_2+\rho\cdot N+\phi(I_{12}+I_{32}+I_{42}))\\
&- \frac{\beta}{N}S_4(I_3+\rho\cdot N+\phi(I_{13}+I_{23}+I_{43}))-\mu S_4
\end{aligned}
$$



$$
\begin{aligned}
\dot{I}_{12} &= \frac{\beta}{N}S_1(I_2+\rho\cdot N+\phi(I_{12}+I_{32}+I_{42}))-(\gamma+\mu)I_{12} && \text{(A.14)}\\
\dot{I}_{13} &= \frac{\beta}{N}S_1(I_3+\rho\cdot N+\phi(I_{13}+I_{23}+I_{43}))-(\gamma+\mu)I_{13} && \text{(A.15)}\\
\dot{I}_{14} &= \frac{\beta}{N}S_1(I_4+\rho\cdot N+\phi(I_{14}+I_{24}+I_{34}))-(\gamma+\mu)I_{14} && \text{(A.16)}
\end{aligned}
$$

$$
\begin{aligned}
\dot{I}_{21} &= \frac{\beta}{N}S_2(I_1+\rho\cdot N+\phi(I_{21}+I_{31}+I_{41}))-(\gamma+\mu)I_{21} && \text{(A.17)}\\
\dot{I}_{23} &= \frac{\beta}{N}S_2(I_3+\rho\cdot N+\phi(I_{13}+I_{23}+I_{43}))-(\gamma+\mu)I_{23} && \text{(A.18)}\\
\dot{I}_{24} &= \frac{\beta}{N}S_2(I_4+\rho\cdot N+\phi(I_{14}+I_{24}+I_{34}))-(\gamma+\mu)I_{24} && \text{(A.19)}
\end{aligned}
$$

$$
\begin{aligned}
\dot{I}_{31} &= \frac{\beta}{N}S_3(I_1+\rho\cdot N+\phi(I_{21}+I_{31}+I_{41}))-(\gamma+\mu)I_{31} && \text{(A.20)}\\
\dot{I}_{32} &= \frac{\beta}{N}S_3(I_2+\rho\cdot N+\phi(I_{12}+I_{32}+I_{42}))-(\gamma+\mu)I_{32} && \text{(A.21)}\\
\dot{I}_{34} &= \frac{\beta}{N}S_3(I_4+\rho\cdot N+\phi(I_{14}+I_{24}+I_{34}))-(\gamma+\mu)I_{34} && \text{(A.22)}
\end{aligned}
$$

$$
\begin{aligned}
\dot{I}_{41} &= \frac{\beta}{N}S_4(I_1+\rho\cdot N+\phi(I_{21}+I_{31}+I_{41}))-(\gamma+\mu)I_{41} && \text{(A.23)}\\
\dot{I}_{42} &= \frac{\beta}{N}S_4(I_2+\rho\cdot N+\phi(I_{12}+I_{32}+I_{42}))-(\gamma+\mu)I_{42} && \text{(A.24)}\\
\dot{I}_{43} &= \frac{\beta}{N}S_4(I_3+\rho\cdot N+\phi(I_{13}+I_{23}+I_{43}))-(\gamma+\mu)I_{43} && \text{(A.25)}
\end{aligned}
$$

