Modeling COVID-19

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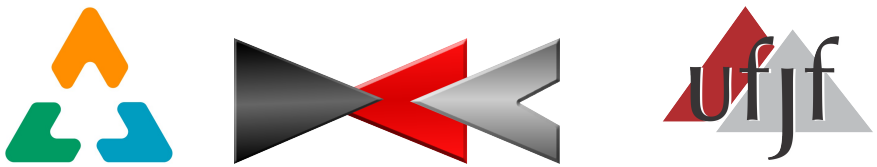


Pós-Graduação em Modelagem Computacional
Departamento de Ciência da Computação
Universidade Federal de Juiz de Fora

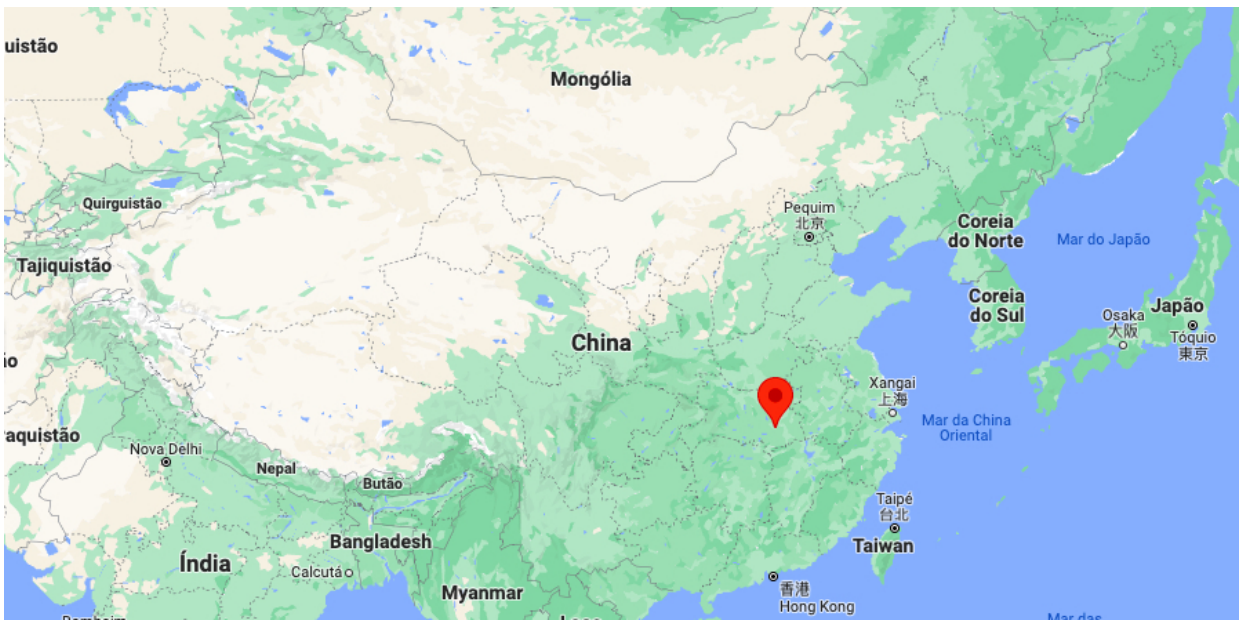
July 11, 2023

Overview

Overview

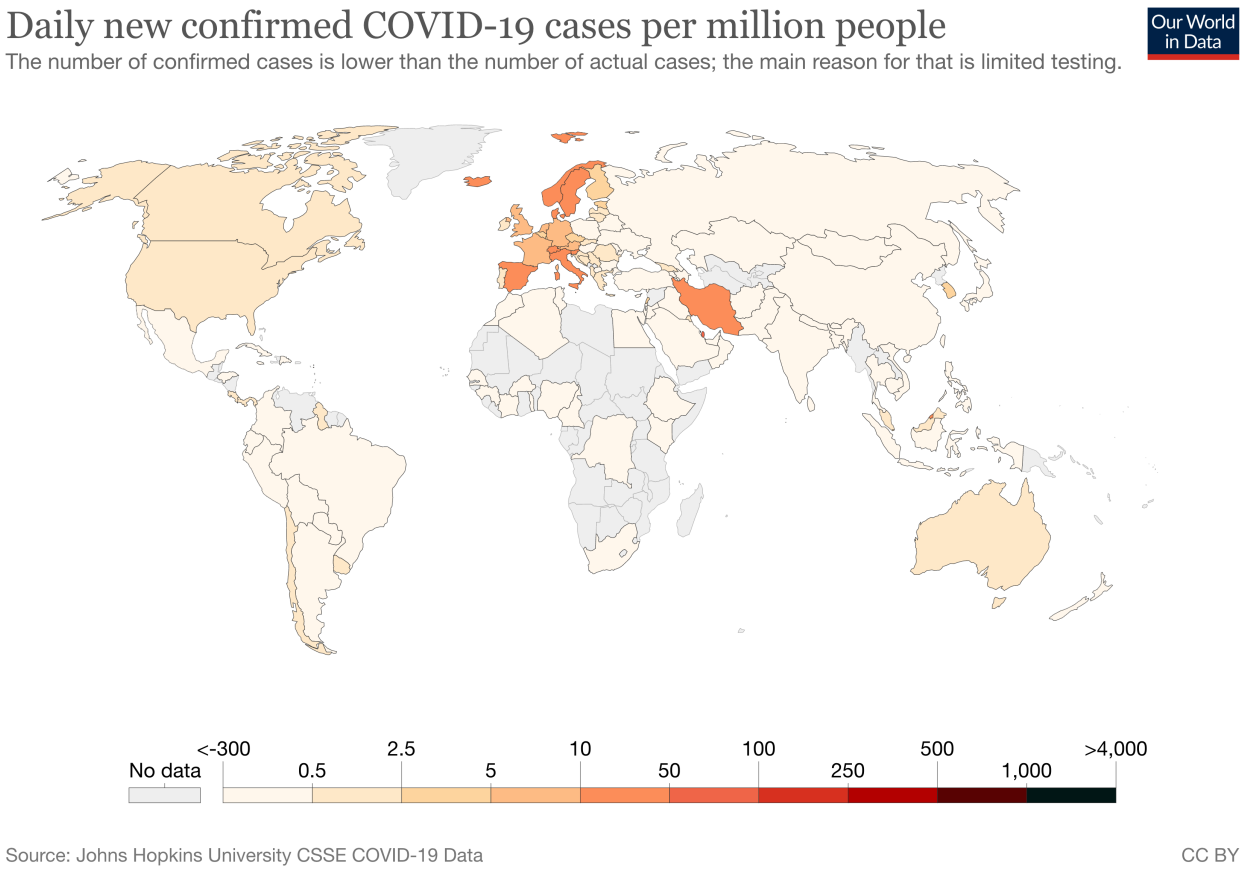
Motivation

- Late in 2019, China identified a new type of coronavirus, Sars-CoV-2, circulating in Wuhan following an outbreak of pneumonia.



Motivation

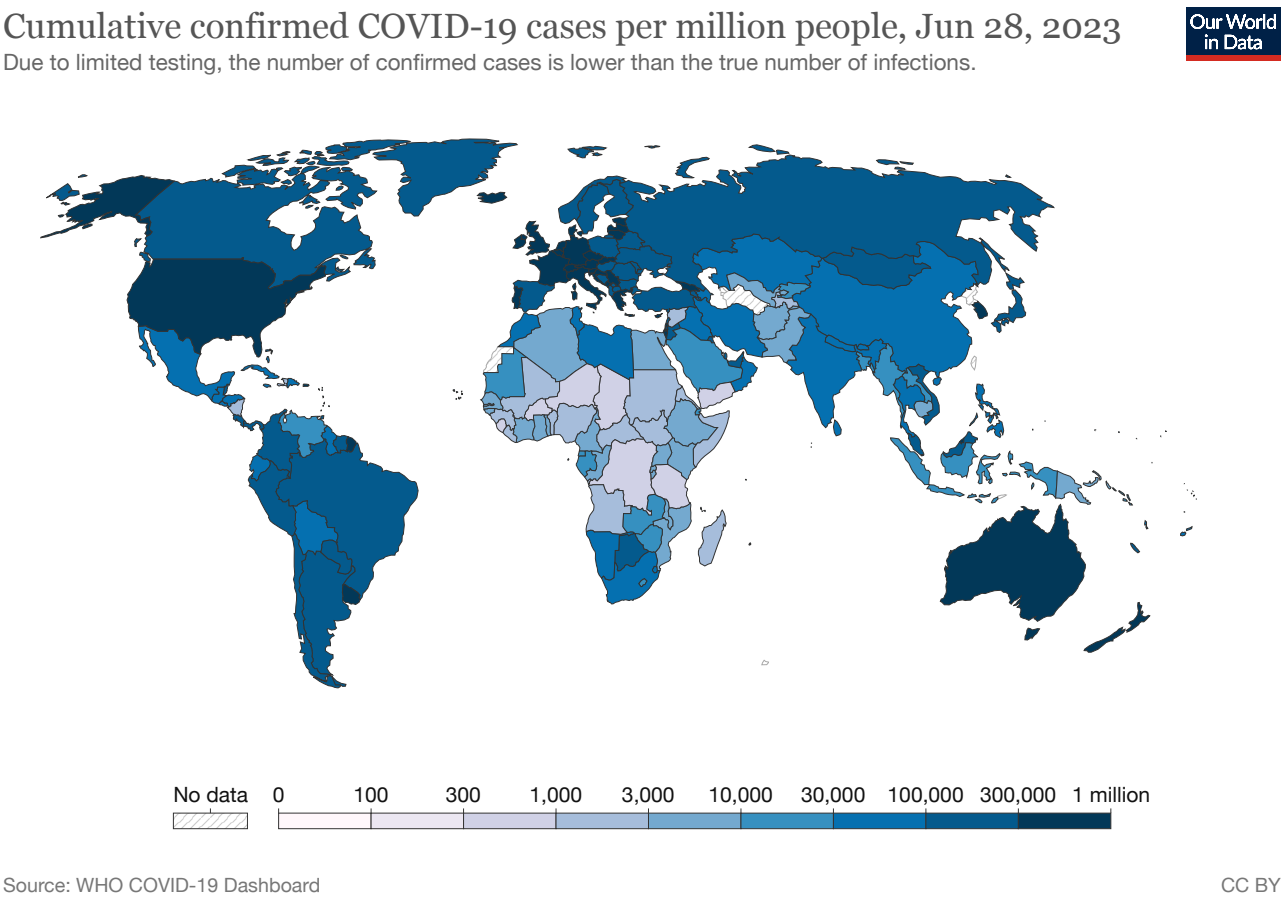
Due to the rapid spread of the virus, the World Health Organization declared a pandemic of this new disease called COVID-19 on March 11, 2020 [1]



[1] https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-

Motivation

On June 28, 2023, the cumulative total of cases per million people is as follows



Overview

Once upon a time...

- The group started meeting to discuss modeling COVID-19 on March 20, 2020
- All the modeling and strategies adopted have always been based on the principle of simplicity: K.I.S.S. (keep it simple and straightforward)
  1. A new disease, little was knowledge (and still lacking knowledge) about the virus
  2. Lack of specific data (ICU, division by age, etc.)
  3. The larger the model, the more parameters. Parameters of a new disease that little is known about acceptable values
  4. Few variables, simplifies validation
- We conclude that SIRD-based models are sufficient to capture the dynamics of COVID-19 propagation.

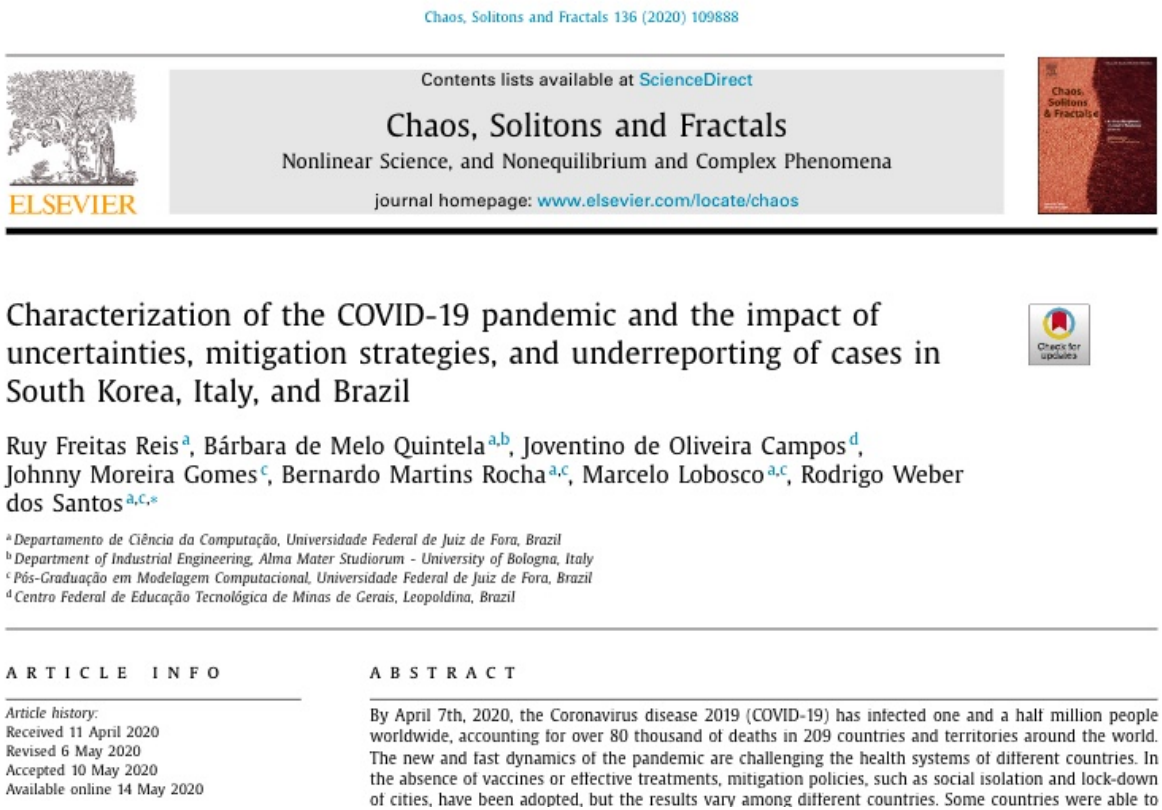
Overview

Characterization

The first work published was based on the idea of **characterizing the pandemic**

- What is the local transmission rate?
- What is the mortality rate?
- What is underreporting?
- What is the influence of border control?

