UNIVERSITY OF WARSAW

UNIVERSITY OF WARSAW
Interdisciplinary Centre for Mathematical and Computational Modelling
icm.edu.pl

# The ICM Epidemiological model and its applications.

Experience Sharing Seminar: Medicine and HPC

Riga, EuroCC Latvia

12 June 2025

Franciszek M. Rakowski

Interdisciplinary Centre for Mathematical and Computational Modelling,

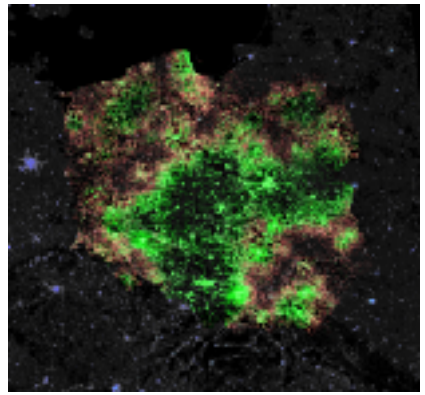
University of Warsaw

# ICM UW Epidemiological Model
# Our Story

UNIVERSITY OF WARSAW

UNIVERSITY OF WARSAW
Interdisciplinary Centre for Mathematical and Computational Modelling
icm.edu.pl

- In the years 2008 - 2010 the full-population Agent Based Model for simulating influenza spread has been developed
- The works on the model have not been continued - the code was on the shelf, and the team was dispersed
- In February 2020 we have reanimated the model, and started to vigorously work on adaptation to Covid-19 epidemic specificity: both in biology and crisis governance
- But, we were institutionally “nobody”. A gang of strange freaks who claim to be able can predict and control the epidemics.



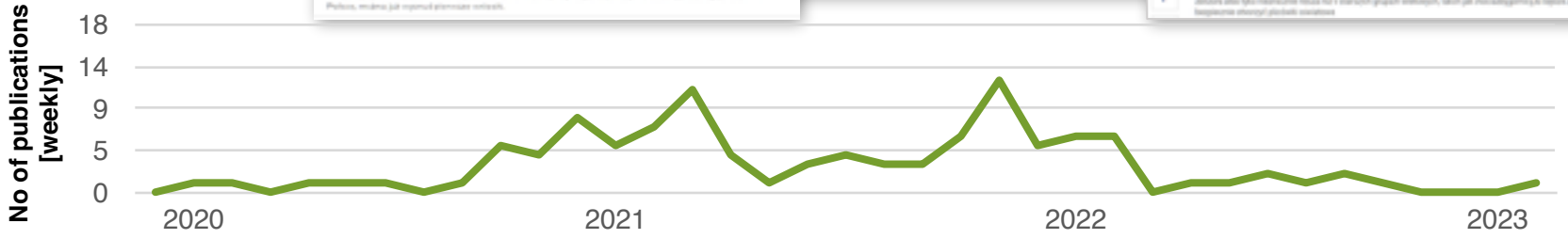
Historical snapshot from AH1N1 influenza study.

# ICM UW Epidemiological Model
# Our Story

UNIVERSITY OF WARSAW

UNIVERSITY OF WARSAW
Interdisciplinary Centre for Mathematical and Computational Modelling
icm.edu.pl

- We have experienced also a substantial exposition to the media.
  It was important, due to educational reasons, but it was also really hard work.

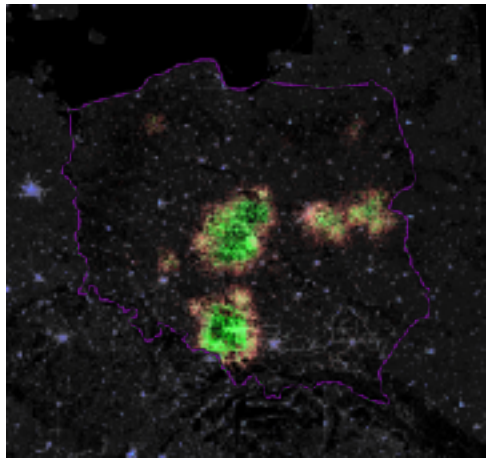
# The landscape of epidemiological models.

UNIVERSITY OF WARSAW

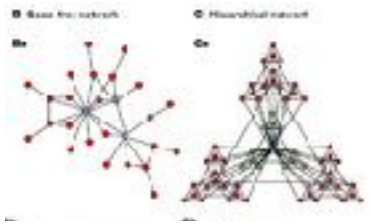
UNIVERSITY OF WARSAW
Interdisciplinary Centre for Mathematical and Computational Modelling
icm.edu.pl

