Ensuring quality of modeling of ARI dynamics: uncertainty quantification and features of calibration to data

Kseniya Sahatova, Aleksandr Kharlunin, Vasiliy Leonenko

ITMO University, Saint Petersburg, Russian Federation

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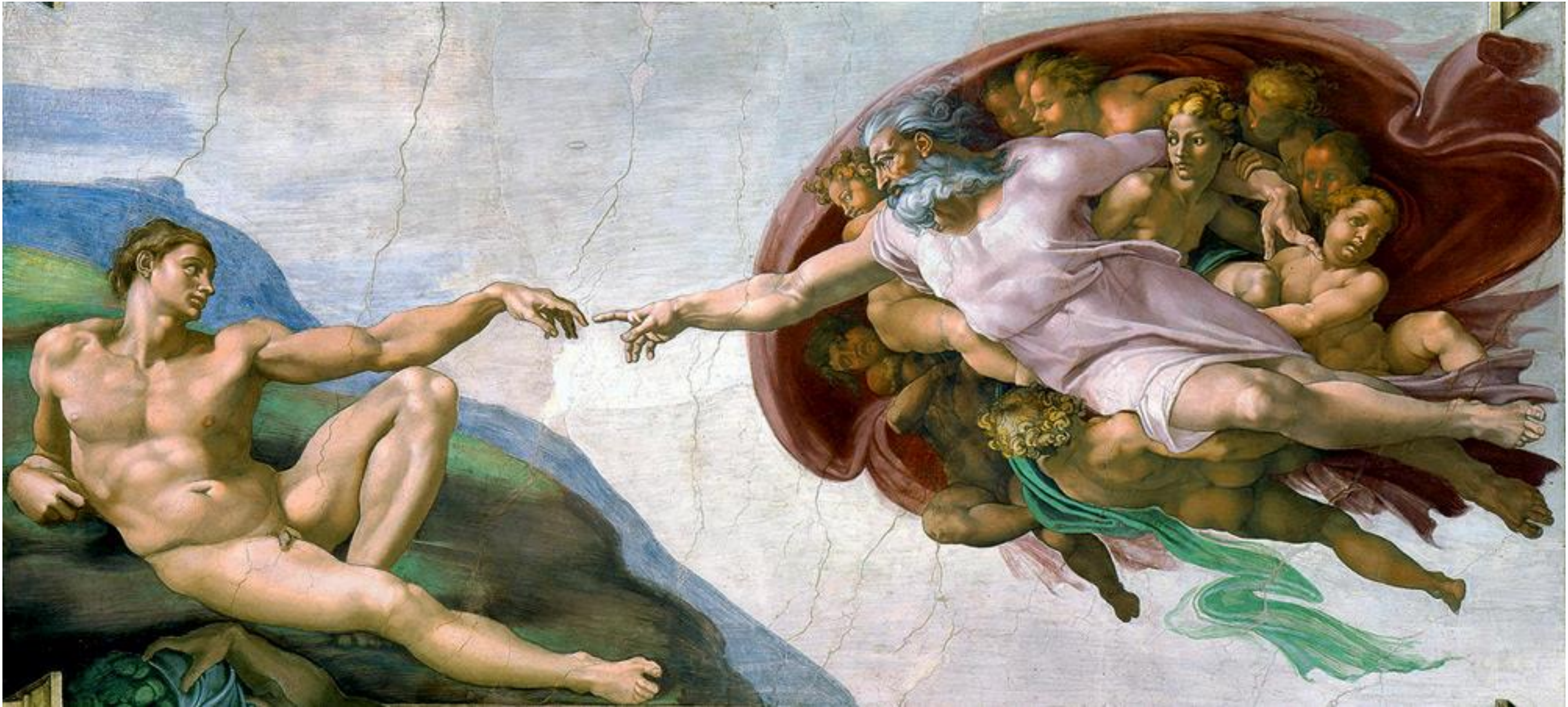
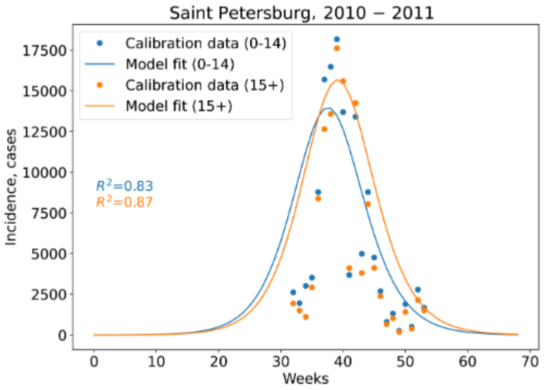
The main problem of mathematical epidemiology