Characterization



Chaos, Solitons and Fractals 136 (2020) 109888

Contents lists available at ScienceDirect

Chaos, Solitons and Fractals

Nonlinear Science, and Nonequilibrium and Complex Phenomena

journal homepage: www.elsevier.com/locate/chaos

Characterization of the COVID-19 pandemic and the impact of uncertainties, mitigation strategies, and underreporting of cases in South Korea, Italy, and Brazil

Ruy Freitas Reis[a], Bárbara de Melo Quintela[a,b], Joventino de Oliveira Campos[d], Johnny Moreira Gomes[c], Bernardo Martins Rocha[a,c], Marcelo Lobosco[a,c], Rodrigo Weber dos Santos[a,c,*]

[a] Departamento de Ciência da Computação, Universidade Federal de Juiz de Fora, Brazil
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ABSTRACT

By April 7th, 2020, the Coronavirus disease 2019 (COVID-19) has infected one and a half million people worldwide, accounting for over 80 thousand of deaths in 209 countries and territories around the world. The new and fast dynamics of the pandemic are challenging the health systems of different countries. In the absence of vaccines or effective treatments, mitigation policies, such as social isolation and lock-down of cities, have been adopted, but the results vary among different countries. Some countries were able to

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[2] Reis, R. F., de Melo Quintela, B., de Oliveira Campos, J., Gomes, J. M., Rocha, B. M., Lobosco, M., and Dos Santos, R. W. (2020). Characterization of the COVID-19 pandemic and the impact of uncertainties, mitigation strategies, and underreporting of cases in South Korea, Italy, and Brazil. Chaos, Solitons & Fractals, 136, 109888.

Characterization

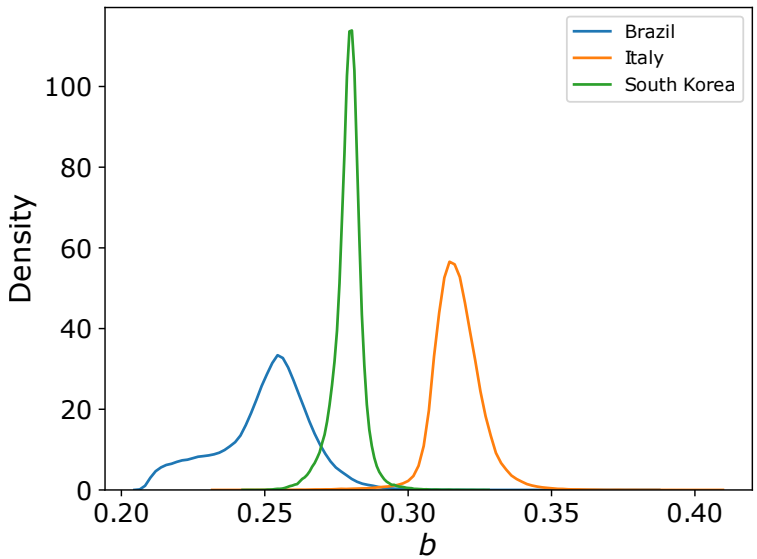
Mathematical Model

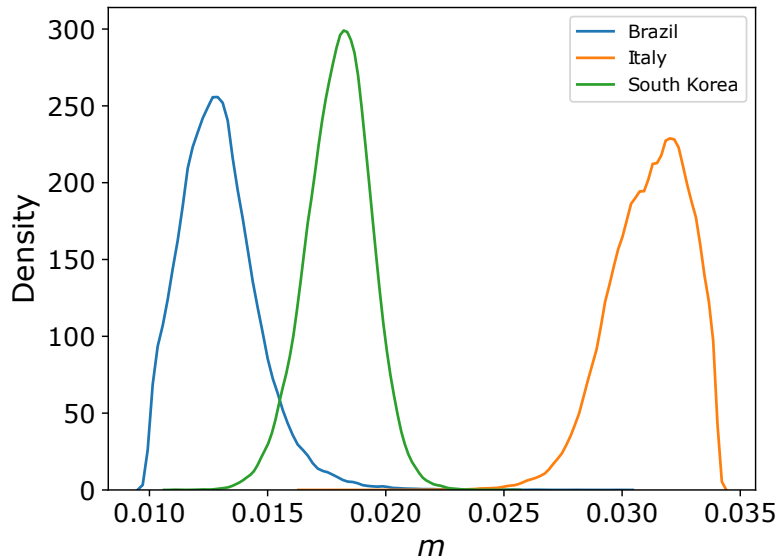
The model used in this first work is described by the following equations:

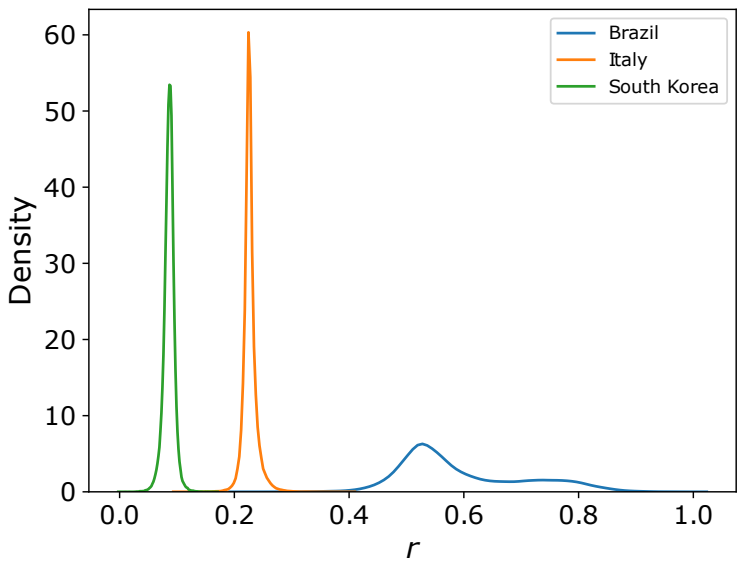
$$\begin{cases} \frac{dS}{dt} & = -\frac{\alpha(t)}{N} SI, \\ \frac{dI}{dt} & = \frac{\alpha(t)}{N} SI + f(t) - \beta I - \gamma I, \\ \frac{dR}{dt} & = \gamma I, \\ \frac{dD}{dt} & = \beta I, \\ I_r & = \theta I(t - (1-\theta)\tau_1), \end{cases}$$

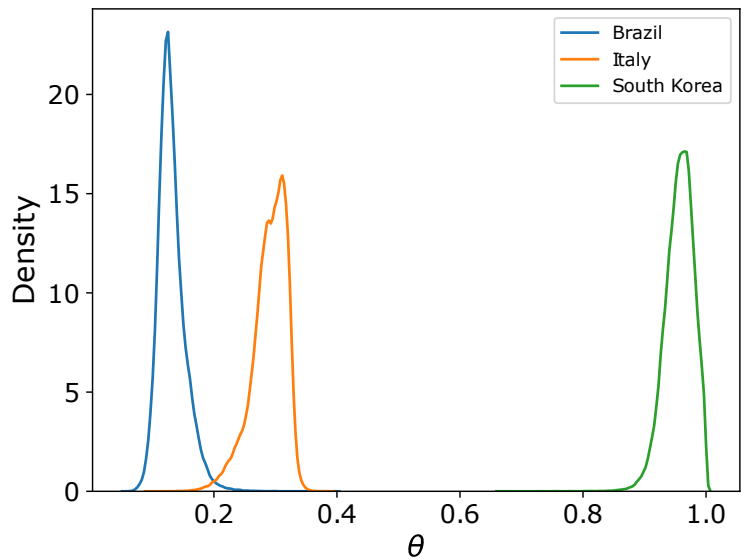
$$a(t) = \begin{cases} 1, & \text{se } t < t_i, \\ \frac{r-1}{\Delta}(t - t_i) + 1, & \text{se } t_i \leq t \text{ e } t \leq t_i + \Delta, \\ r, & \text{c.c..} \end{cases}$$

Results

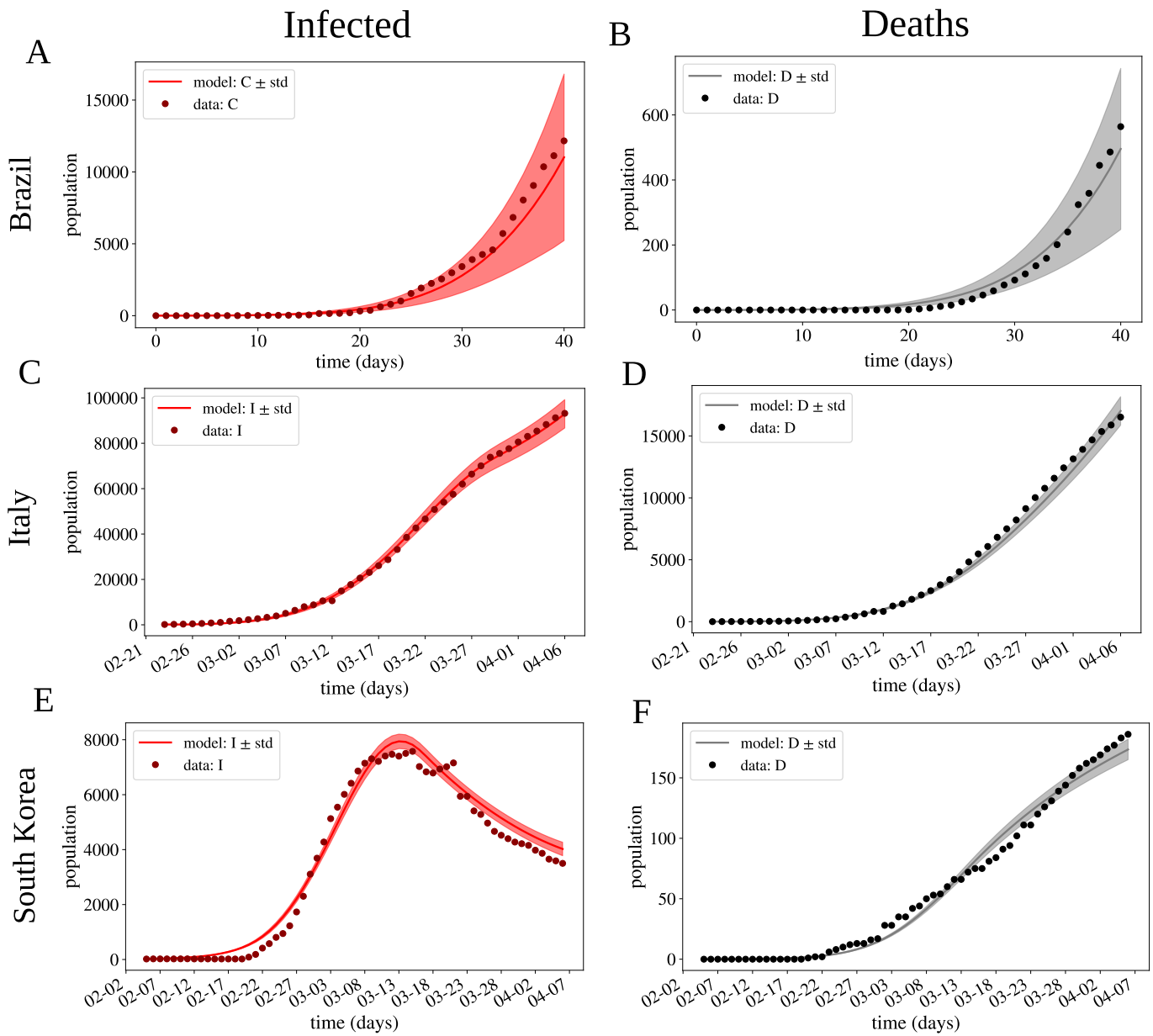

Brazil
Italy
South Korea
Density
b


Brazil
Italy
South Korea
Density
m


Brazil
Italy
South Korea
Density
r


Brazil
Italy
South Korea
Density
θ

Results


Infected
Deaths
A
B
C
D
E
F
Brazil
Italy
South Korea
model: C ± std
data: C
model: I ± std
data: I
model: D ± std
data: D
population
time (days)

Overview

Forecasting

- Forecasting: *act or effect of predicting; foresight, prescience.*
- How about predicting the pandemic using modeling?

Forecasting I

- In fact, we can find in the literature examples of predictions that failed using:
  - **SEIR:** Kuniya, T. (2020). Prediction of the epidemic peak of coronavirus disease in Japan, 2020. Journal of clinical medicine, 9(3), 789.
  - **SIRD:** Fanelli, D., & Piazza, F. (2020). Analysis and forecast of COVID-19 spreading in China, Italy and France. Chaos, Solitons & Fractals, 134, 109761.
  - **Extensões do SEIR:** Liu, Z., Magal, P., & Webb, G. (2021). Predicting the number of reported and unreported cases for the COVID-19 epidemics in China, South Korea, Italy, France, Germany and United Kingdom. Journal of theoretical biology, 509, 110501.

Forecasting II

- **Modelos Estatísticos: 1)** Li, L., Yang, Z., Dang, Z., Meng, C., Huang, J., Meng, H., ... & Shao, Y. (2020). Propagation analysis and prediction of the COVID-19. Infectious Disease Modelling, 5, 282-292; **2)** Jewell, N. P., Lewnard, J. A., & Jewell, B. L. (2020). Caution warranted: using the institute for health metrics and evaluation model for predicting the course of the COVID-19 pandemic.
- **Agent-based:** Chang, S. L., Harding, N., Zachreson, C., Cliff, O. M., & Prokopenko, M. (2020). Modelling transmission and control of the COVID-19 pandemic in Australia. Nature communications, 11(1), 1-13.
- **Machine Learning:** Alzahrani, S. I., Aljamaan, I. A., & Al-Fakih, E. A. (2020). Forecasting the spread of the COVID-19 pandemic in Saudi Arabia using ARIMA prediction model under current public health interventions. Journal of infection and public health, 13(7), 914-919.

Forecasting III

- **Chaos-Based theory:** Mangiarotti, S., Peyre, M., Zhang, Y., Huc, M., Roger, F., & Kerr, Y. (2020). Chaos theory applied to the outbreak of COVID-19: an ancillary approach to decision making in pandemic context. Epidemiology & Infection, 148.