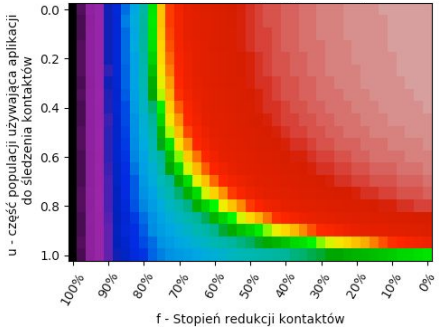
## Agent-based models

1. Geo-referential models



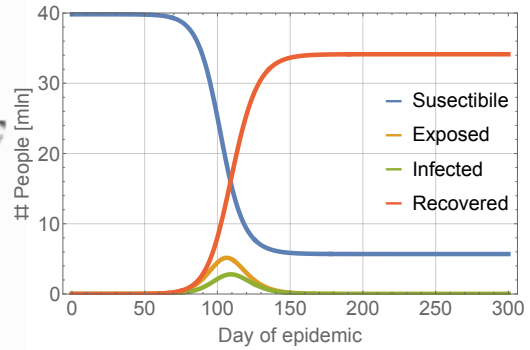
2. Network-based models



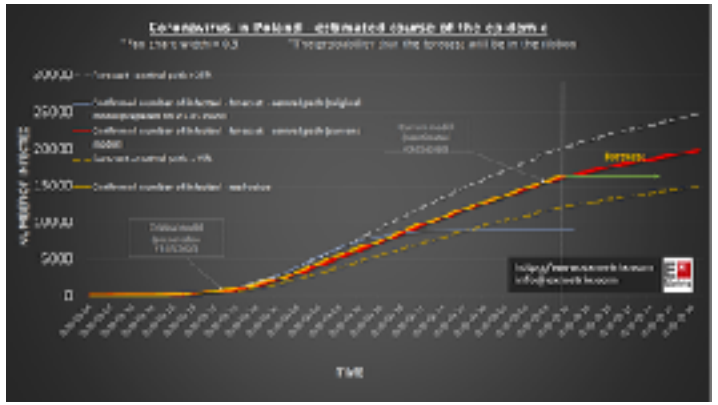



## ODE's SEIR models

$$\frac{dS}{dt} = -\frac{\beta S I}{N}$$
$$\frac{dE}{dt} = \frac{\beta S I}{N} - \sigma E$$
$$\frac{dI}{dt} = \sigma E - \gamma I$$
$$\frac{dR}{dt} = \gamma I$$




## Machine learning models



# ICM UW Epidemiological Model
# Our Story

UNIVERSITY OF WARSAW

UNIVERSITY OF WARSAW
Interdisciplinary Centre for Mathematical and Computational Modelling
icm.edu.pl

- After calibrating the model and getting initial results we started writing letters to “all saints” and selected institutions like Ministry of Health, Polish Sanitary Inspection, Institute of Public Health or Governmental Bureau of Security

- Some of the officials and decision makers reacted and begun to listen to us and consider the power and putative benefits coming from **mathematical modeling of the epidemic.** Some - but not all of them, which is also a current situation

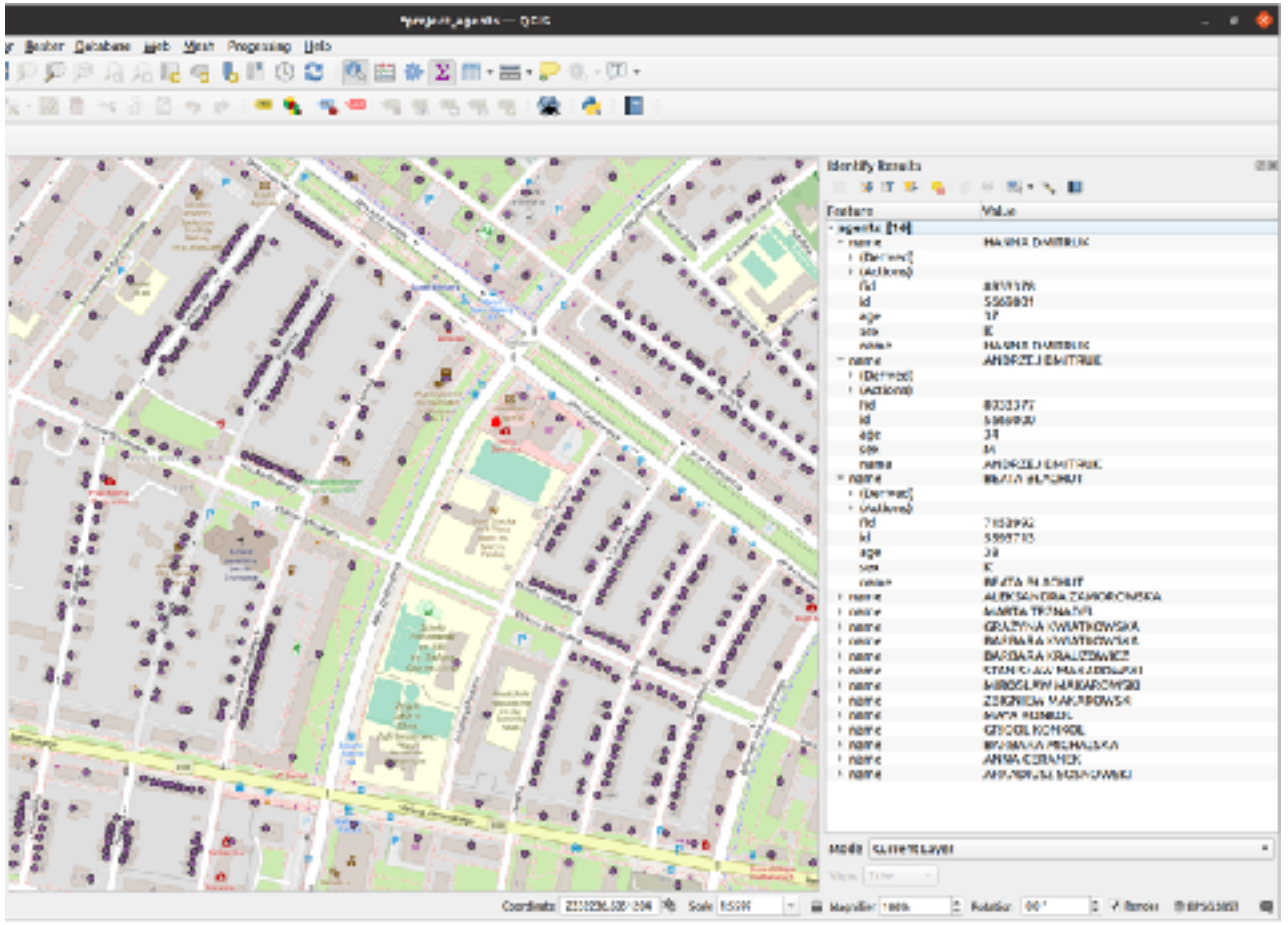
- Finally, after shorter or longer way, our team (often together with MOCOS team) started to play the role of the official advisors to many key institutions and decision makers: Chancellery of the Prime Minister, Ministry of Health, Governmental Bureau of Security,

# Introduction of the model

- Our model is a full-population model with over 38 millions of virtual inhabitants - agents.
- All of them are assigned to various settings (contexts): households, educational units, workplaces
- Contacts may also occur in common, public space, where probability of contact is age-stratified
- Transportation module is covering, local, commuting and long-distance travels

# Detailed synthetic population

- Our generic virtual social structure is more detailed then needed by epidemic spread simulator
- As an example,  we can visualise house holds, (QGIS+OpenStreet map) with precision down to address points.
- Agents have individual, artificially generated names and forenames.