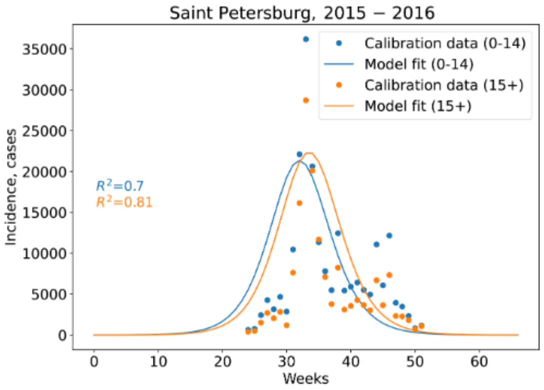


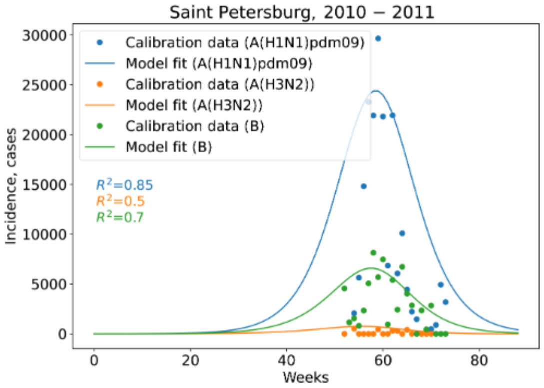
Motivation

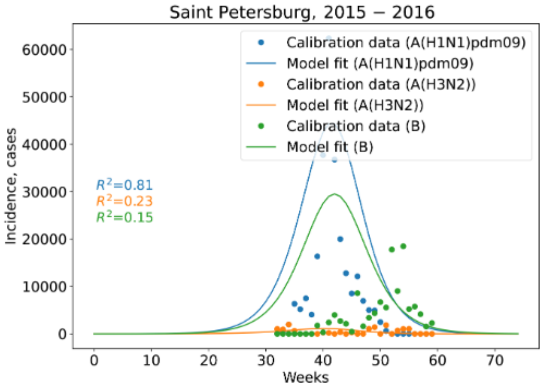
- Big uncertainty in data: the mathematicians cannot make good predictions no matter what, the epidemiologists should not blame us too much (if we have a justification)
- Poor model selection and uncertainty in model structure: the mathematicians should ask the epidemiologists for advice or at least admit the imperfection of modeling methods
- A “good model fit” in terms of mathematics is not good in terms of epidemiology, the mathematicians and the epidemiologists should figure something out together
- The aim of this work is to present an approach which
  - accounts for the uncertainty in the input to assess the uncertainty of the output (how well we can predict the incidence for a given set of input)
  - helps gain new insights from the epidemic data via model calibration and assess epidemic parameters from the model (e.g., R_0, R_t, immunity levels, etc.)
  - allows to change parameters of the calibrated model in interactive mode via a user interface
  - as a result, helps mathematicians and epidemiologists to collaborate more efficiently and facilitates planning of effective control measures