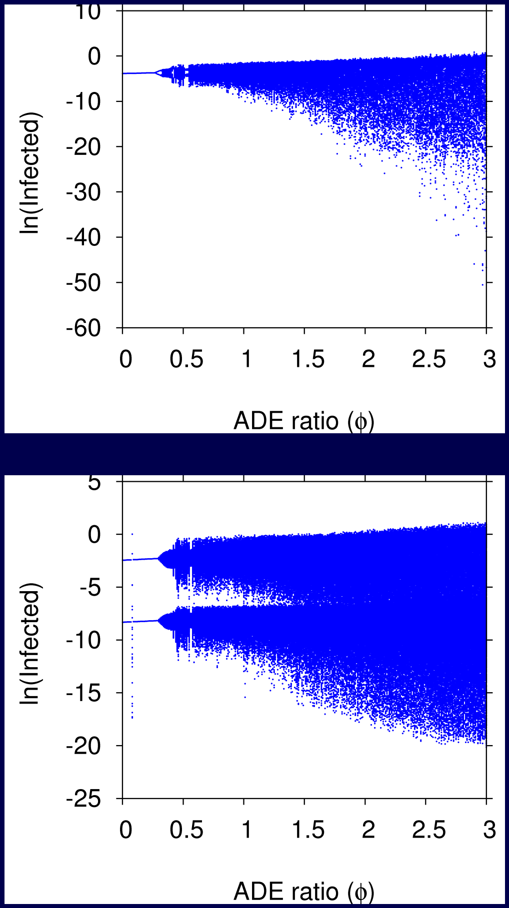
$$
\begin{aligned}
\dot{R} &= \gamma(I_{12}+I_{13}+I_{14}+I_{21}+I_{23}+I_{24}+I_{31} && \text{(A.26)}\\
&+ I_{32}+I_{34}+I_{41}+I_{42}+I_{43})-\mu R
\end{aligned}
$$

25 dimensional system!

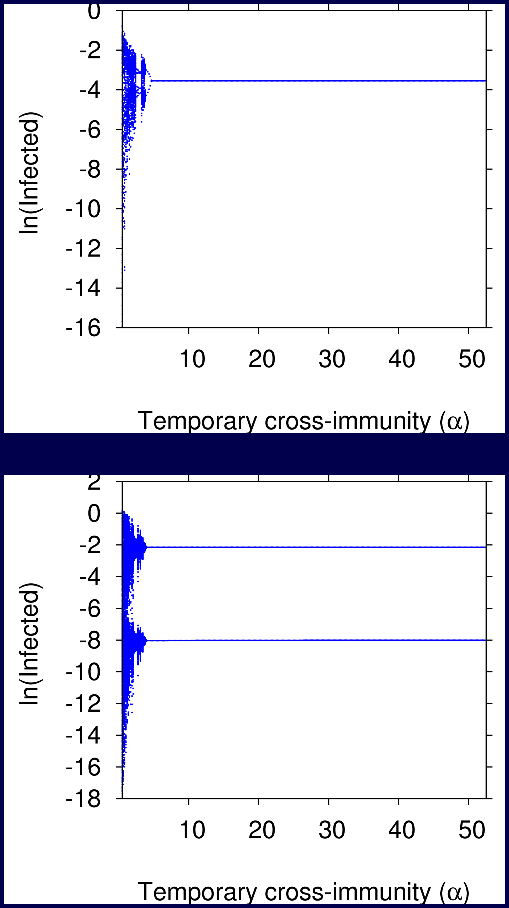
Modeling dengue fever epidemiology

The four-strain model

with strain structure of the pathogens



(α=1/6 months)