Projections

ORIGINAL RESEARCH article

Front. Public Health, 16 March 2021 | https://doi.org/10.3389/fpubh.2021.623521

The Quixotic Task of Forecasting Peaks of COVID-19: Rather Focus on Forward and Backward Projections

 Ruy Freitas Reis[1],  Rafael Sachetto Oliveira[2],  Bárbara de Melo Quintela[1], Joventino de Oliveira Campos[3], Johnny Moreira Gomes[4], Bernardo Martins Rocha[1,4], Marcelo Lobosco[1,4] and Rodrigo Weber dos Santos[1,4*]

[1]Departamento de Ciência da Computação, Universidade Federal de Juiz de Fora, Juiz de Fora, Brazil
[2]Departamento de Ciência da Computação, Universidade Federal de São João del-Rei, São João del-Rei, Brazil
[3]Centro Federal de Educação Tecnológica de Minas de Gerais, Leopoldina, Brazil
[4]Pós-Graduação em Modelagem Computacional, Universidade Federal de Juiz de Fora, Juiz de Fora, Brazil

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[3]Reis, R. F., Oliveira, R. S., Quintela, B. D. M., Campos, J. D. O., Gomes, J. M., Rocha, B. M., ... and Dos Santos, R. W. (2021). The quixotic task of forecasting peaks of COVID-19: Rather focus on forward and backward projections. Frontiers in Public Health, 9, 623521

Projections

Mathematical model

The model is described by the following set of equations:

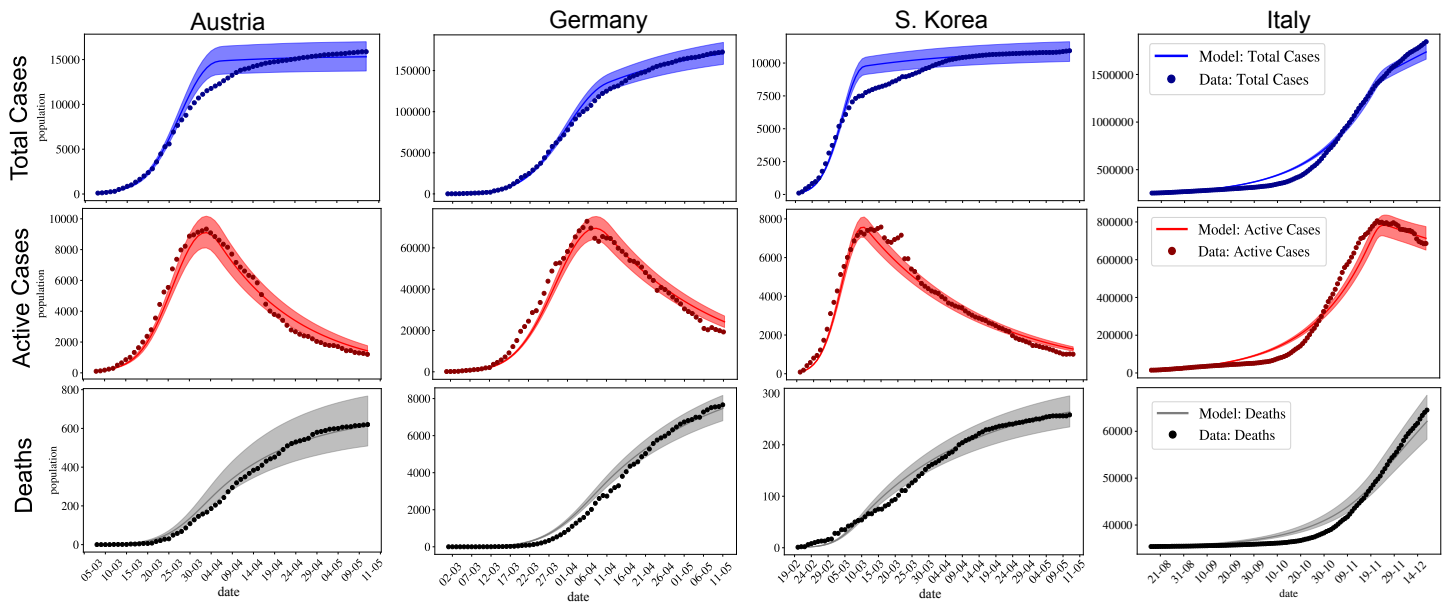
$$\begin{cases} \frac{dS}{dt} & = -\frac{\alpha(t)}{N} SI, \\ \frac{dI}{dt} & = \frac{\alpha(t)}{N} SI - \beta I - \gamma I, \\ \frac{dR}{dt} & = \gamma I, \\ \frac{dD}{dt} & = \beta I, \\ I_r & = \theta I, \\ R_r & = \theta R, \\ C & = I_r + R_r + D, \end{cases}$$

$$a(t) = \begin{cases} 1, & \text{if } t < t_i, \\ \frac{r-1}{\Delta}(t - t_i) + 1, & \text{if } t_i \leq t \leq t_i + \Delta, \\ r, & \text{otherwise.} \end{cases}$$

Results

Model Calibration

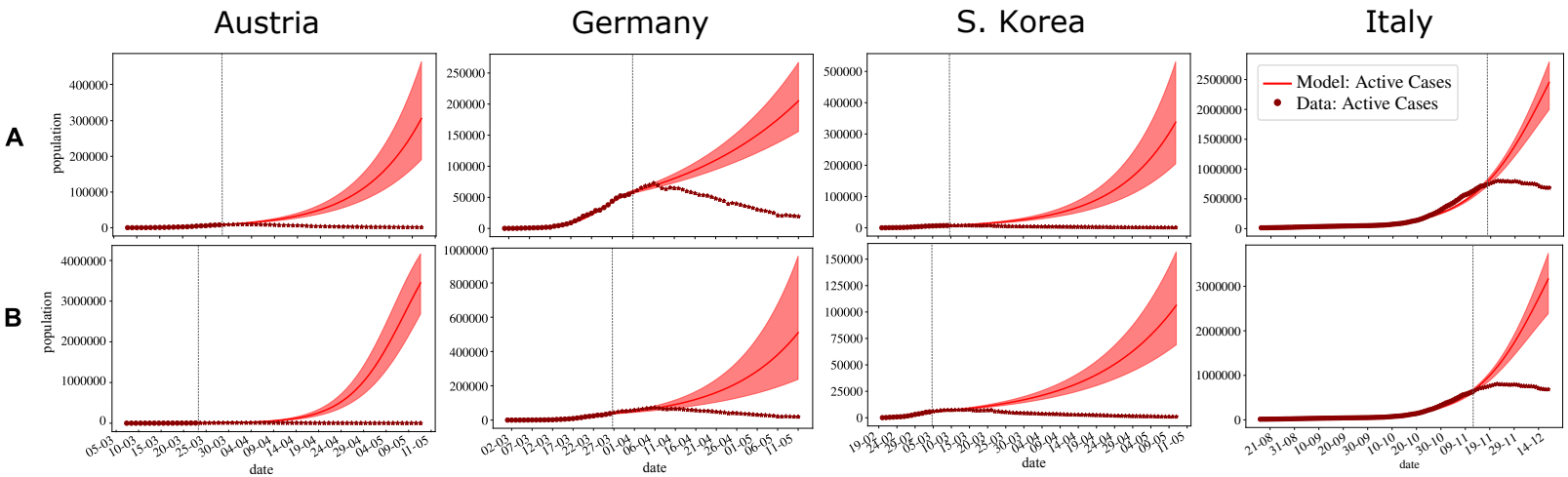
The first question is: Can the model capture the dynamics of the pandemic?



Forecast

Results

Well, if it fits, just simulate more days to make forecasts:



Forecast

Results

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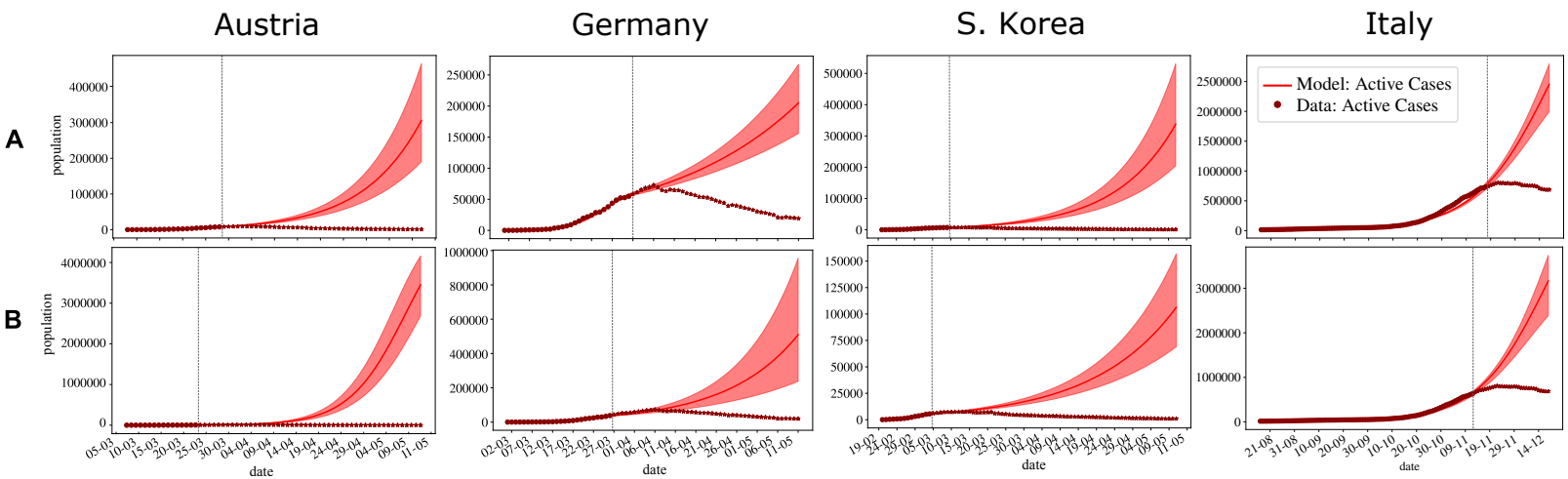


The More You Tighten Your Grip, the More It Slips Through Your Fingers

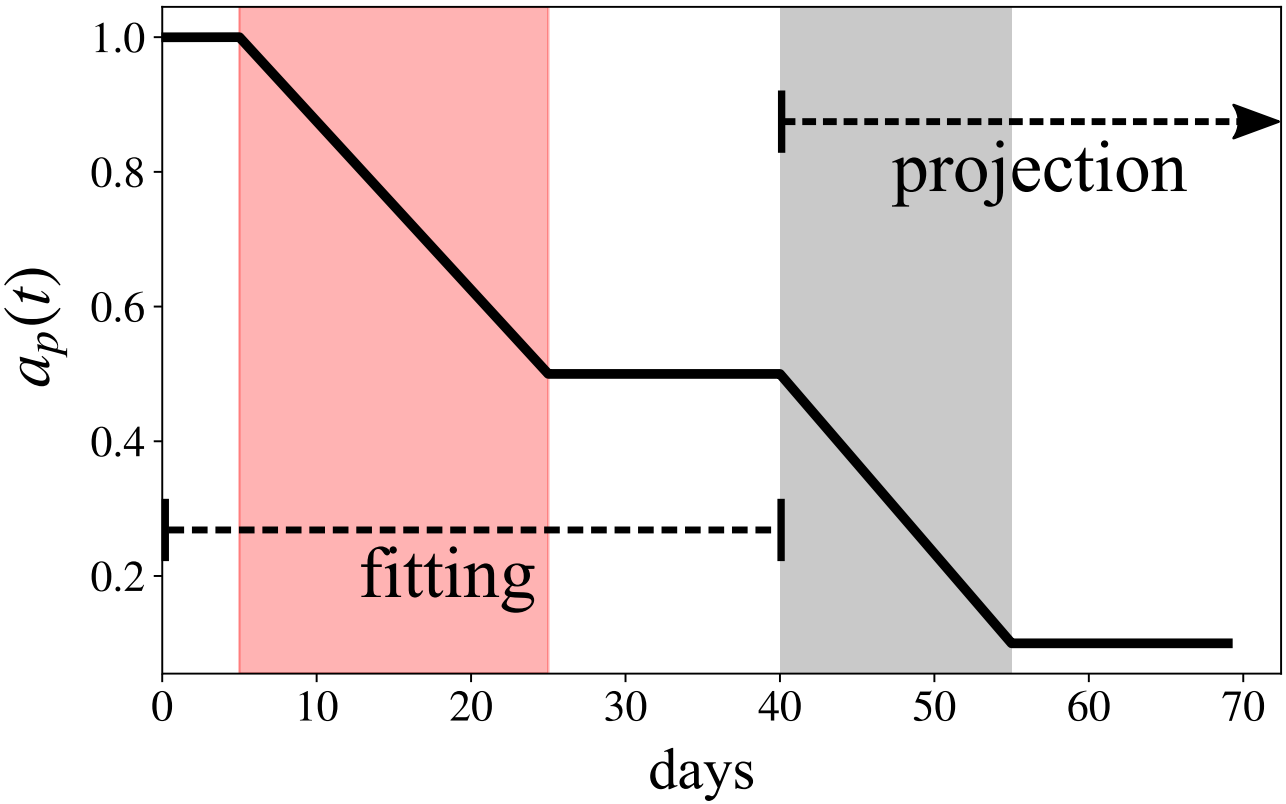
Projections

Mathematical model

$$a_p(t) = \begin{cases} 1, & \text{if } t < t_i, \\ \frac{r-1}{\Delta}(t - t_i) + 1, & \text{if } t_i \leq t \leq t_i + \Delta, \\ r, & \text{if } t_i + \Delta < t \leq t_f, \\ \frac{r_f - r}{\Delta_f}(t - t_f) + r, & \text{if } t_f < t \leq t_f + \Delta_f, \\ r_f, & \text{otherwise} \end{cases}$$

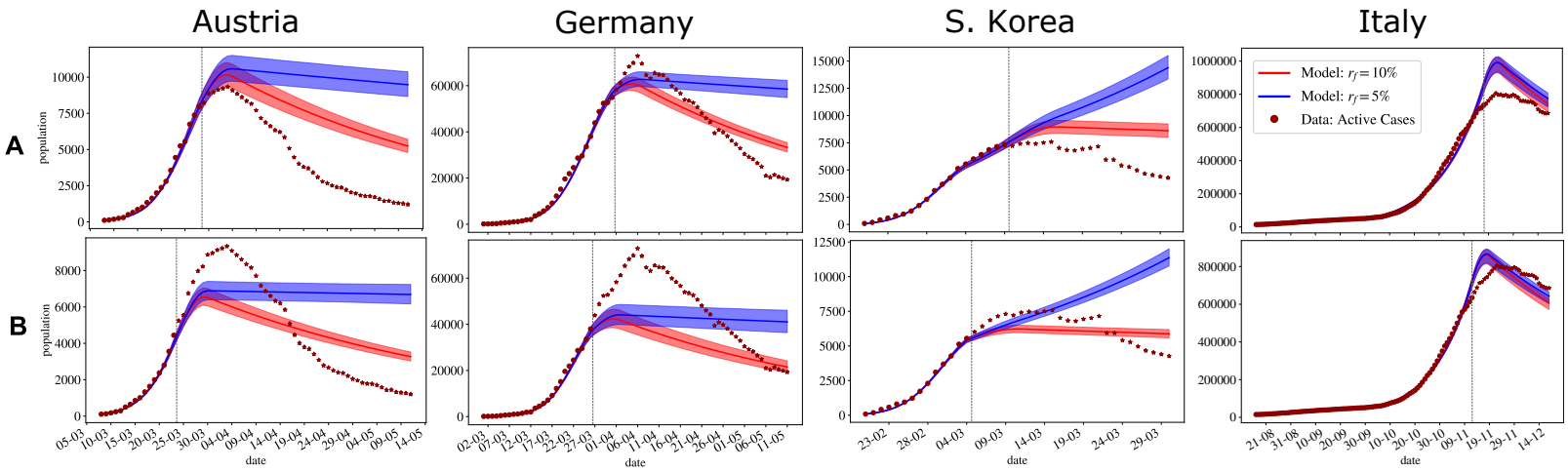
Projections

Unlike forecasts, projections aim to study one or more hypothetical scenarios. In contrast, forecasts use available data and try to predict future trends.