Influenza model fitting







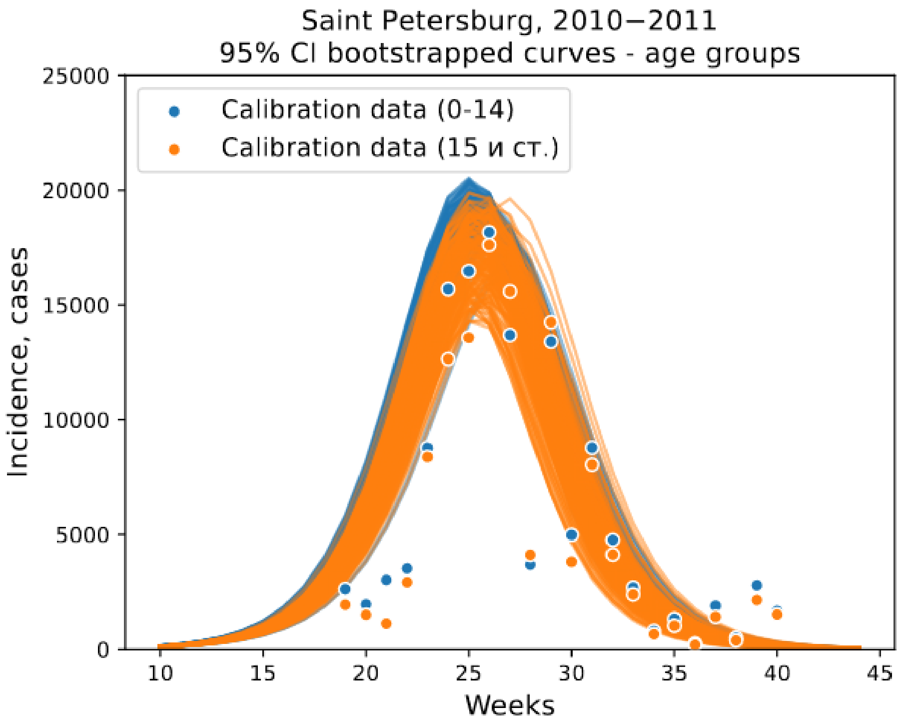


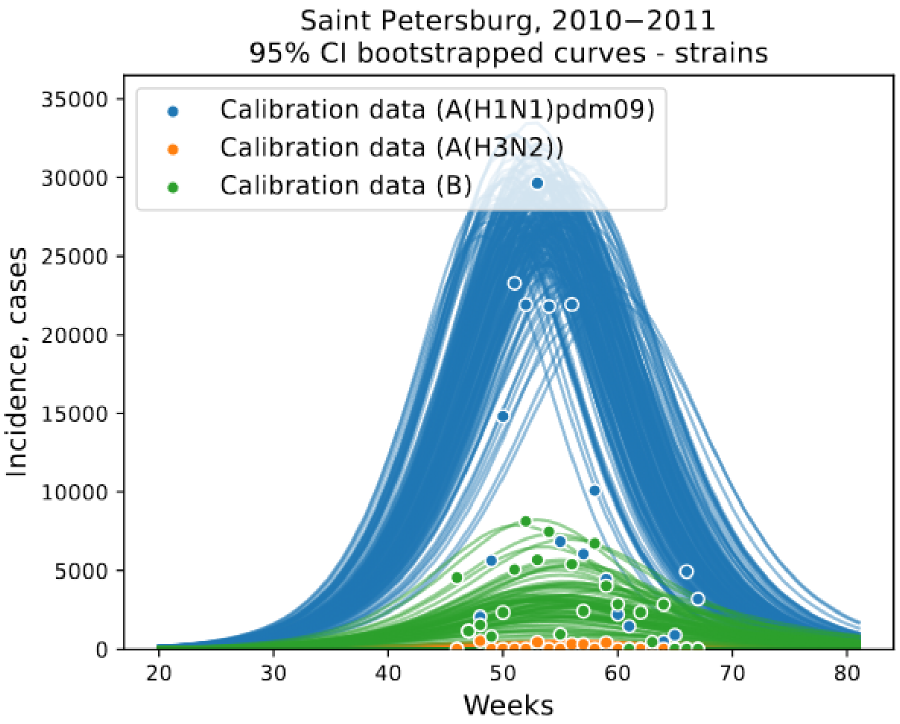
Uncertainty estimation algorithm

- Obtain the best-fit parameter values by calibrating the model to the original incidence data incidence.
- Measure the uncertainty in data and select the model error (wider stripes on the graphs correspond to bigger uncertainty in data)
- Generate 200 datasets by adding random errors to calibrated modeling curve
- Re-estimate the model parameters by calibrating the model on the generated data
- Characterize the distribution of model parameters

Inspired by: Chowell, G.: Fitting dynamic models to epidemic outbreaks with quantified uncertainty: a primer for parameter uncertainty, identifiability, and forecasts. Infect. Dis. Model. 2(3), 379–398 (2017)