# Current implementation for COVID-19 epidemics in Poland

UNIVERSITY OF WARSAW

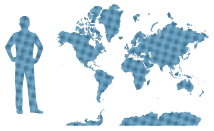
UNIVERSITY OF WARSAW
Interdisciplinary Centre for Mathematical and Computational Modelling
icm.edu.pl

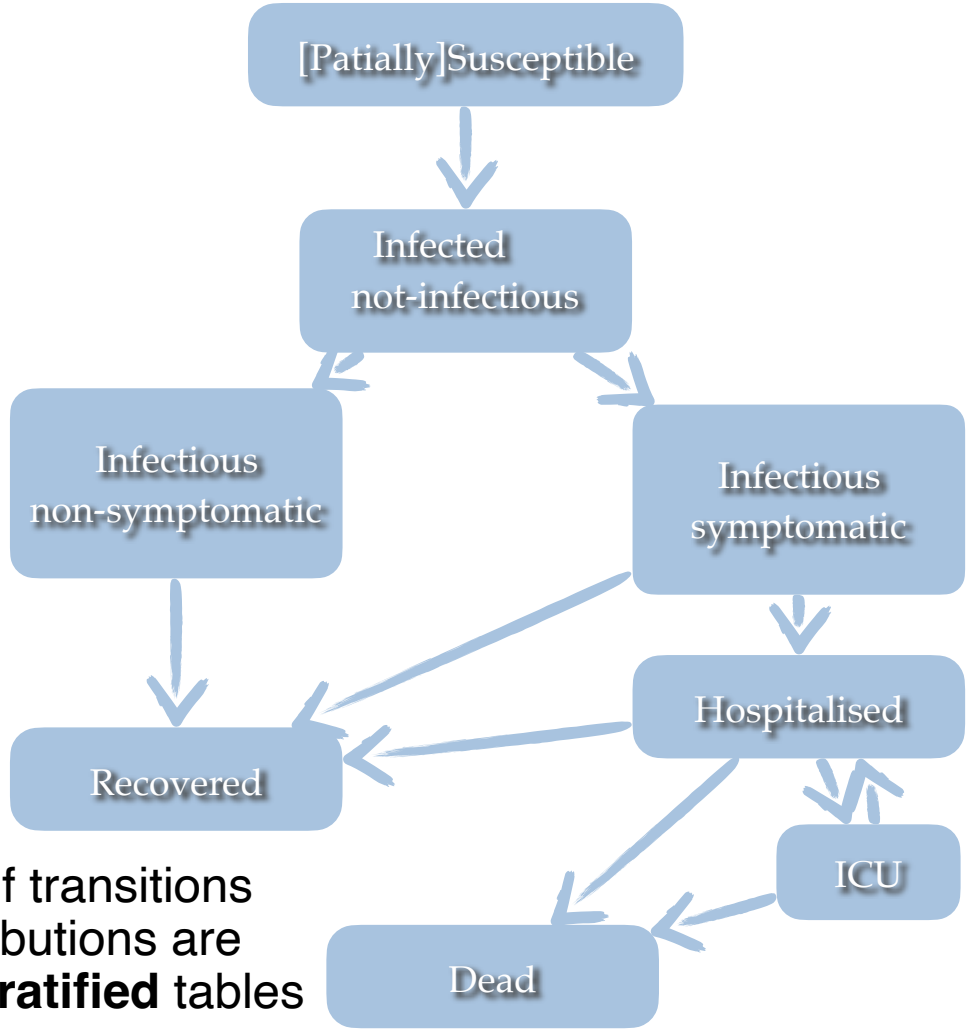
- Variant dependent infection probability Detailed age-grouped and geo-referential vaccination
- Immunity waning processes, in two time-scales:
  - I-st line protection - against any infection
  - II-nd line protection - against severe course of the disease and death.
- Possibility of taking into account many various NPI's
- Detailed reporting of the tens internal variables
  - Some are constantly being compared with the official data
  - Some are potentially comparable to incoming and research data
  - Many are left behind the evidence proof - for the far future research

# Agent structure and infection-related states

Attributes and processes of an **Agent**:

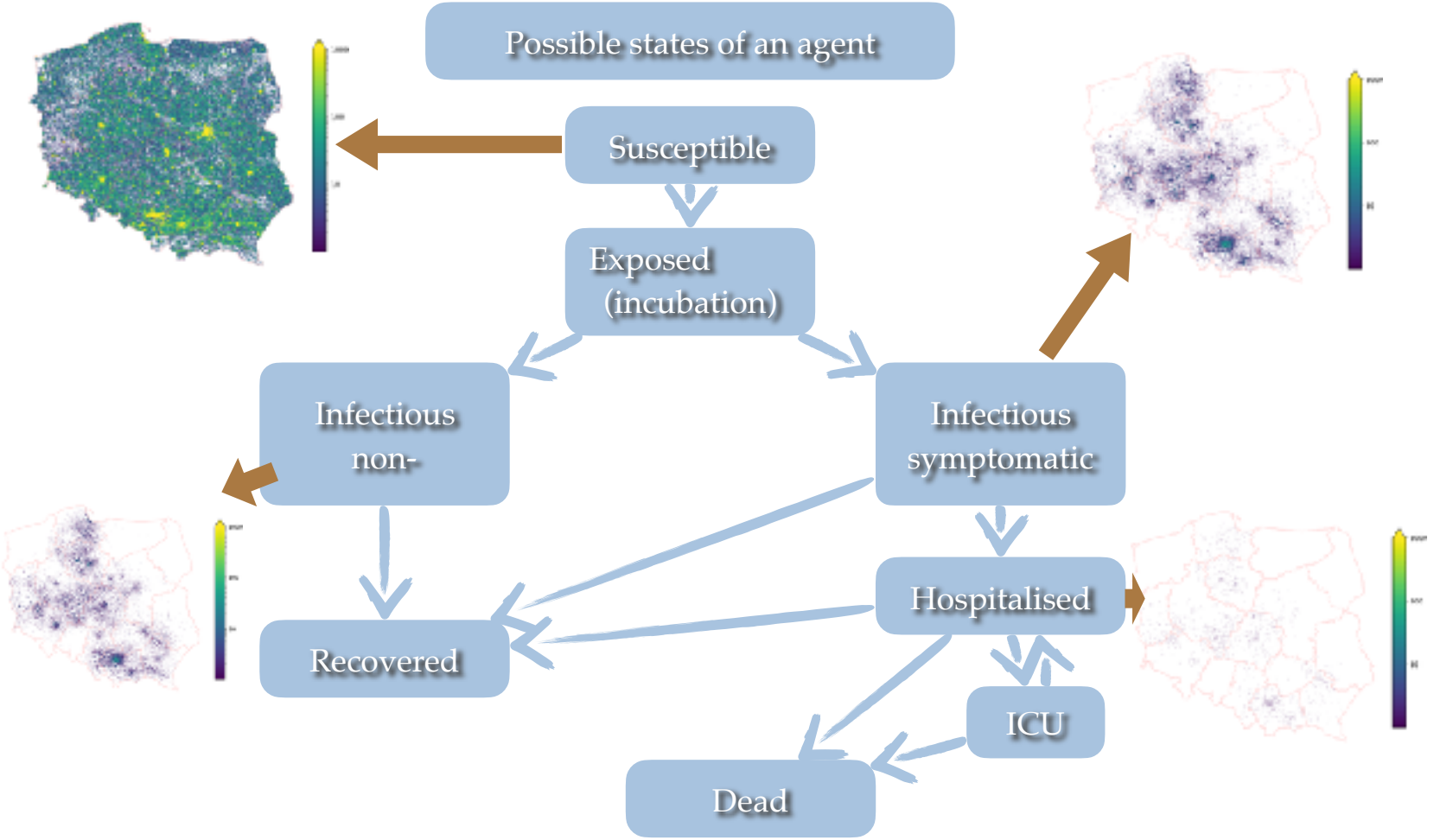
- Age, gender
- Geographical position of HouseHold
- Assignment to contexts: school, workplace, etc
- Contact network in the neighbourhood
- Travel status
- History of infections and vaccinations
- Waning immunity function
- Placeholders for next attributes …



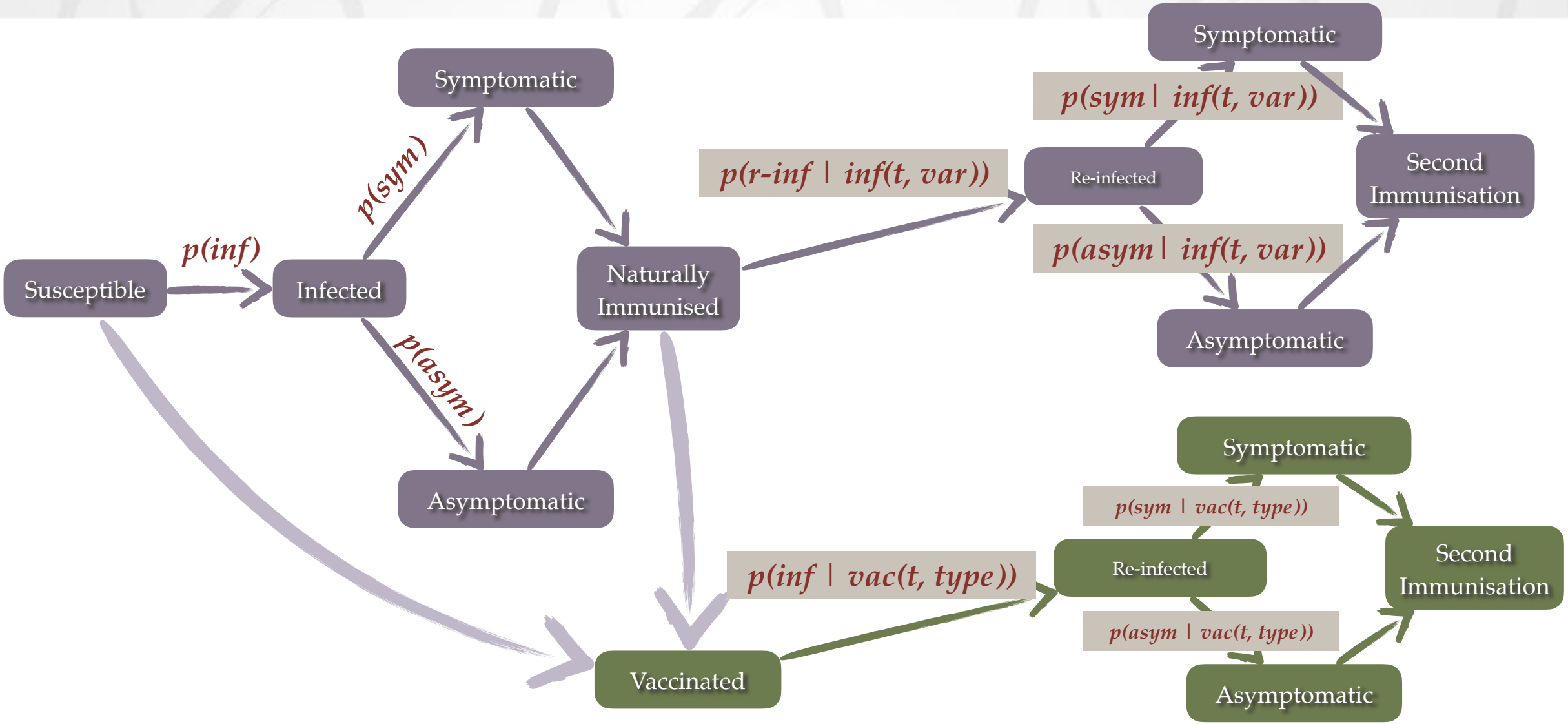



Probabilities of transitions and time distributions are kept in **age-stratified** tables