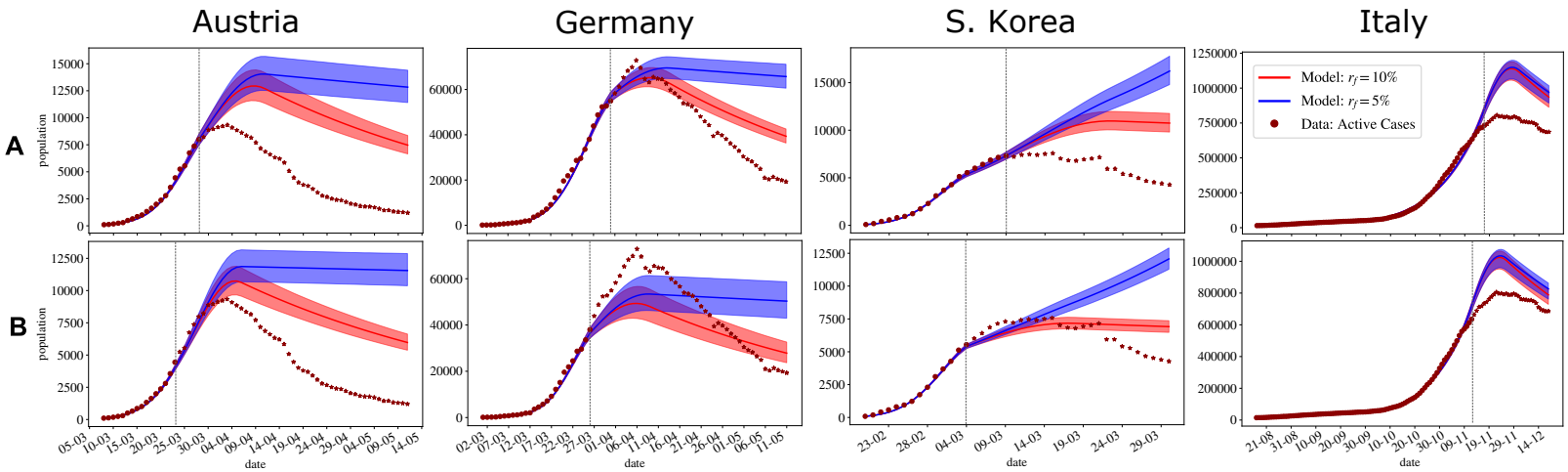
Results

Projections



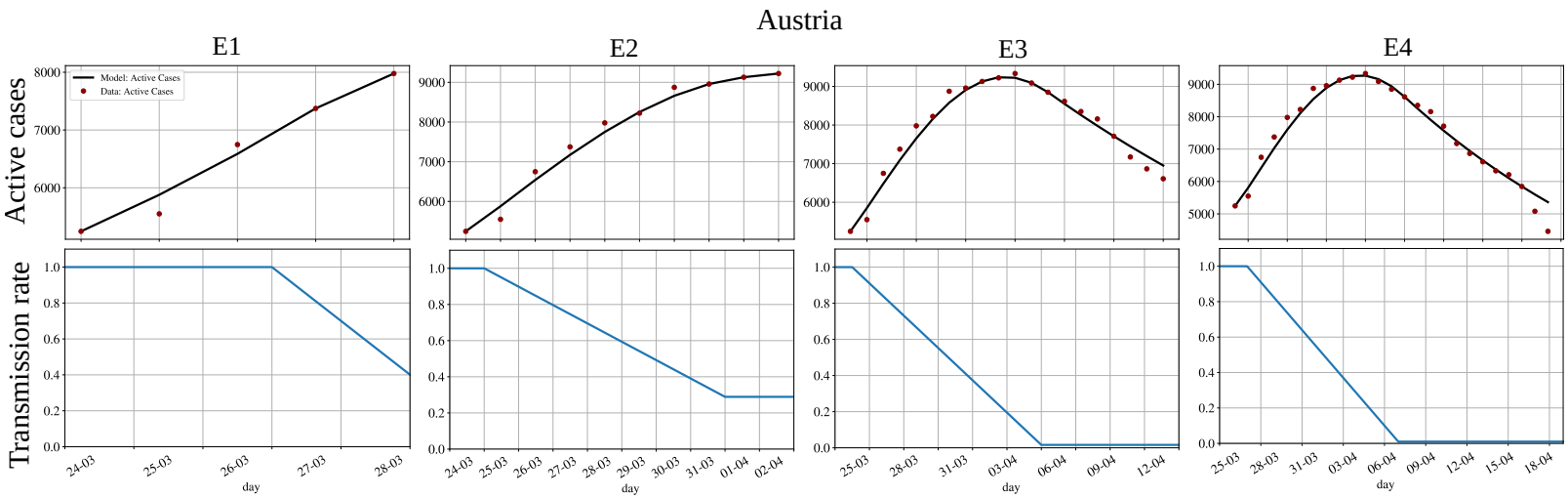
Results

Projections



The main source of error

Incorrect estimate of transmission near the peak



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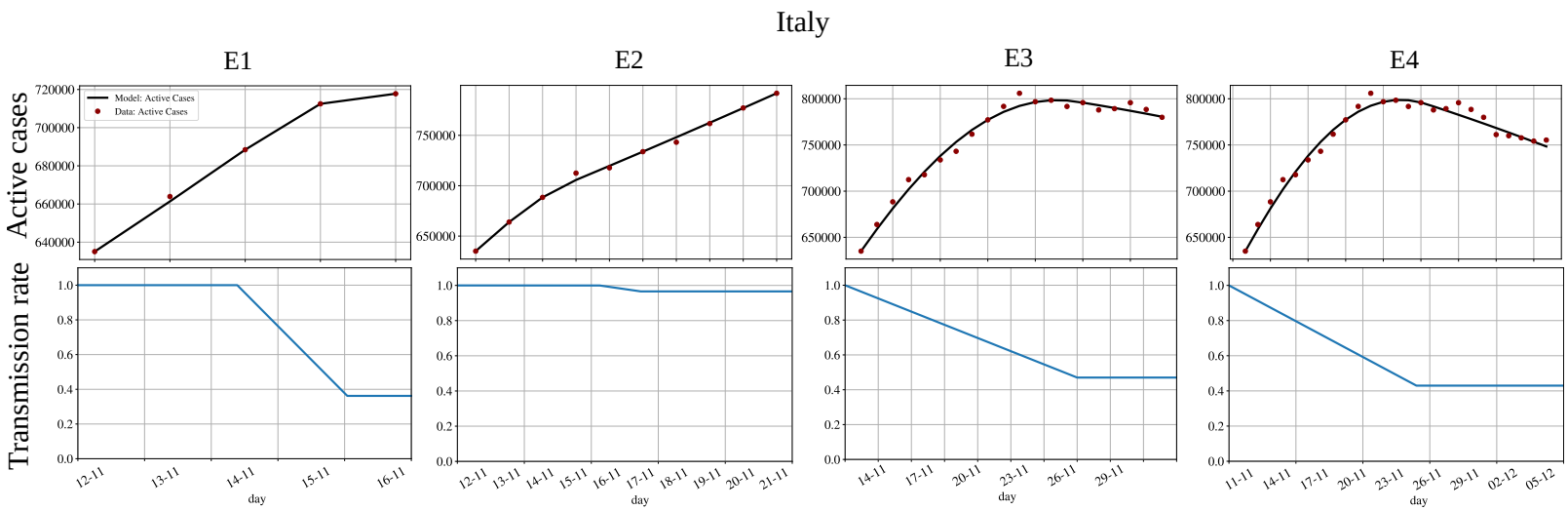
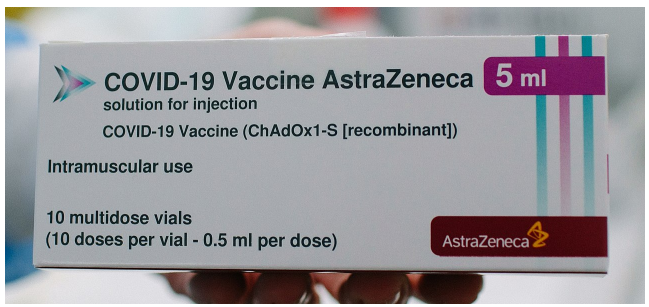


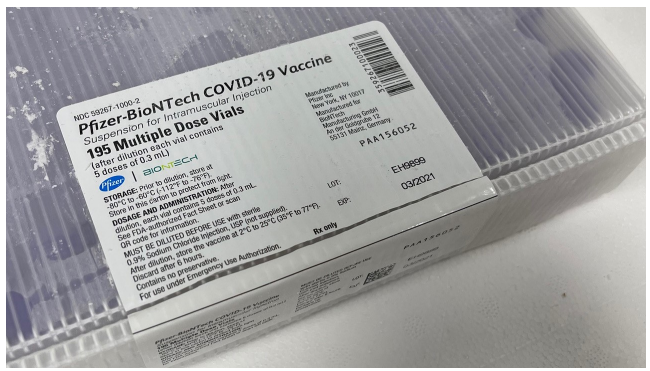
Overview

Vaccination

The first studies on the safety and efficacy of vaccines against COVID-19 were published at the end of 2020:

1. Voysey, Merryn et al. Safety and efficacy of the ChAdOx1 nCoV-19 vaccine (AZD1222) against SARS-CoV-2: an interim analysis of four randomised controlled trials in Brazil, South Africa, and the UK. The Lancet. https://doi.org/10.1016/S0140-6736(20)32661-1
2. Polack, Fernando P. et al. Safety and Efficacy of the BNT162b2 mRNA Covid-19 Vaccine. N. Engl. J. Med. https://doi.org/10.1056/NEJMoa2034577