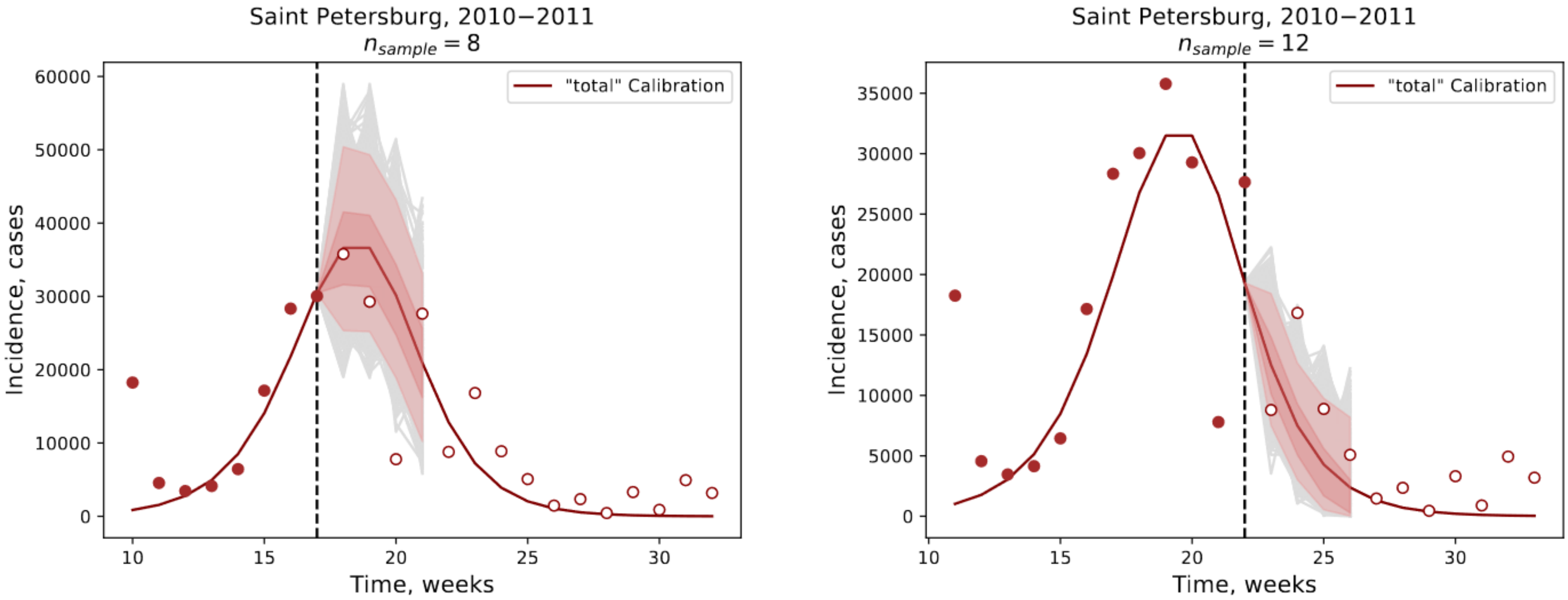
Influenza model re-fitting





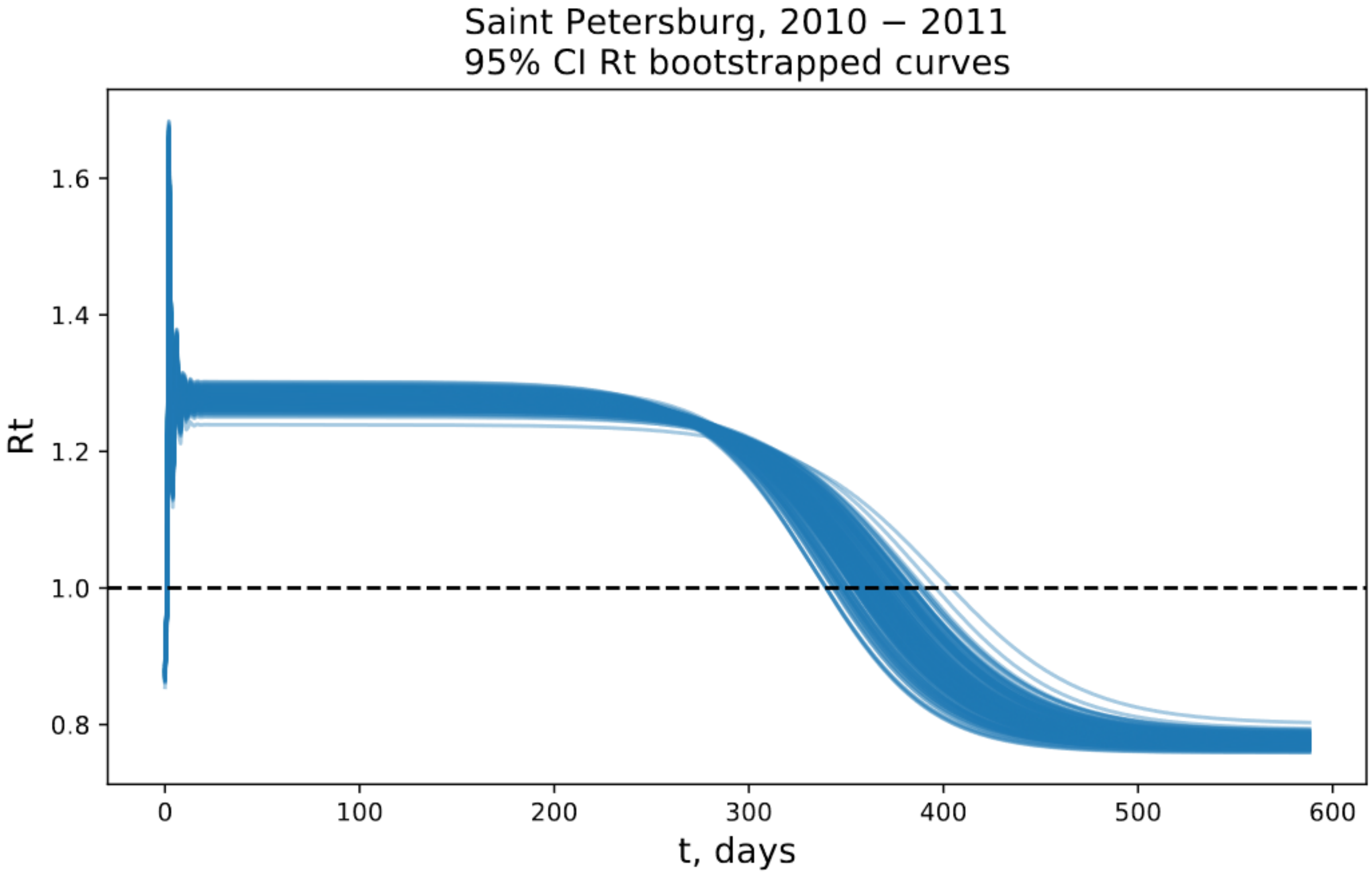
Visualization of re-fitted curves after bootstrap procedure for the epidemic season of influenza in 2010-2011 in St. Petersburg, Russia