# Agent states can be visualised on the maps.

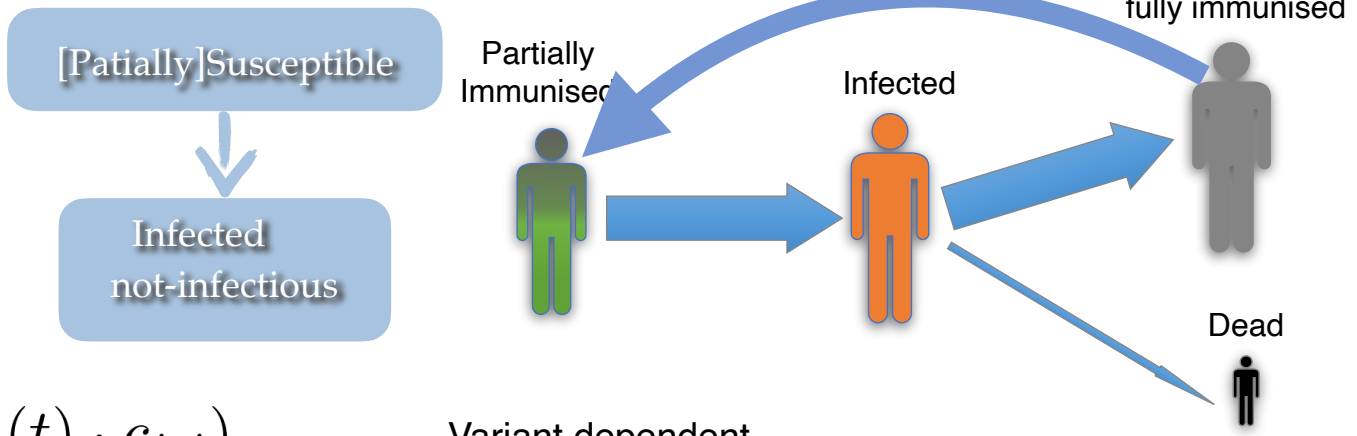


# Extended state diagram



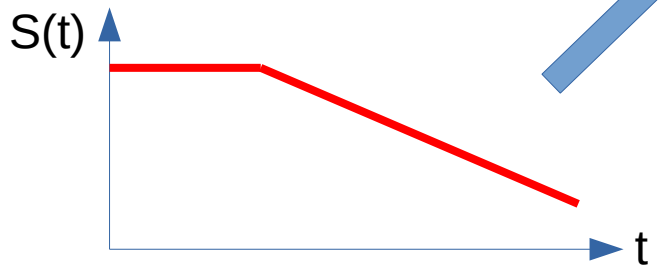
# Math of infection probability:

$$p^j = 1 - \exp(-\alpha\beta_{hh} I^j_{hh} - \alpha \sum_{i}^{contexts} \beta_i \frac{f I^j_i}{1-(1-f)I^j_i})$$




$$p_j = p_{j0} \cdot (1 - \sigma(i,j,t)) = p_{j0} \cdot (1 - S_i(t) \cdot c_{i,j})$$