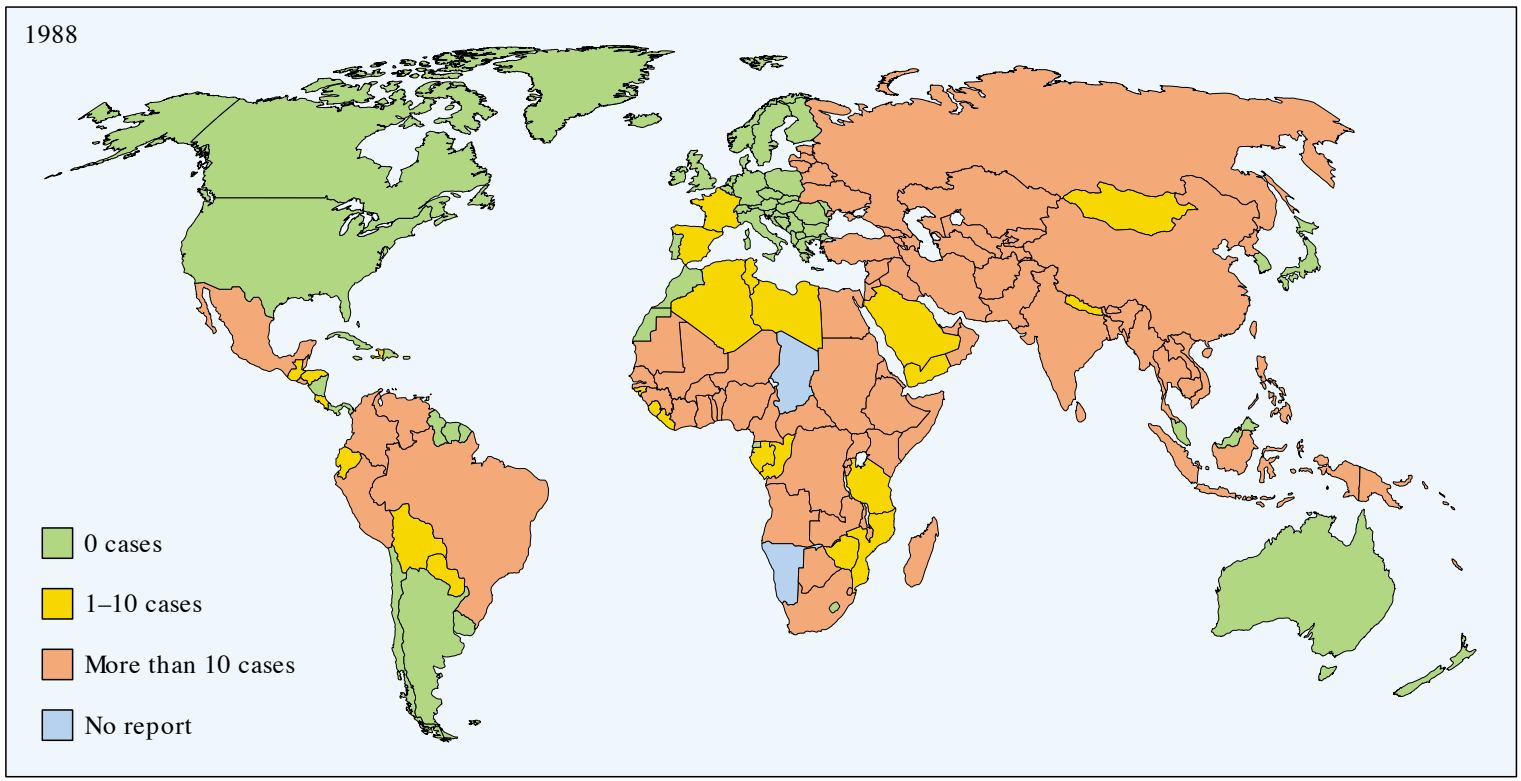




Vaccination

Importance

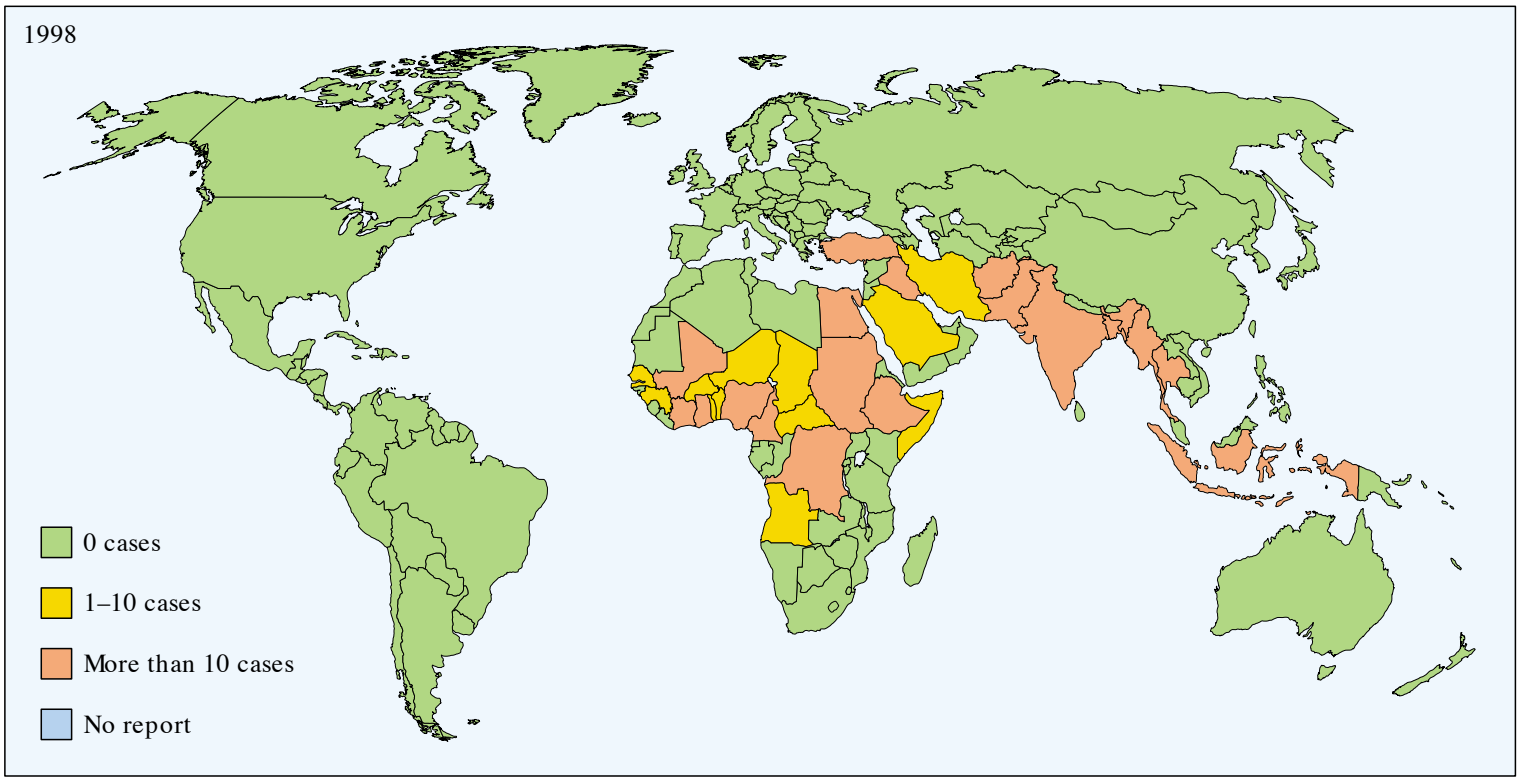
Polio cases in 1988



Vaccination

Importance

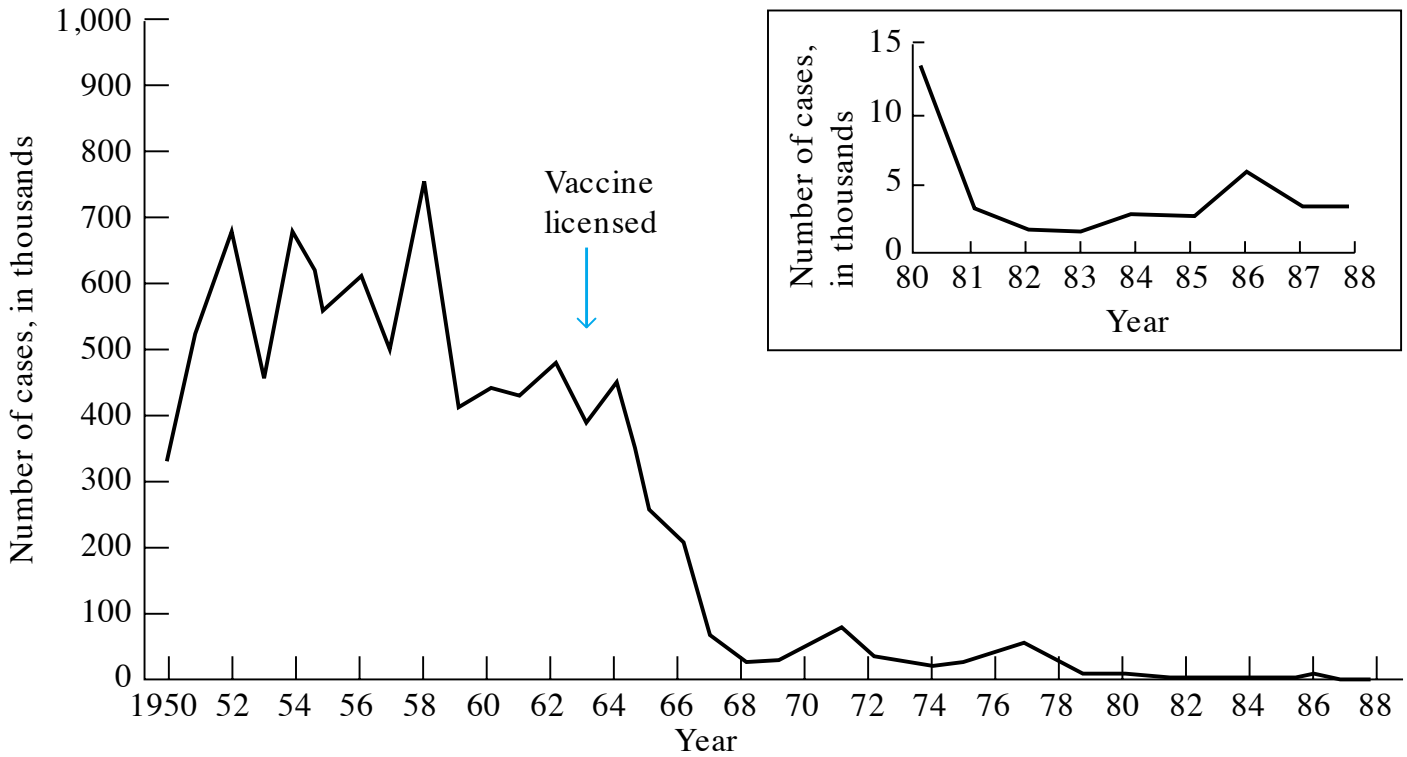
Polio cases in 1998



Vaccination

Importance

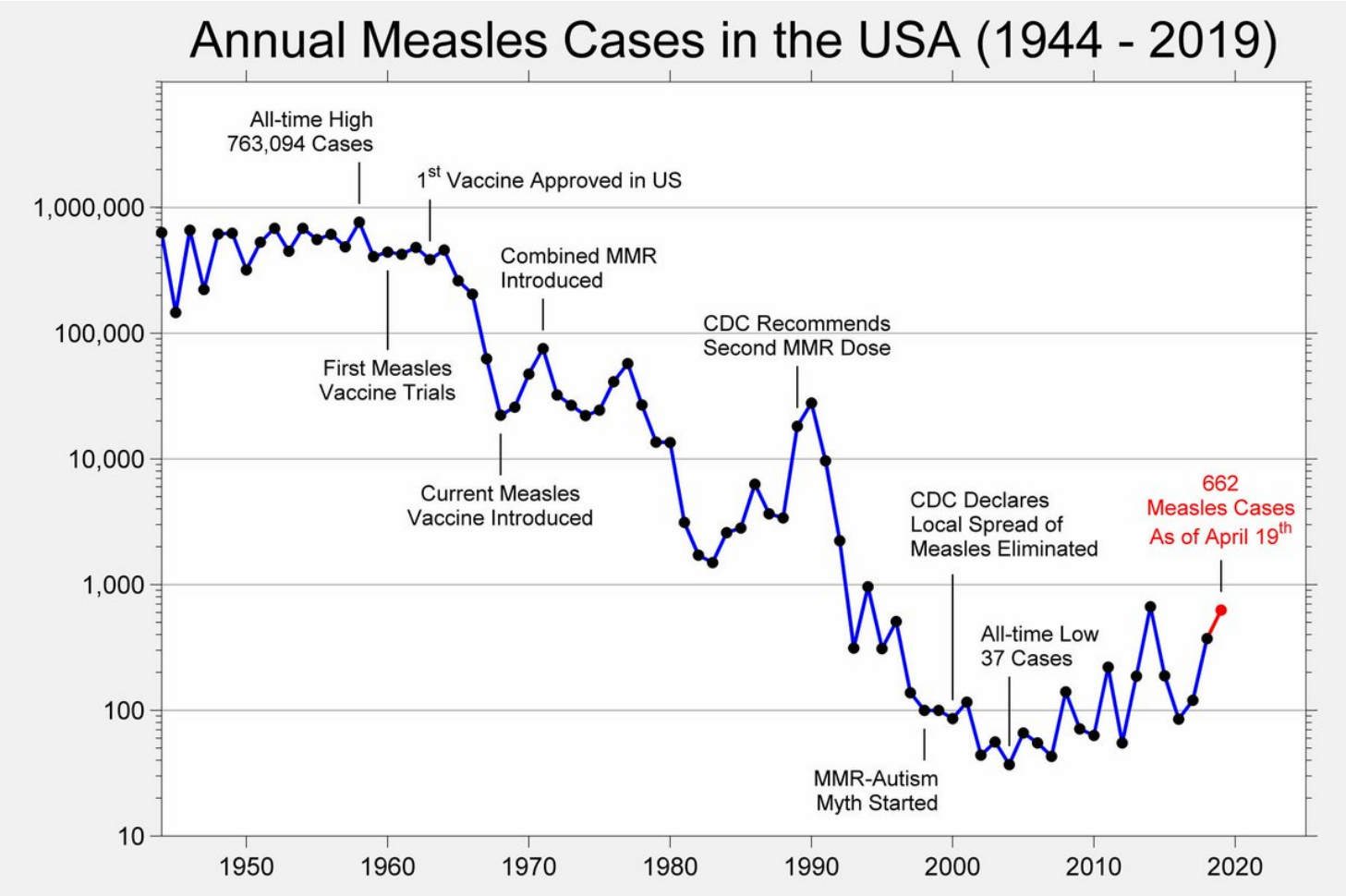
Evolution of measles cases in the US



Vaccination

Importance

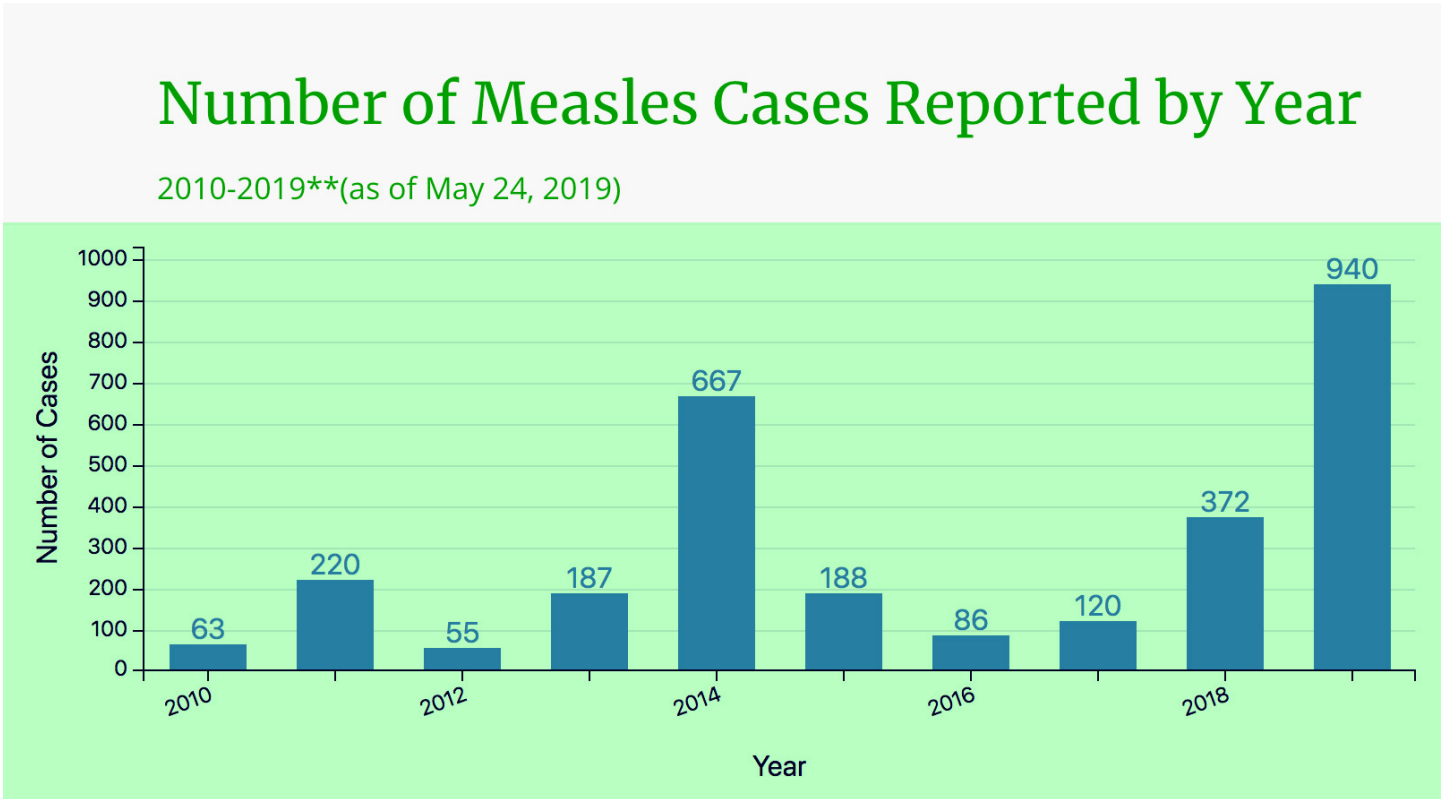
Evolution of measles cases in the US



Vaccination

Importance

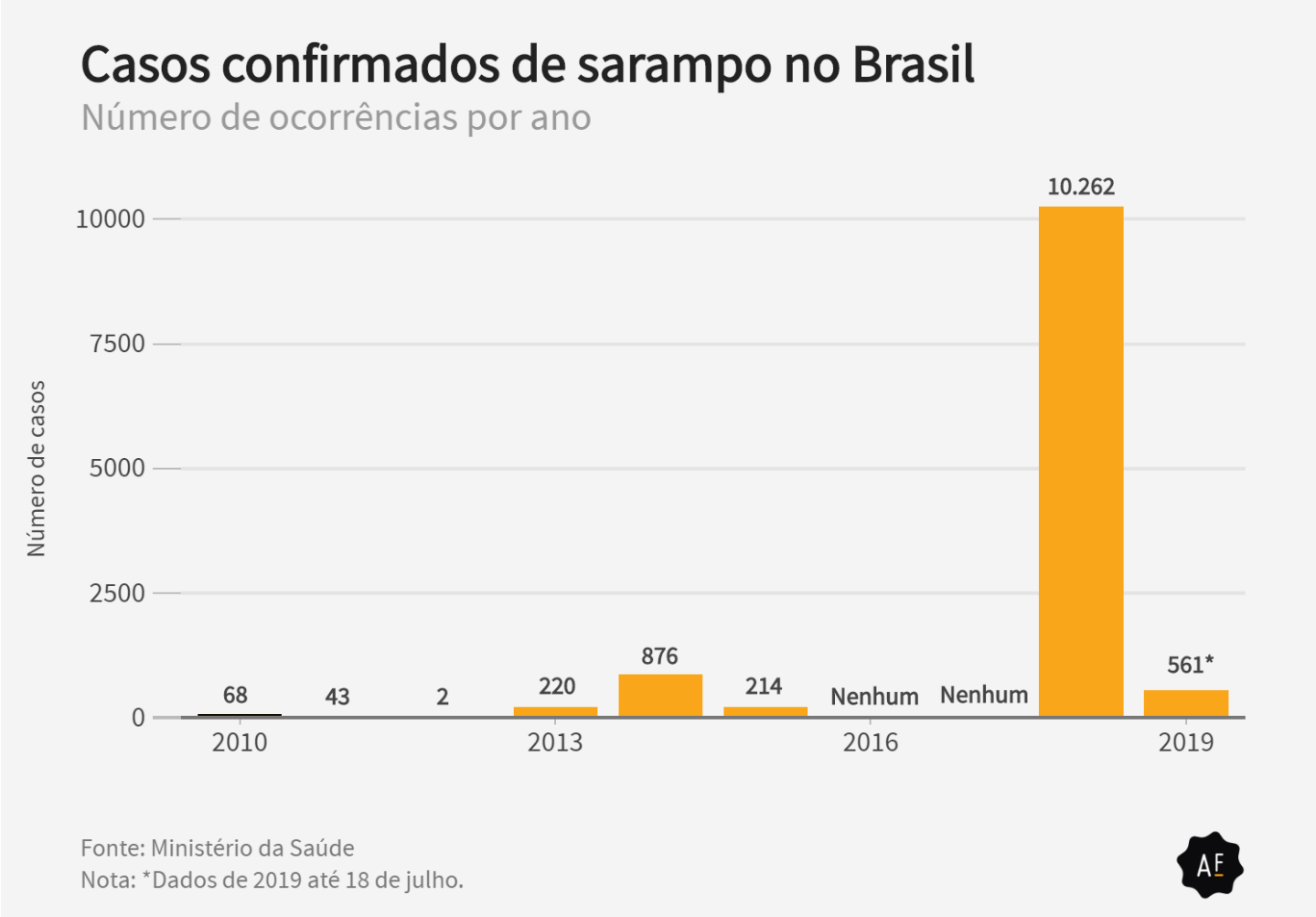
Evolution of measles cases in the US



Vaccination

Importance

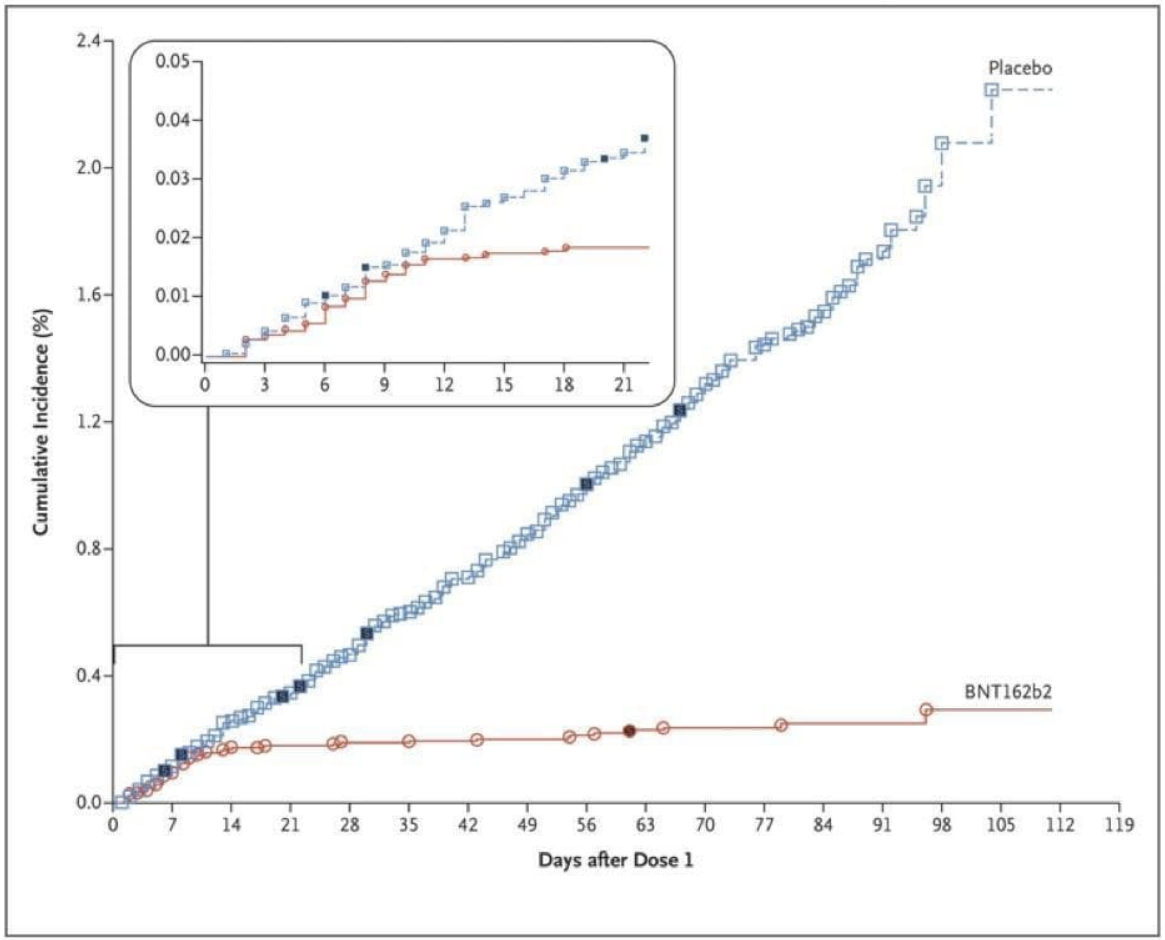
Recent measles cases in Brazil



Vaccination

Importance

We cannot fail to mention the importance of a vaccine in the current pandemic crisis generated by the new COVID-19



PFIZER/BIONTECH/NEJM

Vaccination in Brazil

Projections

International Conference on Computational Science

ICCS 2021: Computational Science – ICCS 2021 pp 497-510 | Cite as

How Fast Vaccination Can Control the COVID-19 Pandemic in Brazil?

Authors | Authors and affiliations

Rafael Sachetto Oliveira ✉, Carolina Ribeiro Xavier, Vinícius da Fonseca Vieira, Bernardo Martins Rocha, Ruy Freitas Reis, Bárbara de Melo Quintela, Marcelo Lobosco, Rodrigo Weber dos Santos