Influenza forecasting

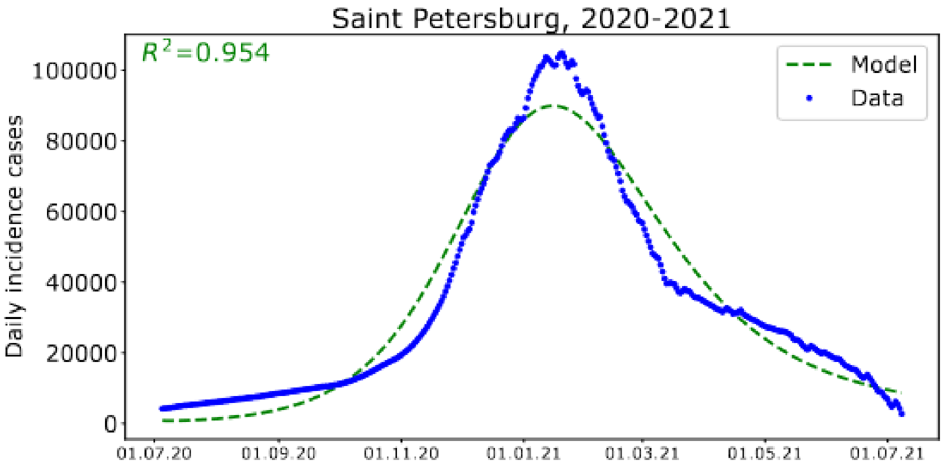


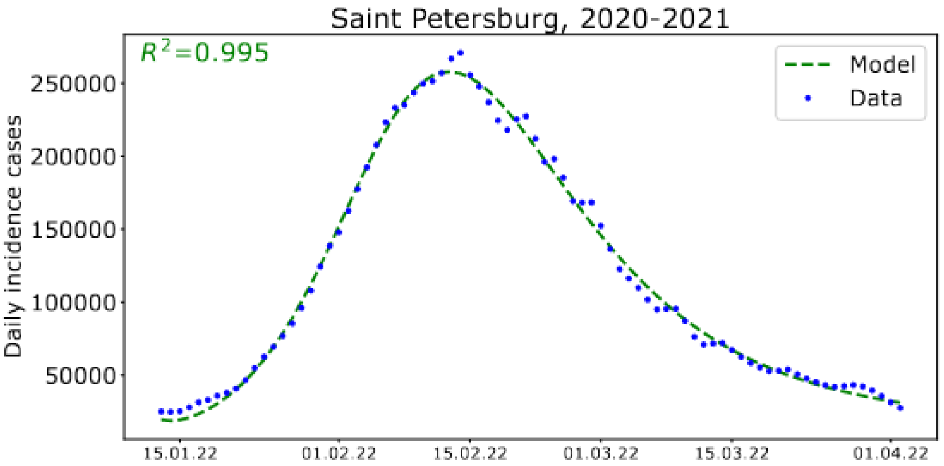
Four weeks forecast derived from the empirical distributions acquired after n = 1000 resamples
(a) ns = 8 (b) ns = 12