Initial infection probability




Immunity degradation

Variant dependent protection

Variant dependent Immunisation

Vaccination

| | $W_1$ | $W_2$ |
|---|---|---|
| $W_1$ | 1.0 | 0.8 |
| $W_2$ | 0.8 | 1.0 |
| $Sz_1$ | 0.9 | 0.3 |

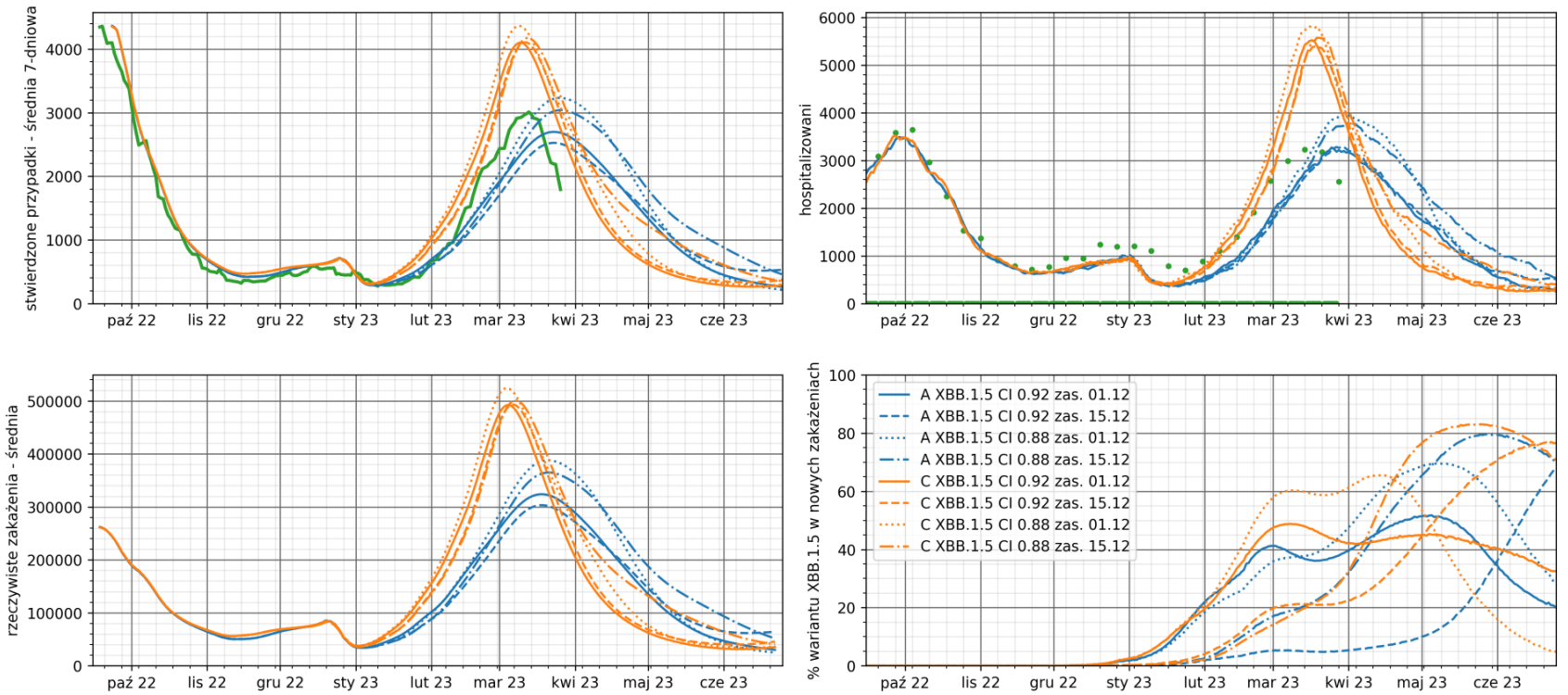
Cross-immunity matrix

# A forecast example (difficult case - spring 2023)

Identified key parameters for wave description and prediction:

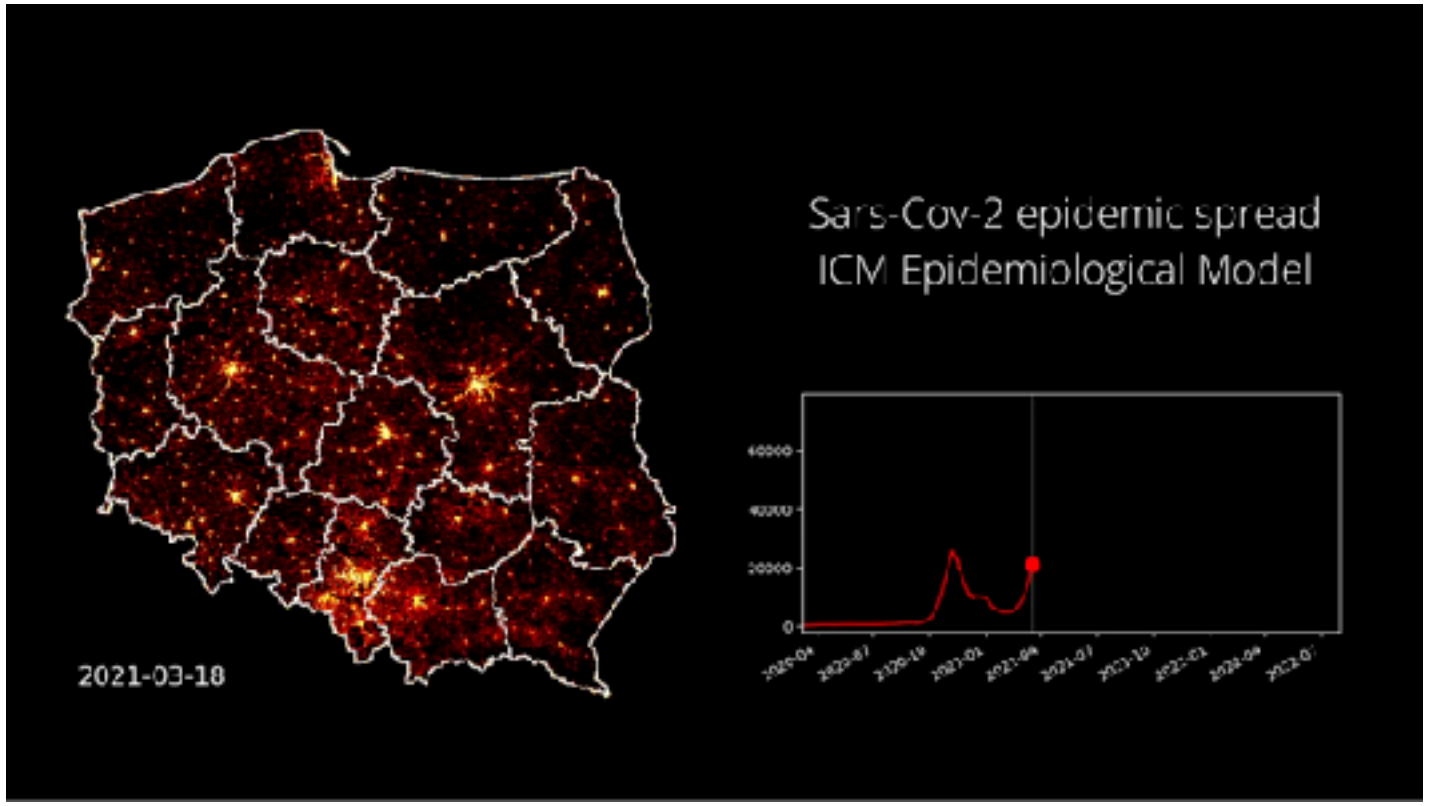
- immunity waning profile
- cross immunity XBB1.5 vs BQ1
- new variant “sowing” date
- detection rate

For those parameters a grid-search is performed and then scenario candidates are selected based on the proximity to the observed data.