Conference paper
First Online: 09 June 2021

536
Downloads

Part of the Lecture Notes in Computer Science book series (LNCS, volume 12743)

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[4]Oliveira, R. S., Xavier, C. R., da Fonseca Vieira, V., Rocha, B. M., Reis, R. F., de Melo Quintela, B., ... and dos Santos, R. W. (2021). How fast vaccination can control the COVID-19 pandemic in Brazil?. In Computational Science–ICCS 2021: 21st International Conference, Krakow, Poland, June 16–18, 2021, Proceedings, Part II 21 (pp. 497-510). Springer International Publishing.

Vaccination

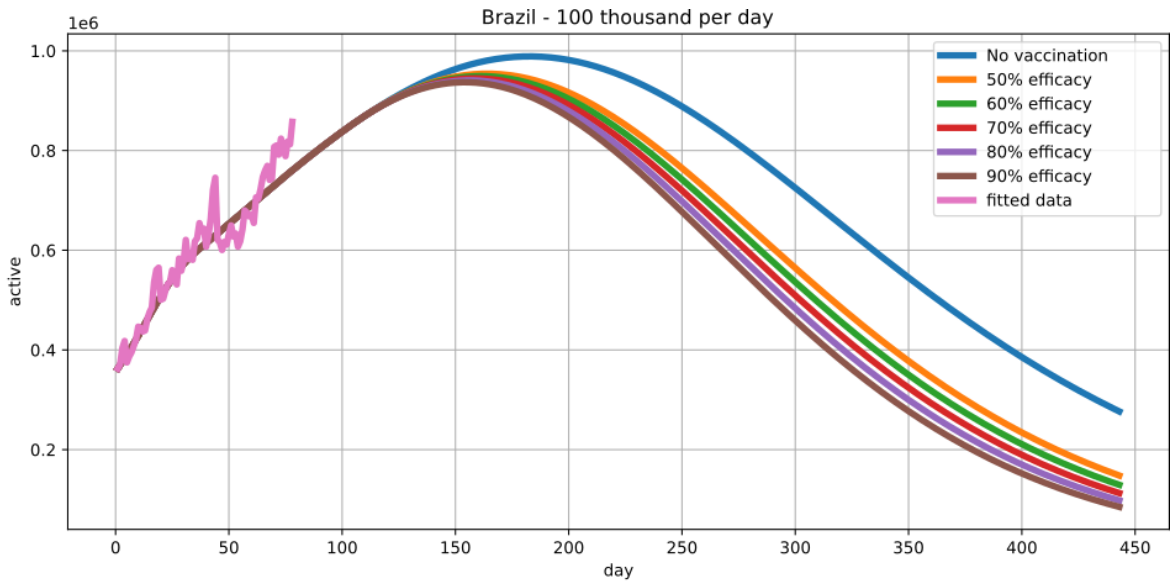
Mathematical model

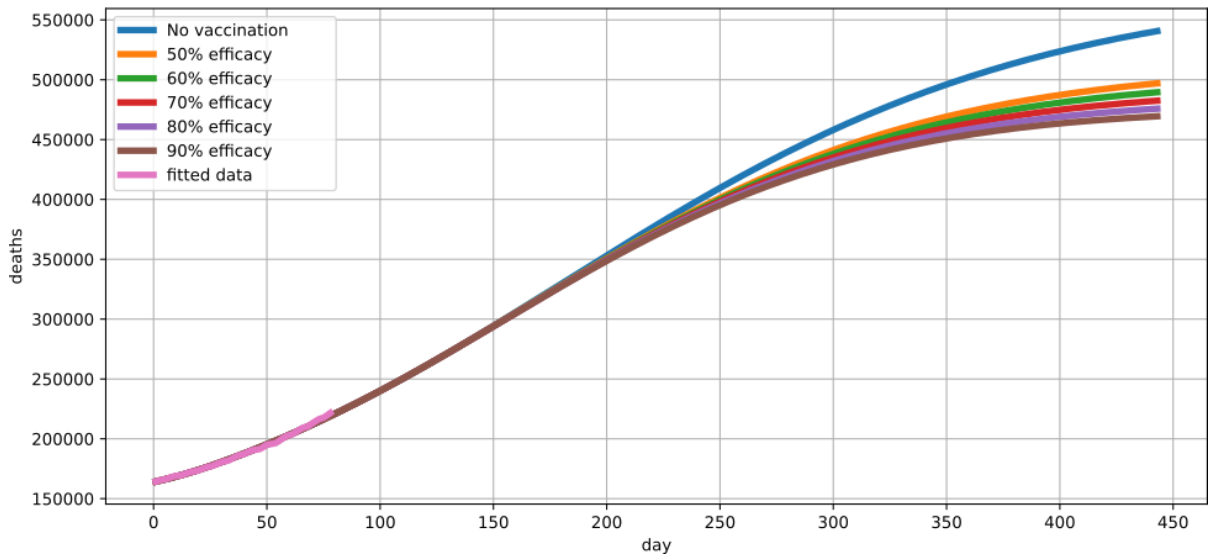
$$\begin{cases} \frac{dS}{dt} &= -\frac{\alpha(t)}{N}(S - v(t)S)I, \\ \frac{dI}{dt} &= \frac{\alpha(t)}{N}(S - v(t)S)I - \beta I - \gamma I, \\ \frac{dR}{dt} &= \gamma I, \\ \frac{dD}{dt} &= \beta I, \\ I_r &= \theta I, \\ R_r &= \theta R, \\ C &= I_r + R_r + D, \end{cases} \tag{1}$$

$$v(t) = \begin{cases} 0, & \text{if } t < (t_{vs} + t_{im}), \\ v_e v_r t, & \text{otherwise} \end{cases} \tag{2}$$