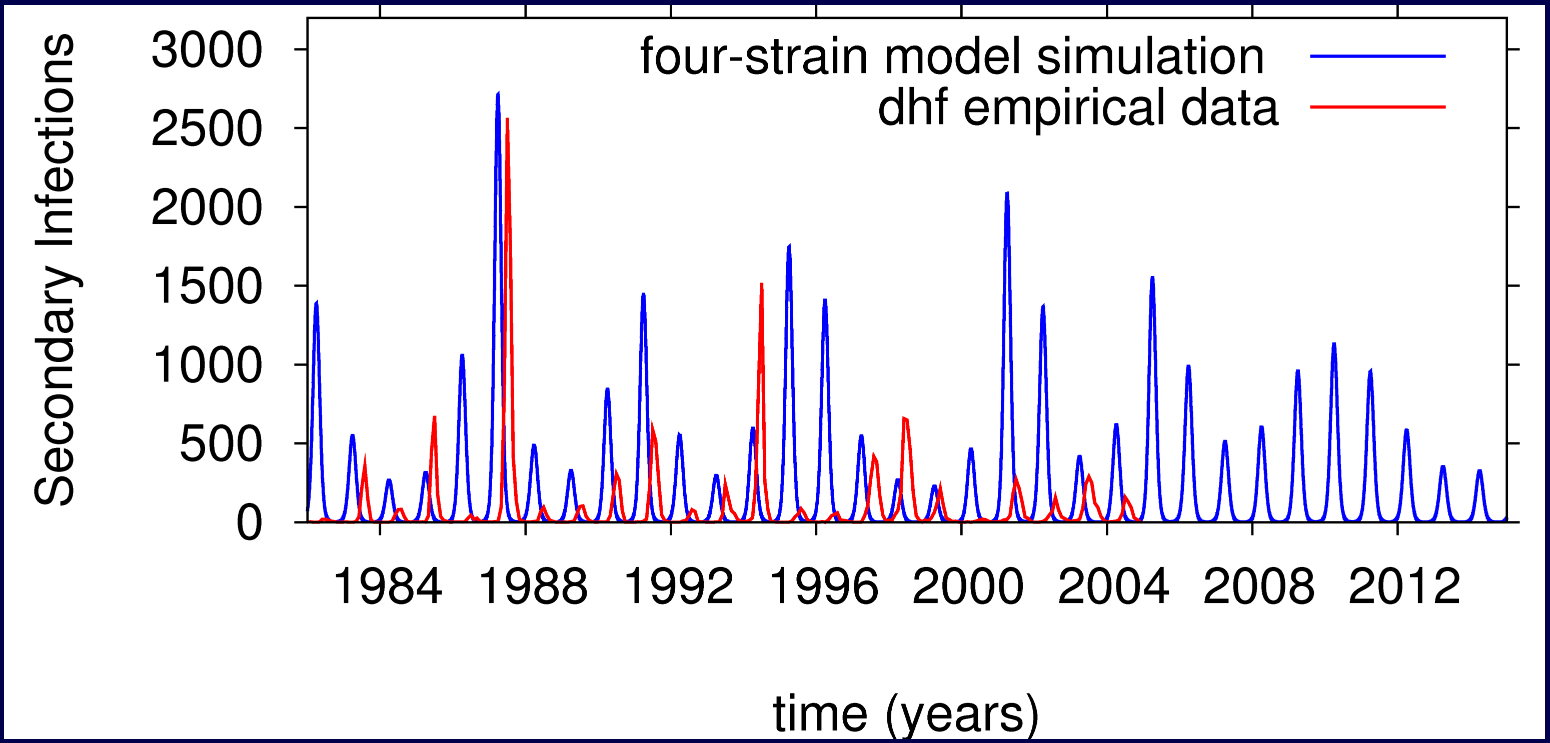


(ϕ=0.6)

Modeling dengue fever epidemiology

The four-strain model

with strain structure of the pathogens

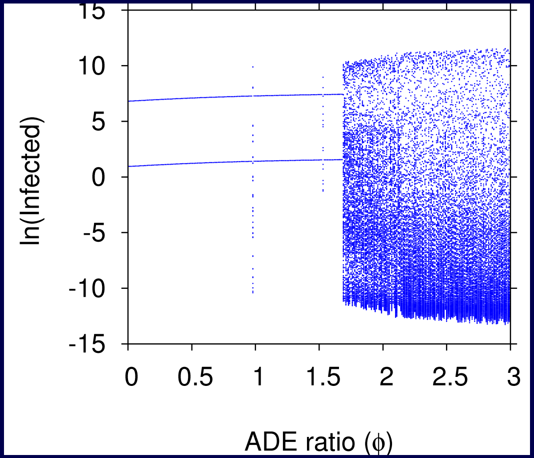


Also qualitatively a very good result when comparing empirical DHF data and model simulation.