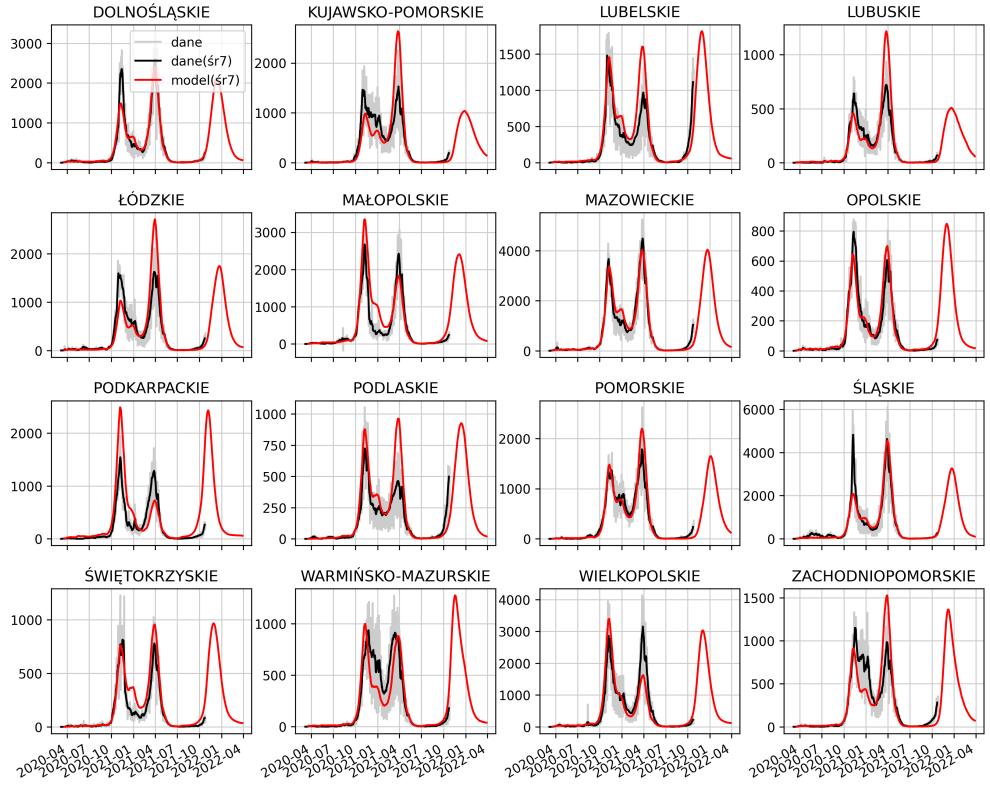


# Support might come from the model

Prediction of the delta wave - the first  one which reached herd immunity level  and turned down without restrictions.




Regions with higher vaccination had lower relative peaks:



UNIVERSITY OF WARSAW

UNIVERSITY OF WARSAW
Interdisciplinary Centre for Mathematical and Computational Modelling
icm.edu.pl

# Part II

## Inspirations coming from the ICM Epidemiological Model

# The OptimAgent Project

Three-year project (May 2022 – May 2025)

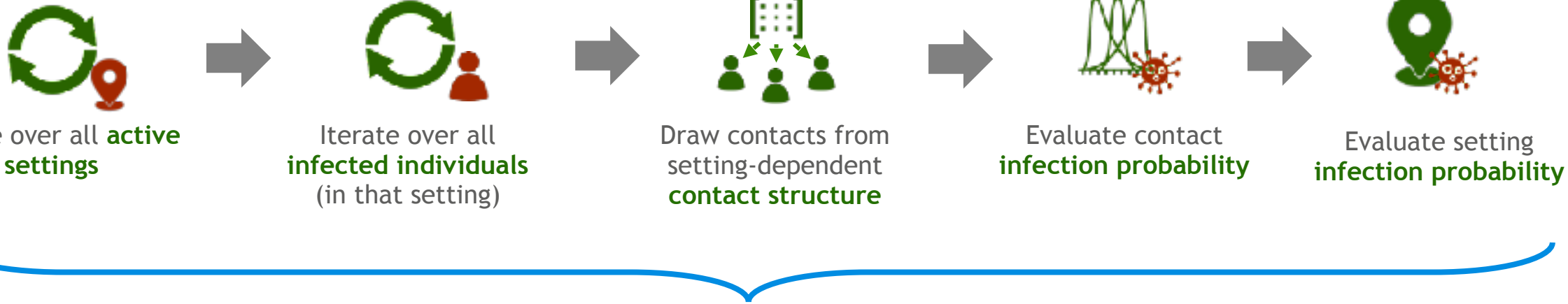
- Focus on public health **decision-making**
- Large-scale model (full German population, ~84m)
- Project team consisting of 14 universities and Institutions

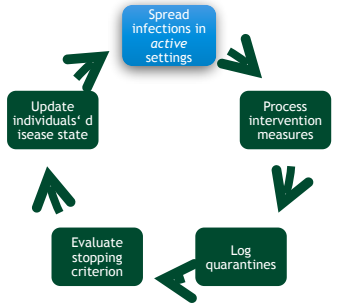
- Goal: Enable simulation-based evaluation of **NPI-effectiveness*** in heterogeneous populations and provide estimations for associated economic-, social-, and health costs.