Assessing values of epidemic indicators

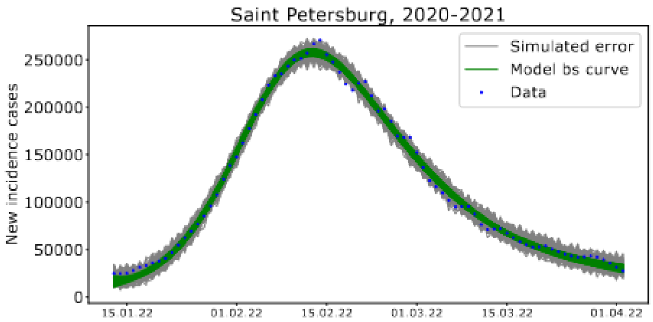


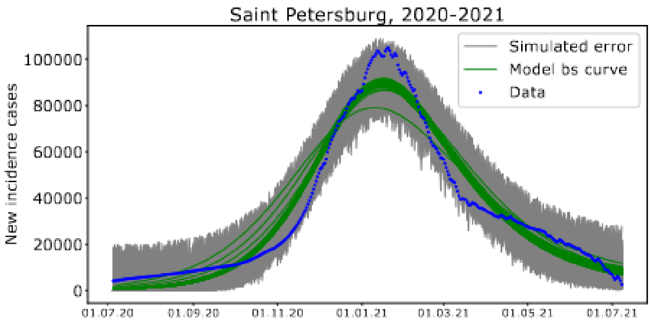
COVID-19 modeling

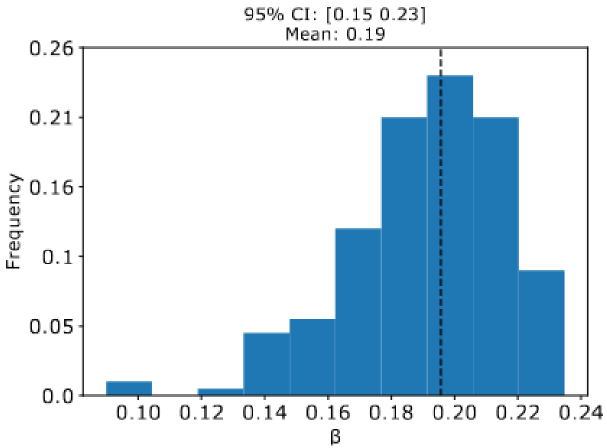


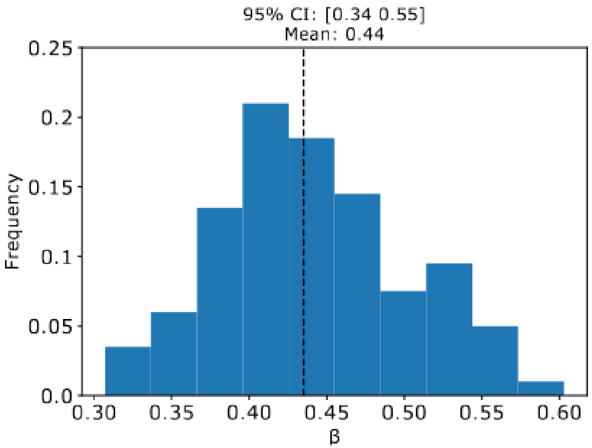


COVID parameter estimation

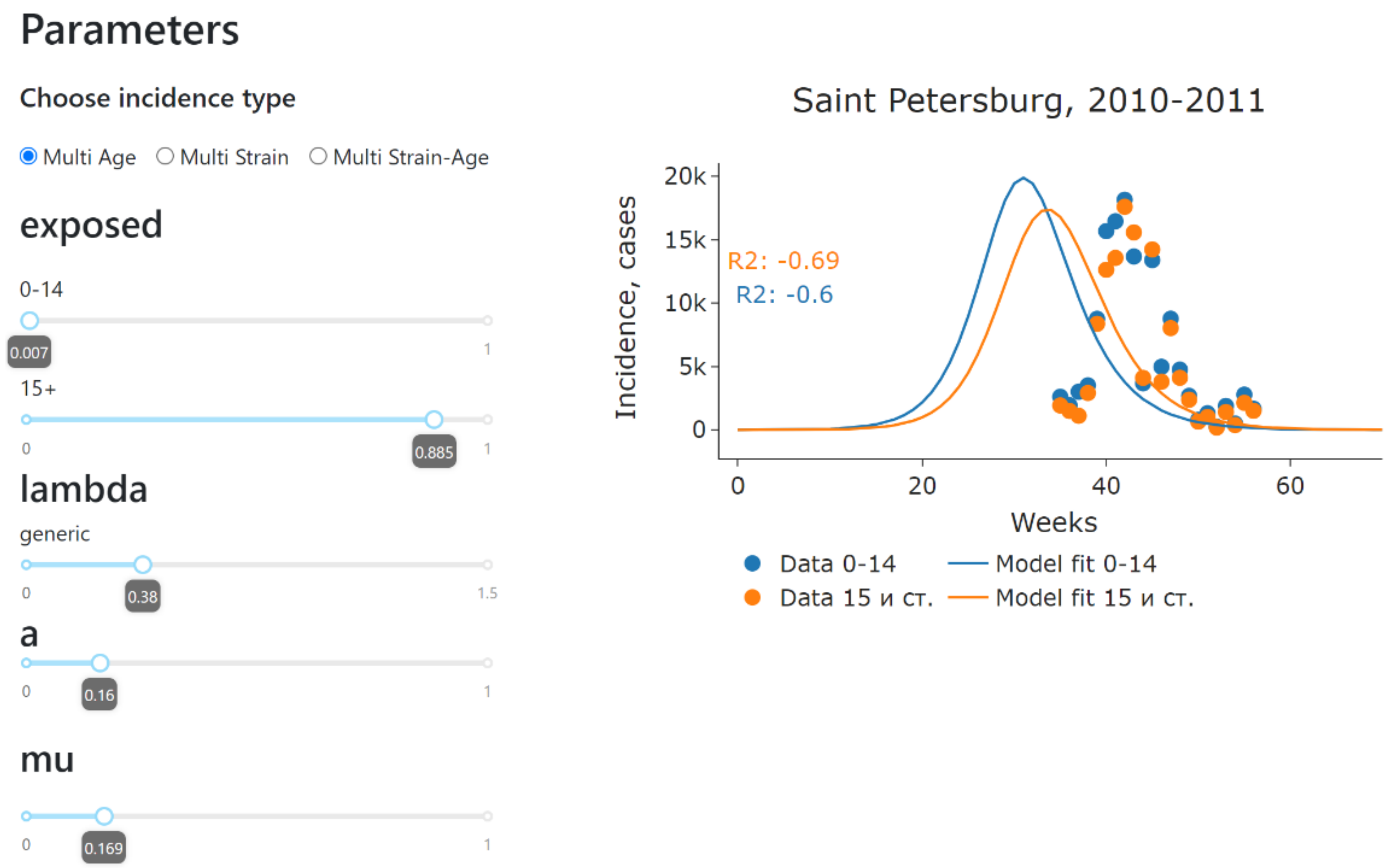




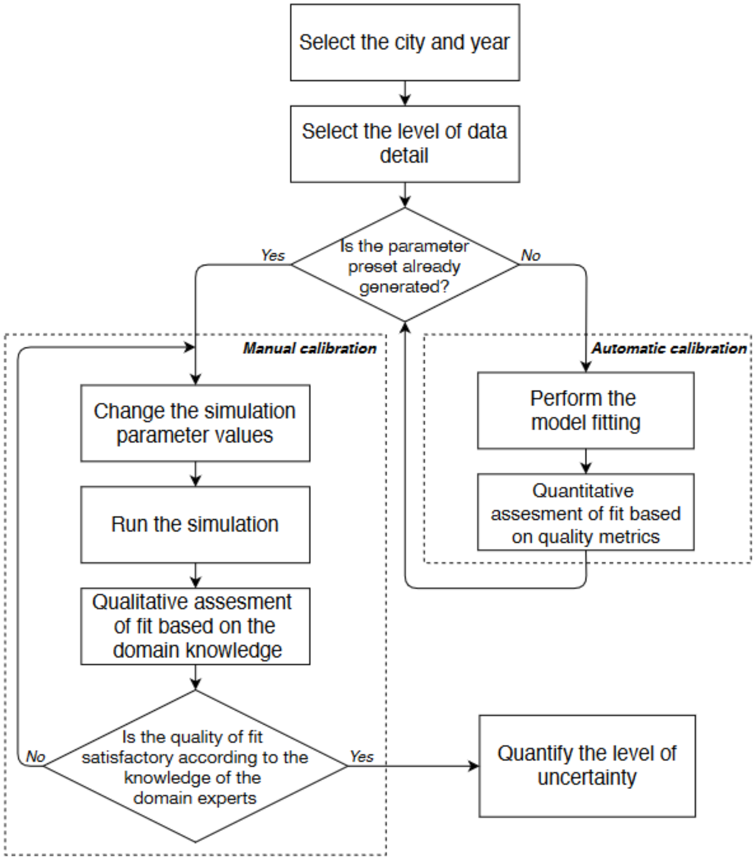


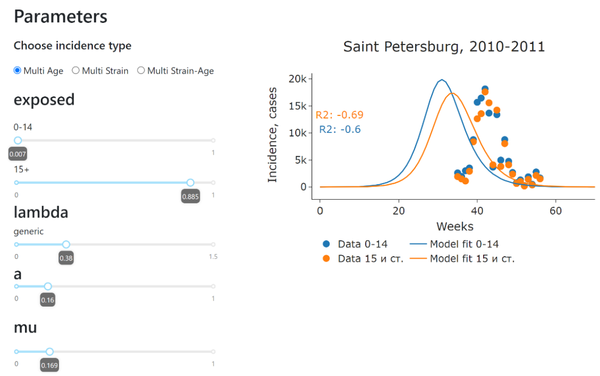


Interface layout

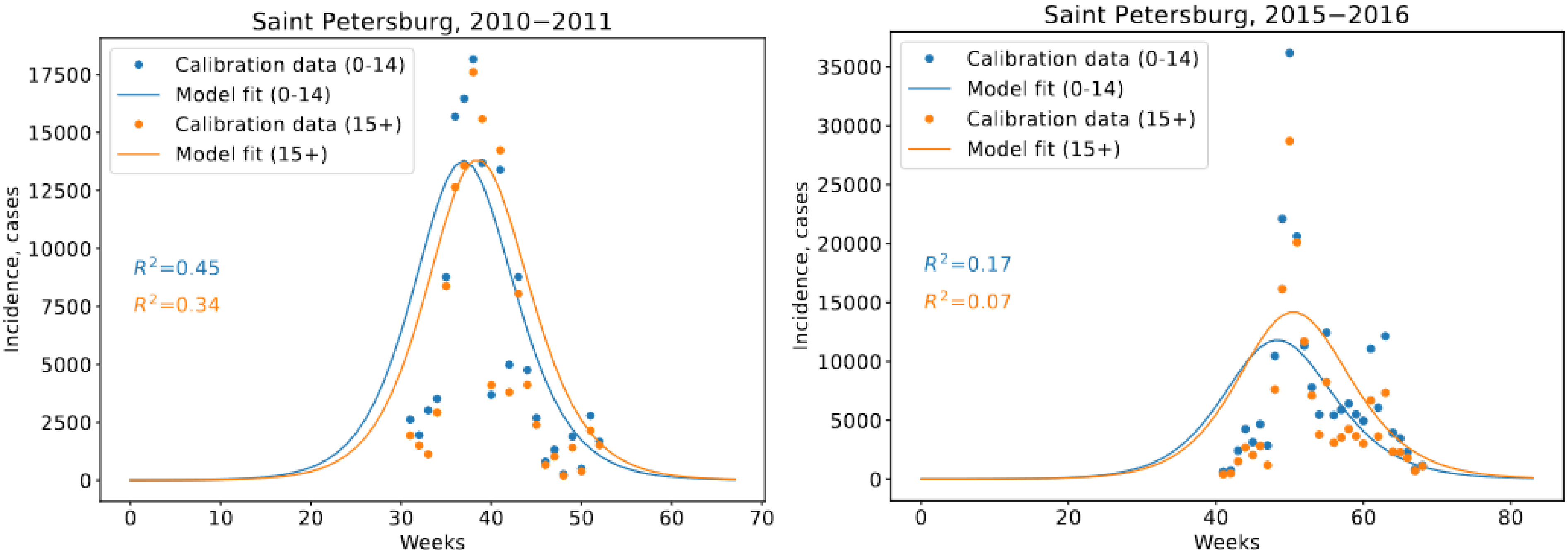


Framework scheme



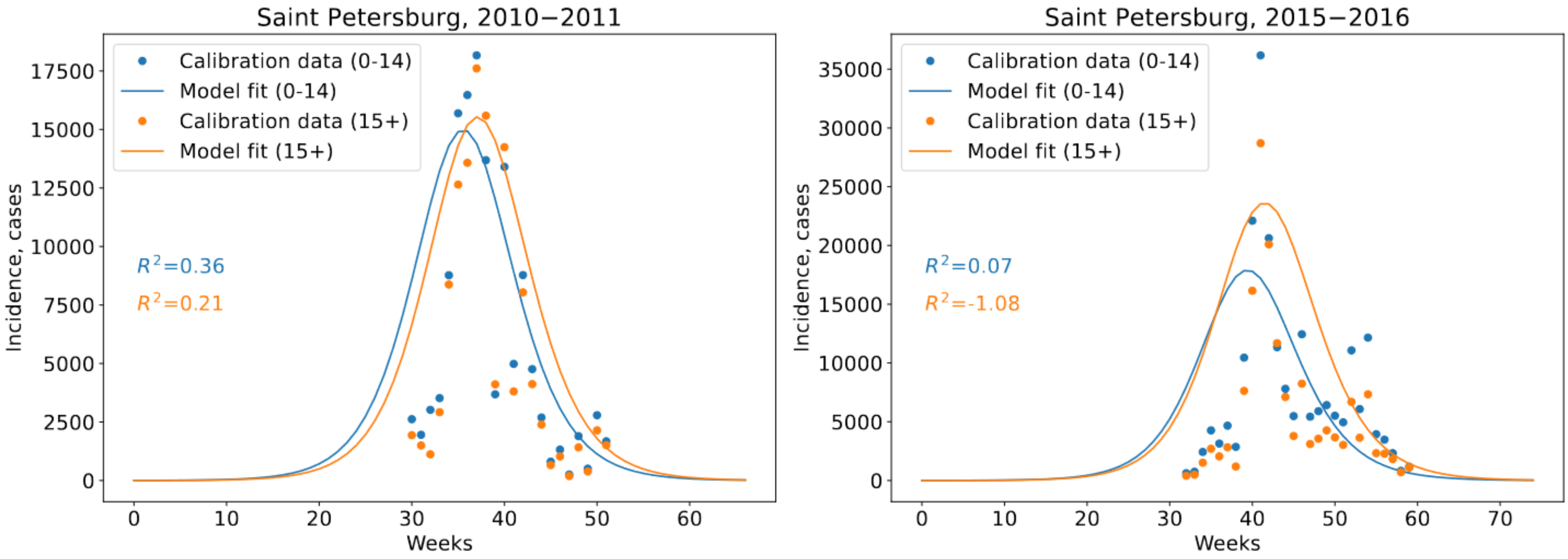


Automatic fitting, no weights



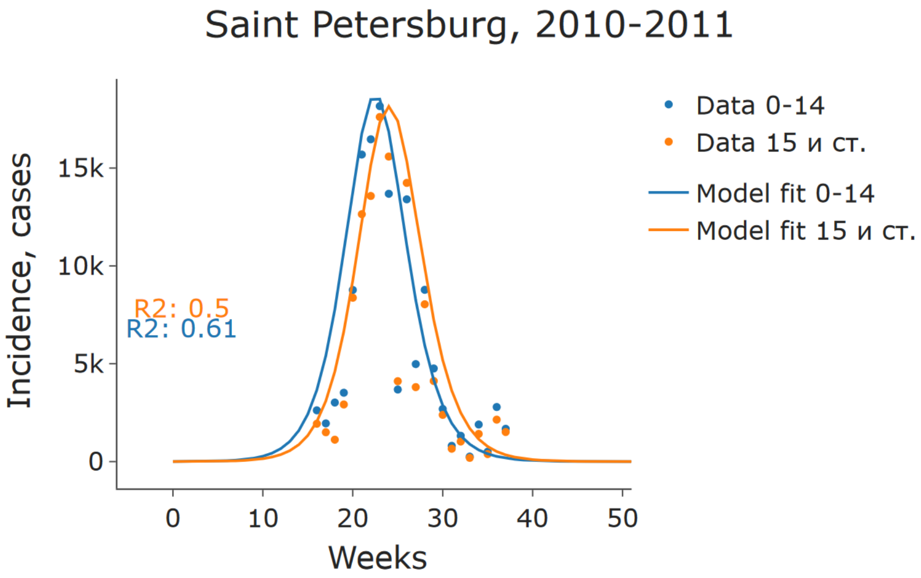