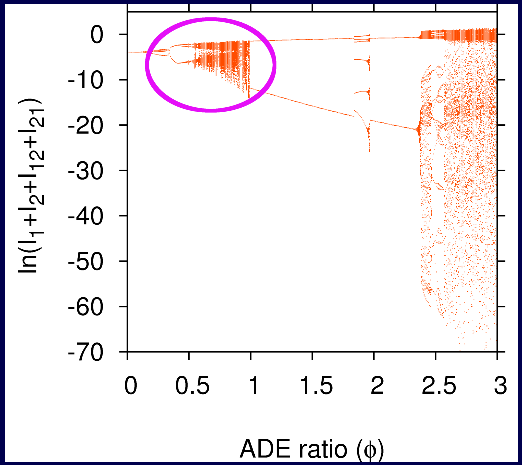
Summary

- *Basic n-strain SIR-type model for the host population, capturing differences between primary and secondary infections.*

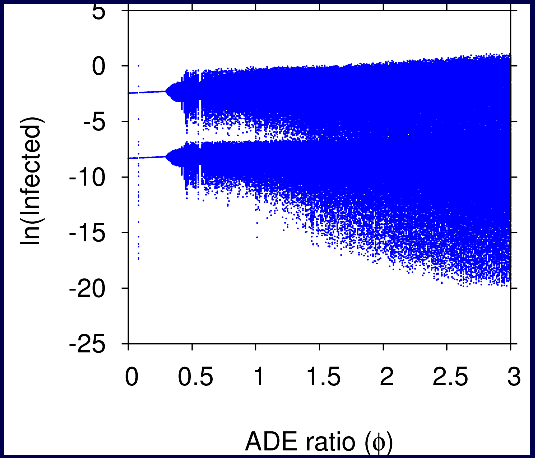
- *Consideration of temporary cross-immunity gives bifurcations up to chaotic attractors in much wider and also unexpected (not predicted by previous models) parameter regions.*



2-infection model



2-strain model

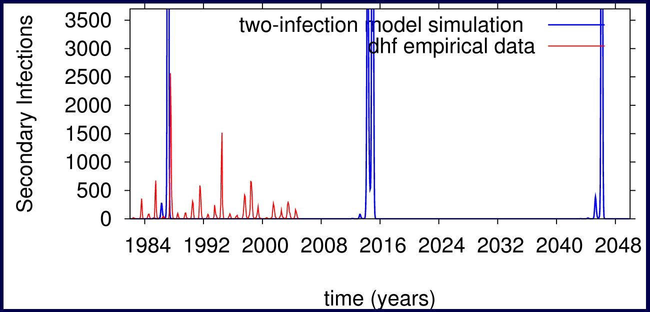


4-strain model

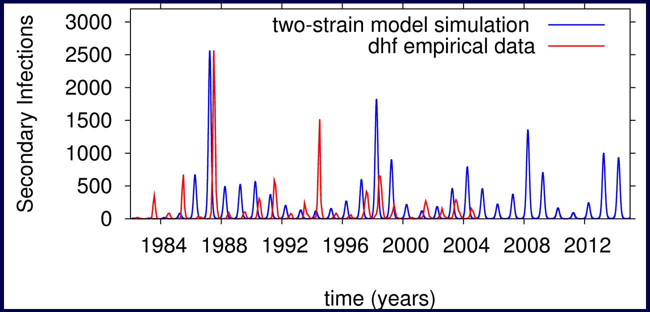
Summary

- *Long term epidemiological data come from the Ministry of Public Health in Thailand and consist on monthly incidences of hospitalized cases.*

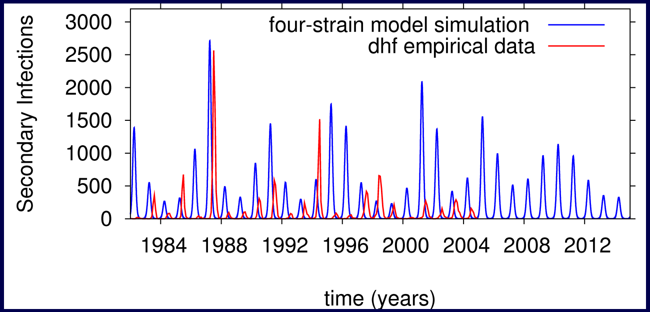
- *For such a data scenario, models that are able to generate both primary and secondary infection cases (with a different strain), have shown a good qualitative agreement between empirical data and model output.*



two-infection model



2-strain model



4-strain model

Thank you for your attention!

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