Vaccination

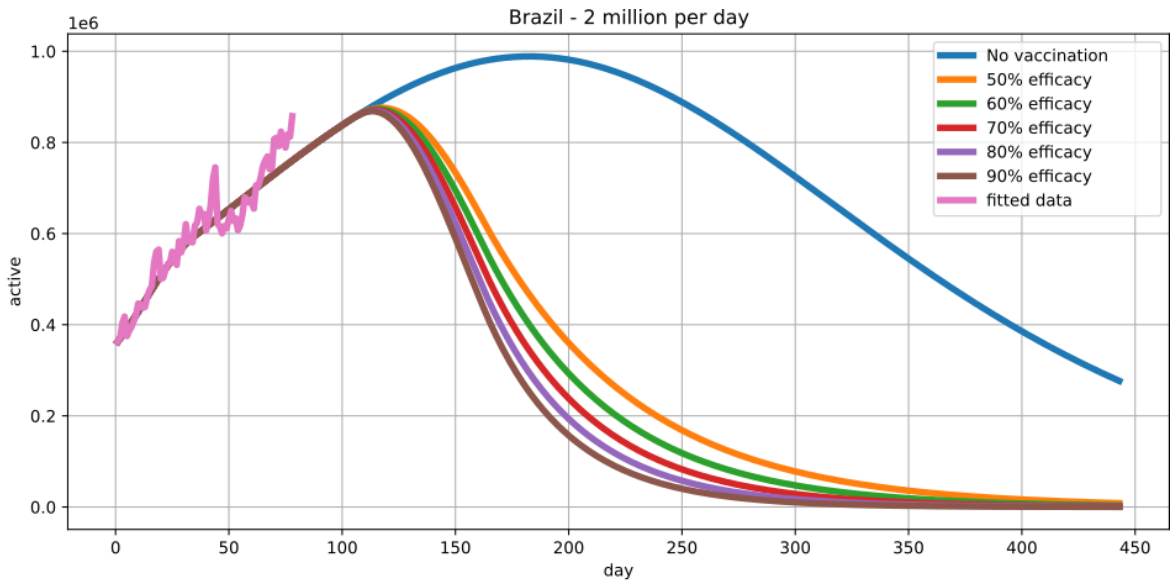
Results

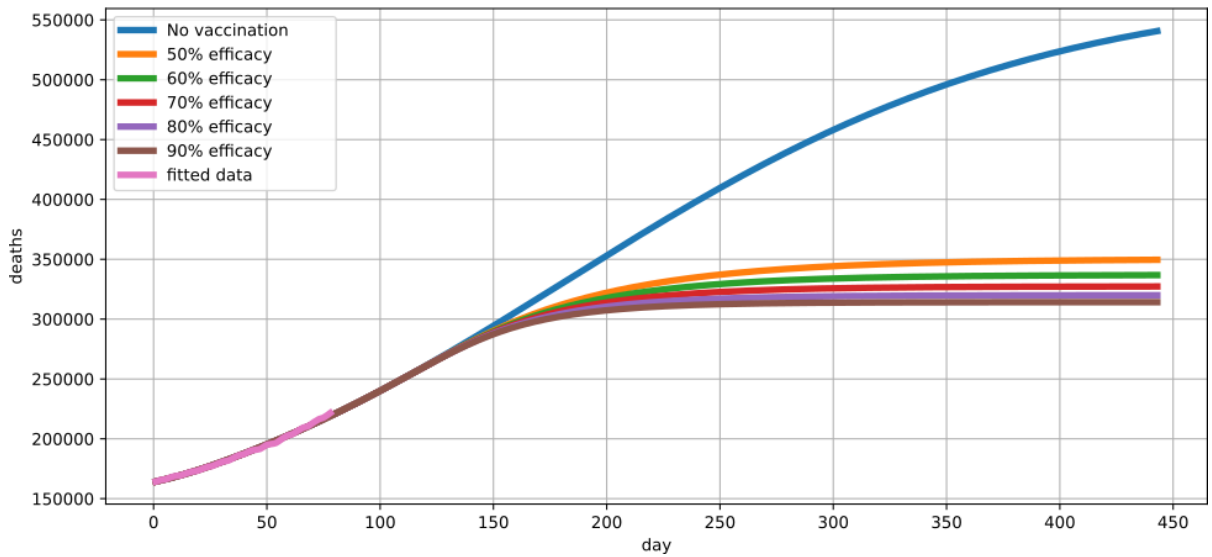




Vaccination

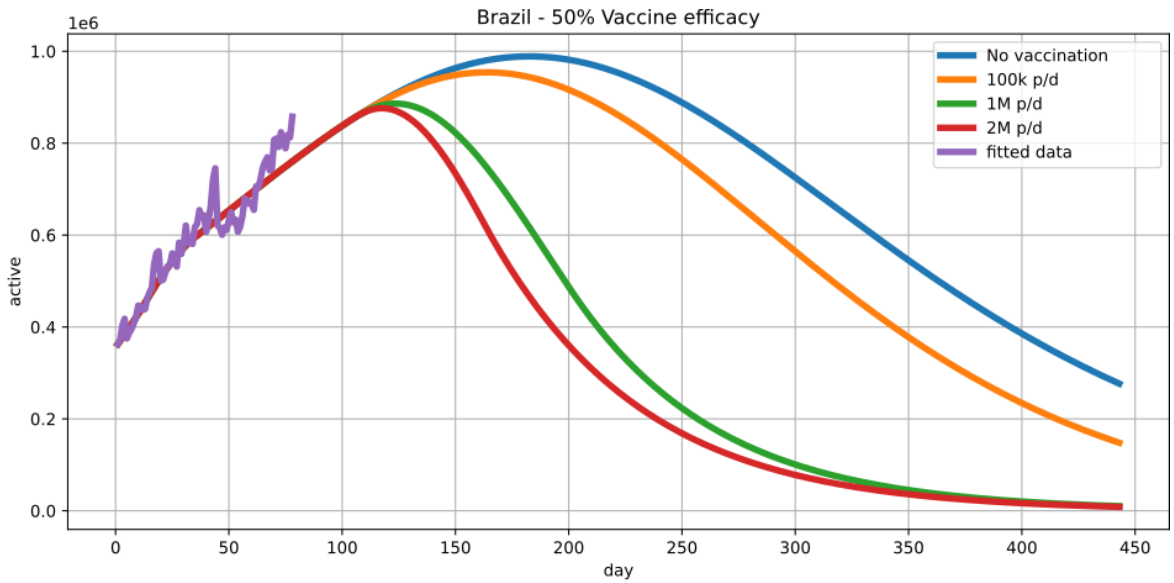
Results

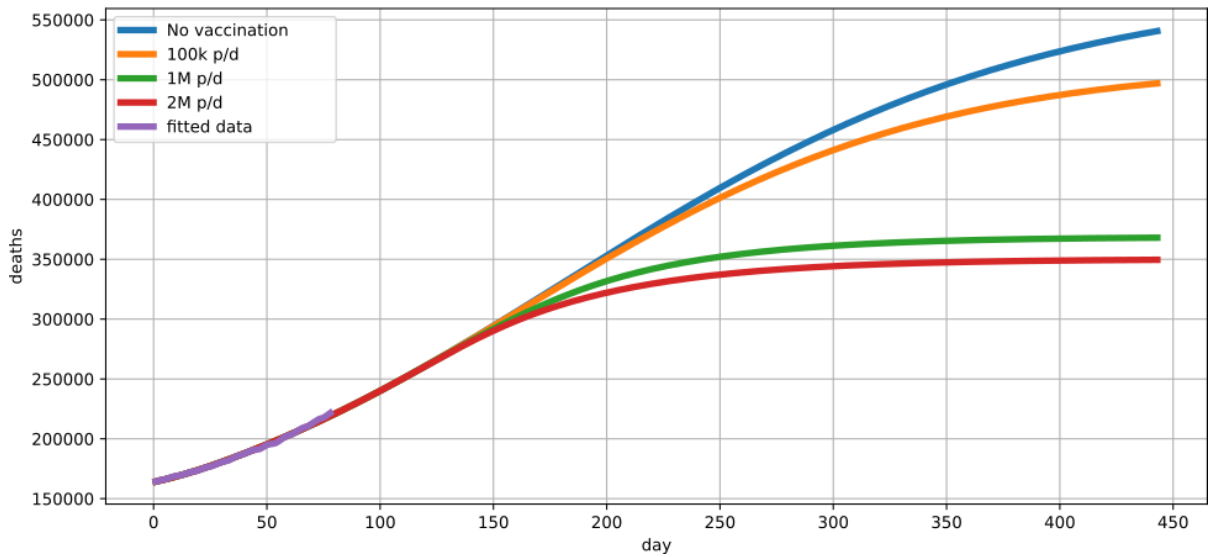




Vaccination

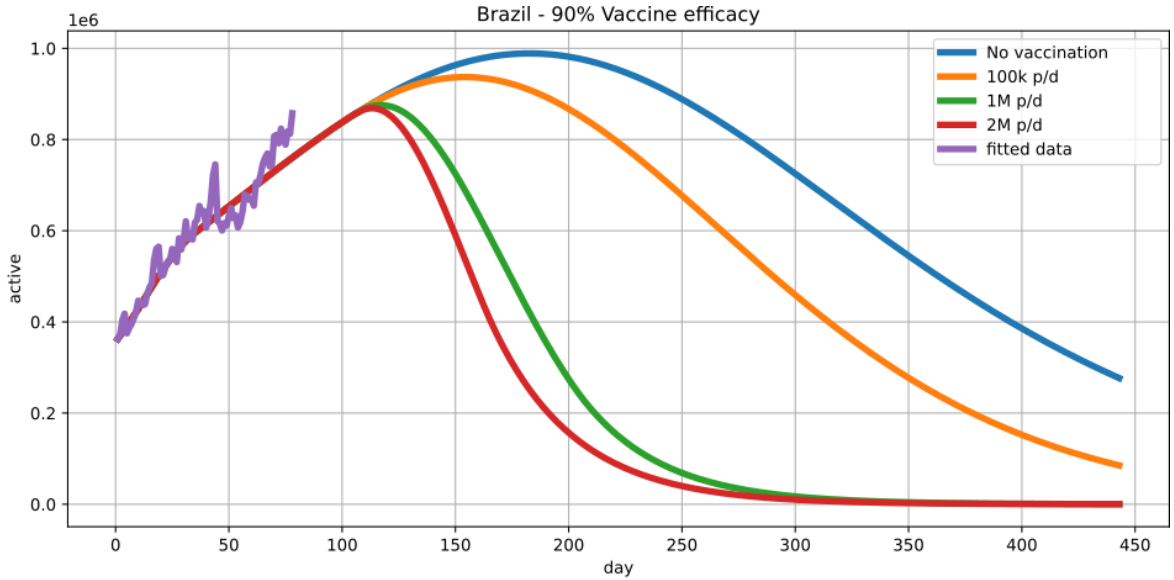
Results

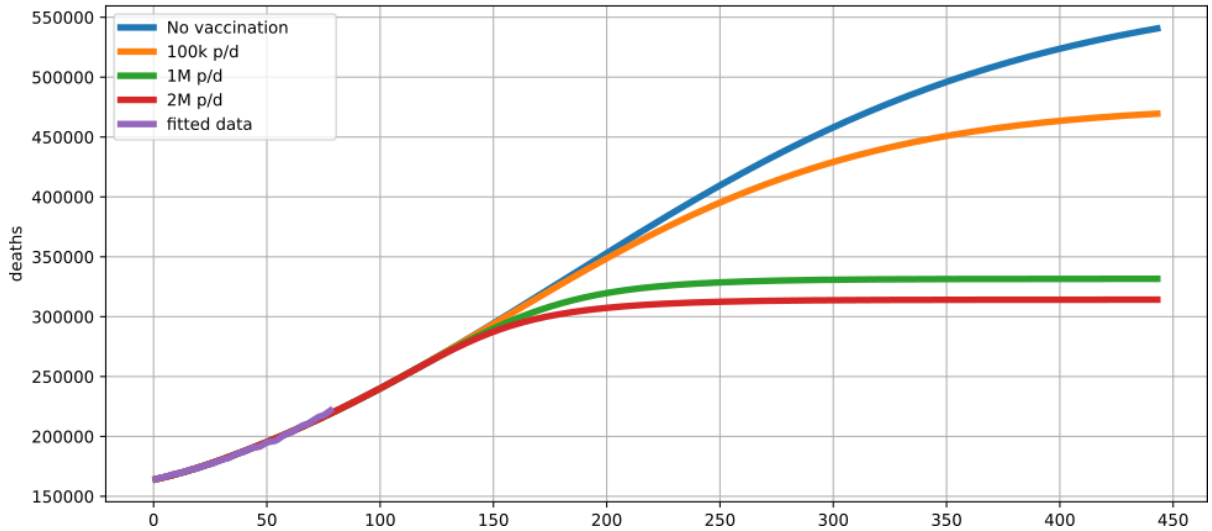




Vaccination

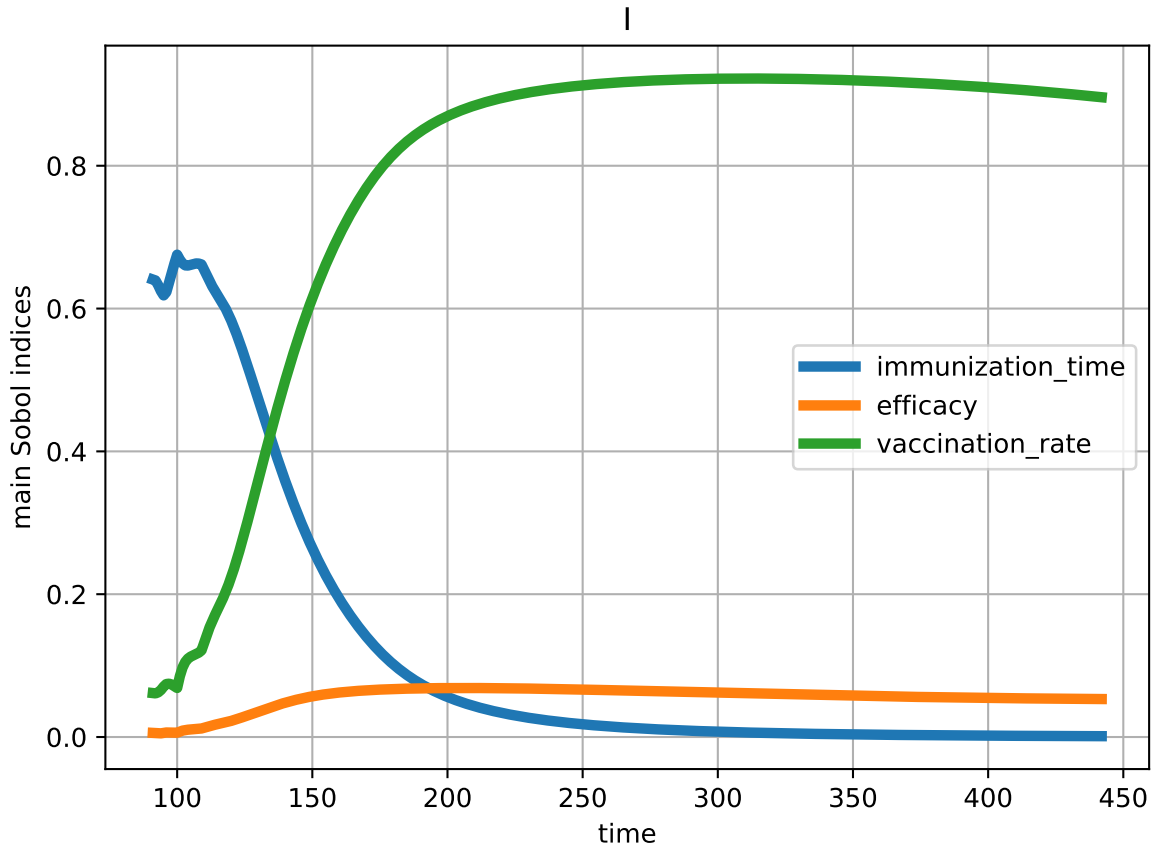
Results





Vaccination

Results



Overview

Cytokine Release Syndrome

- Immune responses are poorly understood: the multiscale interactions among the various components of the human immune system and the pathogen are very complex.
- The Cytokine Release Syndrome (CRS) or cytokine storm has been associated with a wide variety of infectious and non-infectious diseases for the past decades, including influenza and SARS-CoV
- Several mechanisms have been proposed to explain the CRS and the differences between survivors' and non-survivors cases of SARS-CoV-2.
- One hypothesis is that SARS-CoV-2 infects immune defense cells and causes CRS in patients with COVID-19