Model fit over age-specific incidence data of 2010-2011 (left) and 2015-2016 (right) epidemic seasons

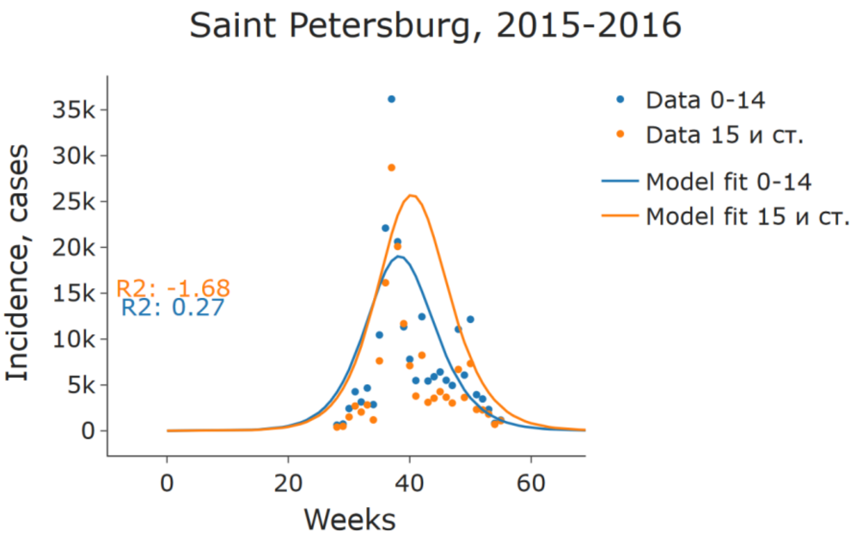
Automatic fitting, weights



Model fit over age-specific incidence data of 2010-2011 (left) and 2015-2016 (right) epidemic seasons

Manual fitting





Model fit over age-specific incidence data of 2010-2011 (left) and 2015-2016 (right) epidemic seasons

Conclusions

- We proposed an algorithm which helps address the problems of use of mathematics in epidemiology:
    - uncertainty in data and model selection
    - unclear metrics of success
- The algorithm calculates predictions and epidemic indicators accounting for uncertainty in data
- The automated calibration process allows to obtain preliminary values of model parameters, whereas the manual calibration helps to discuss the results with the epidemiologists and modify the parameters according to their perception of “a good result”
- As a next step, we plan to prepare a graphical user interface and additional services that will allow the generation of weekly reports on influenza and COVID surveillance in automatic mode

Thank you
for your attention!

E-mail: vnleonenko@itmo.ru