Cytokine Release Syndrome

Immune Model

frontiers in Molecular Biosciences

ORIGINAL RESEARCH
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Check for updates

A Validated Mathematical Model of the Cytokine Release Syndrome in Severe COVID-19

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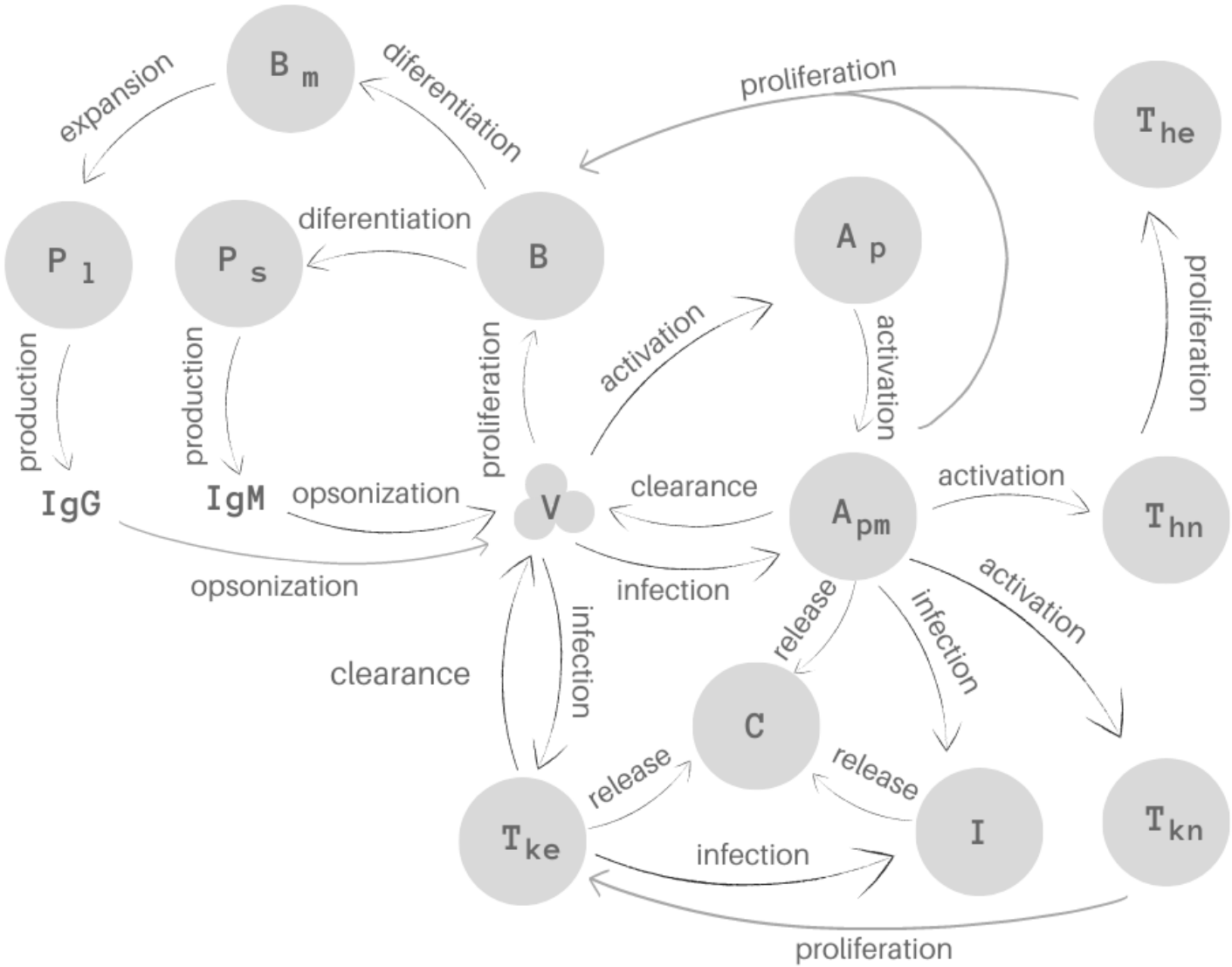
By June 2021, a new contagious disease, the Coronavirus disease 2019 (COVID-19), has infected more than 172 million people worldwide, causing more than 3.7 million deaths. Many aspects related to the interactions of the disease's causative

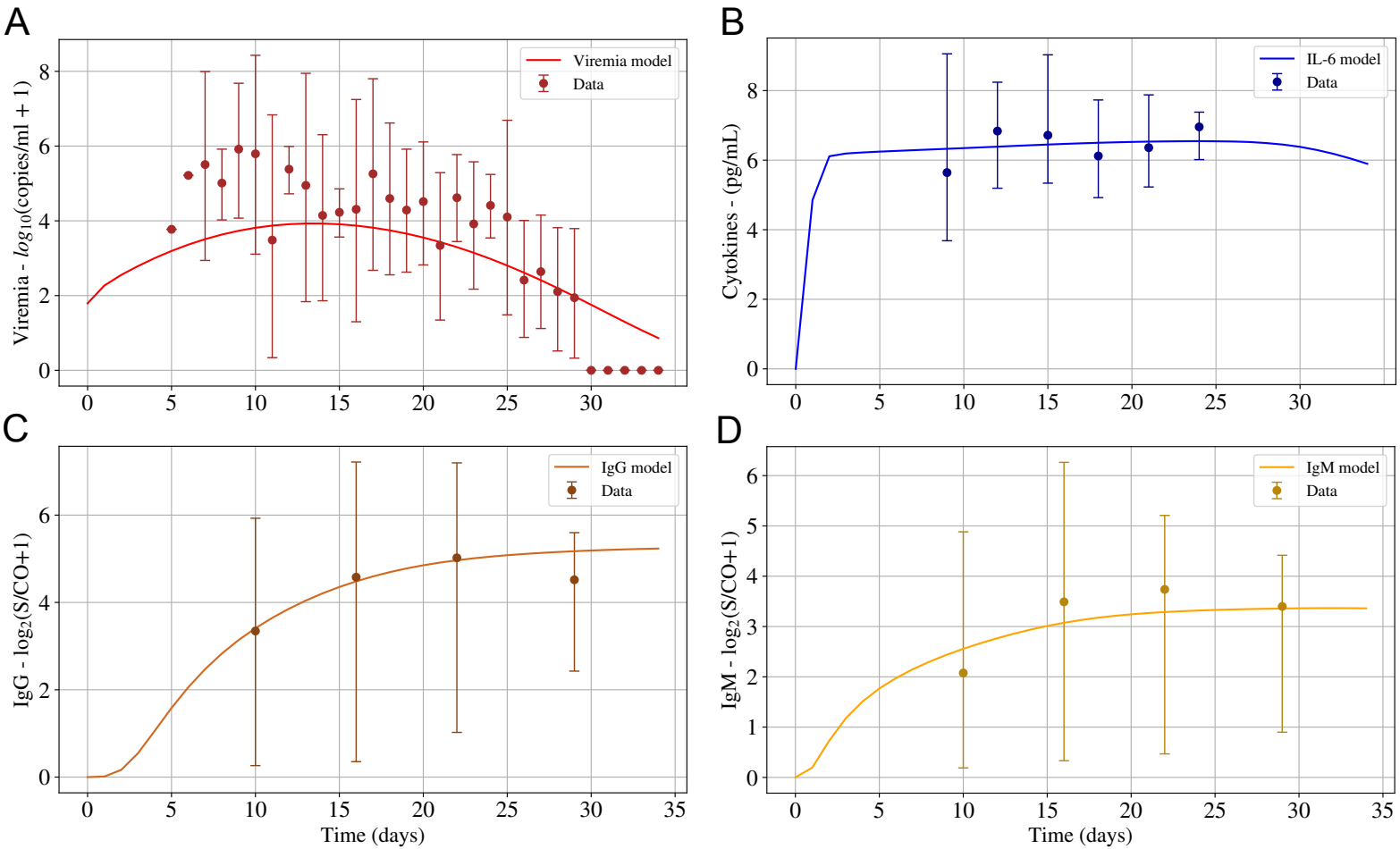
Immune System

Scheme of the Mathematical Model



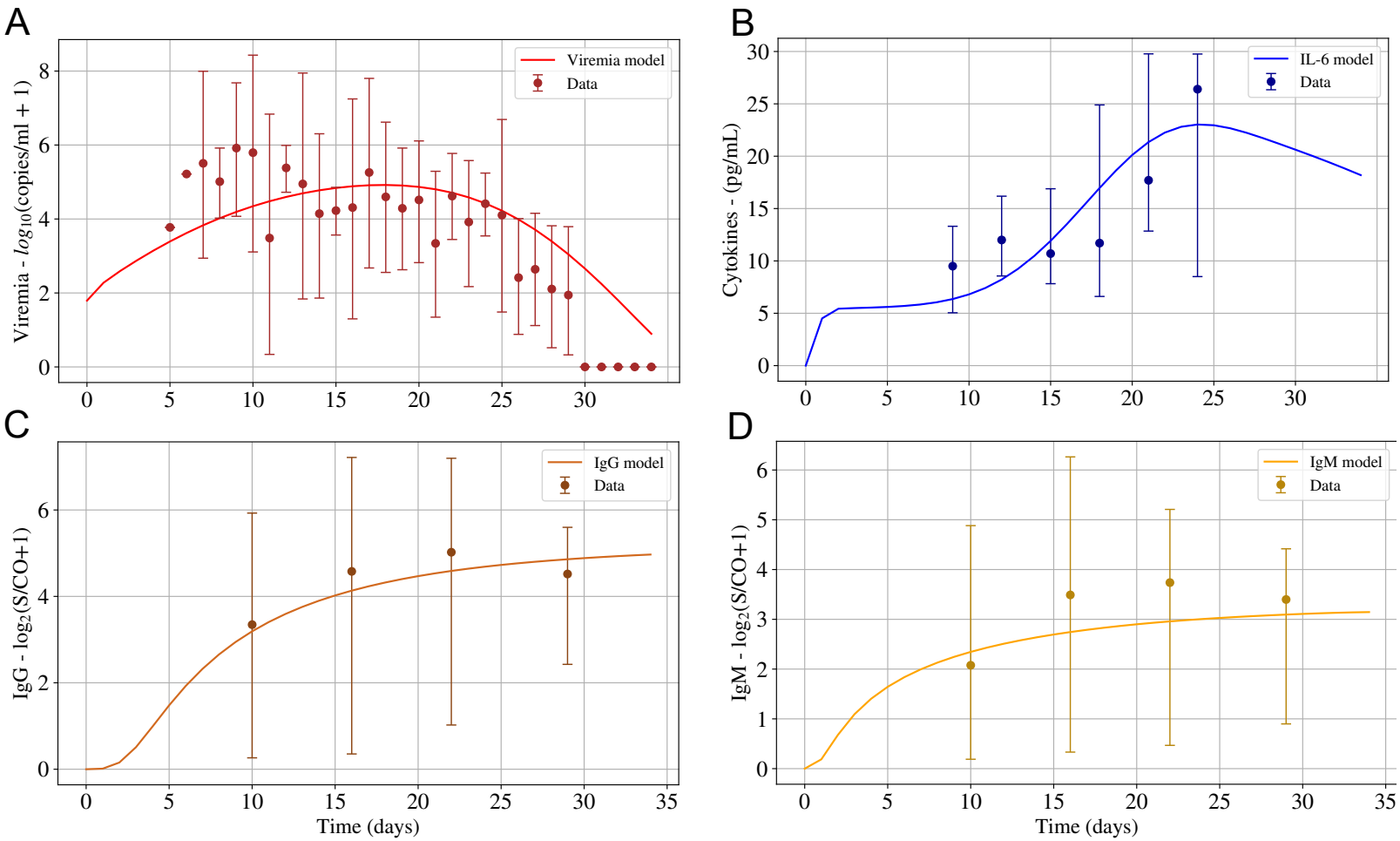
Numerical Adjustment

Survivor



Numerical Adjustment

Non-Survivor



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Danke Shön!
Obrigado!
Thanks!

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[5] 423278/2021-5
[6] APQ-01226-21

Overview

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