*Non-Pharmaceutical Interventions

# Infection Procedure

How the disease spreads

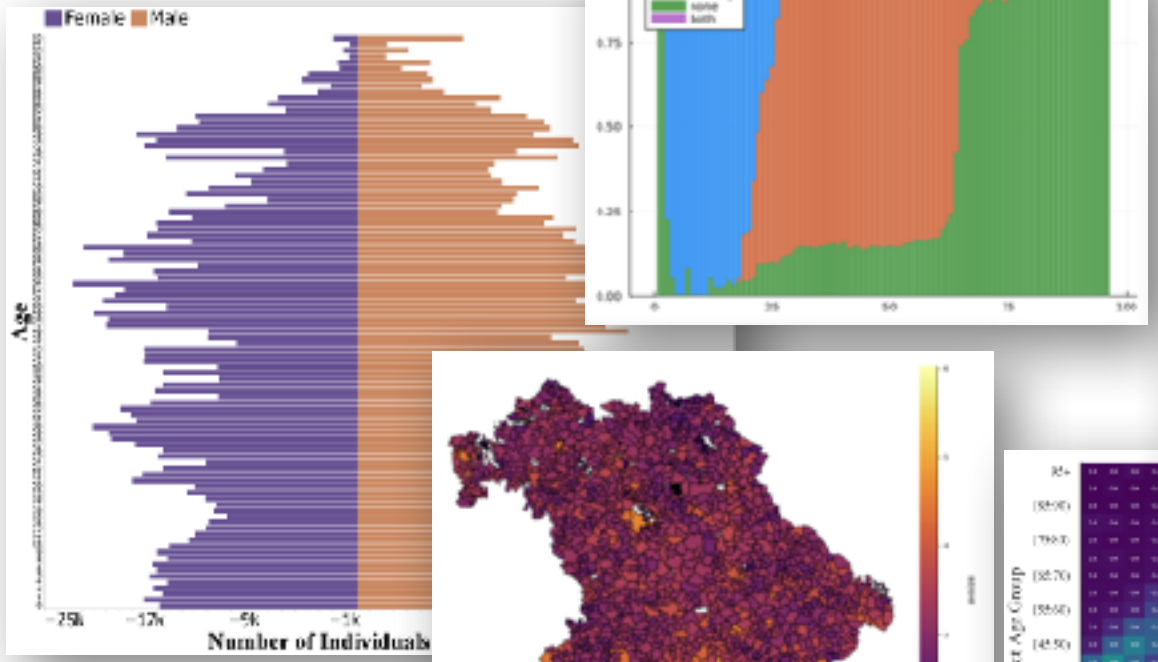


# Visualizations

The `gemsplot()` function

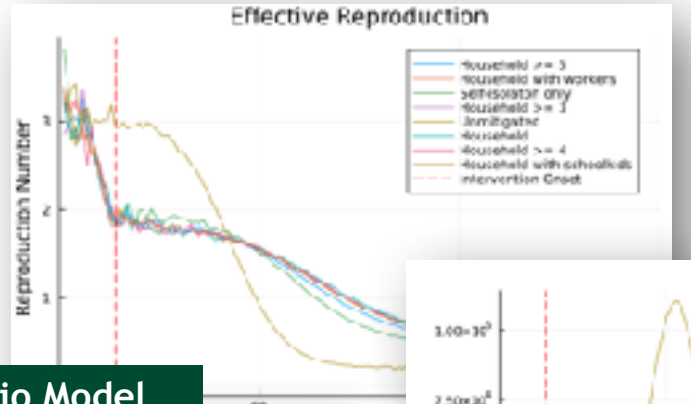
Population Model

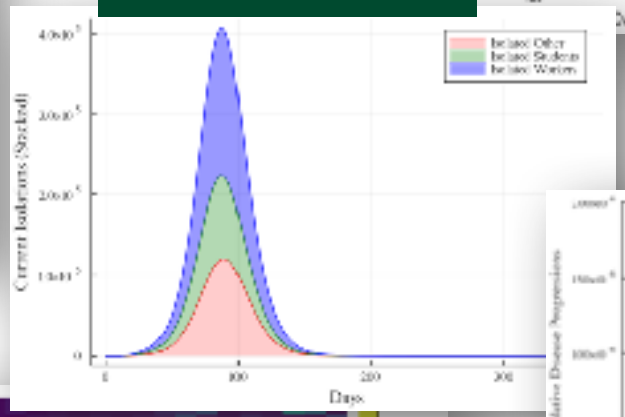


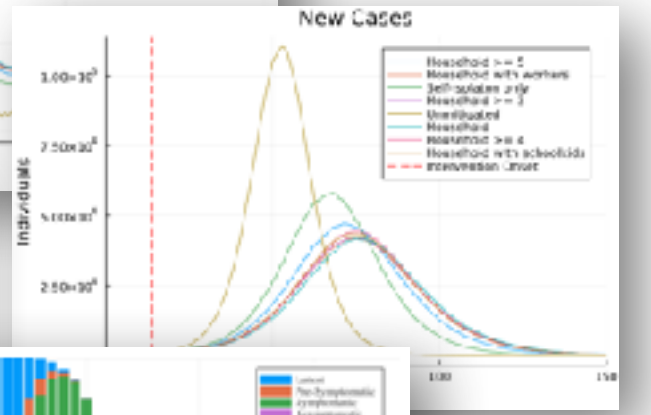




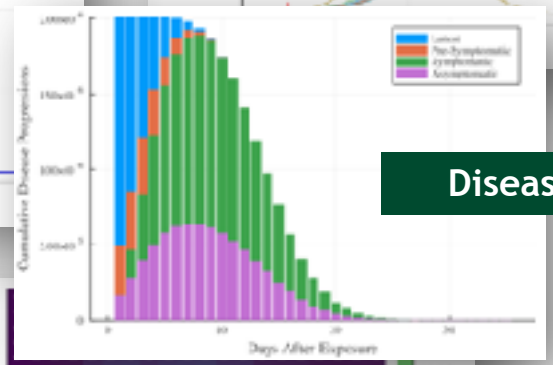

Scenario Model



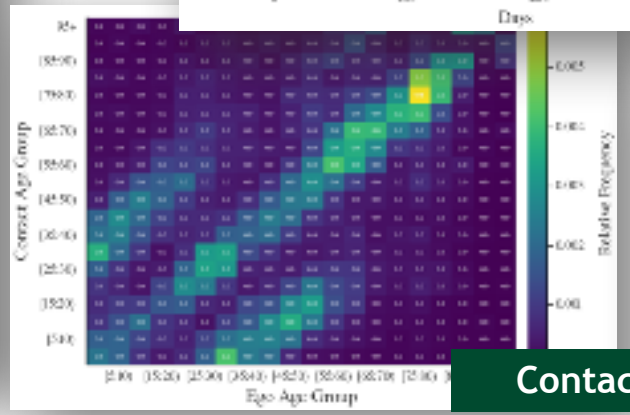



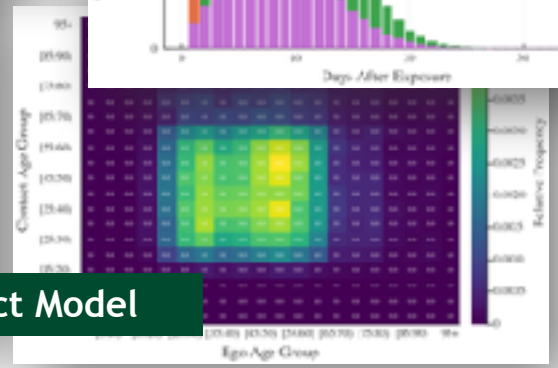




Disease Model




Contact Model



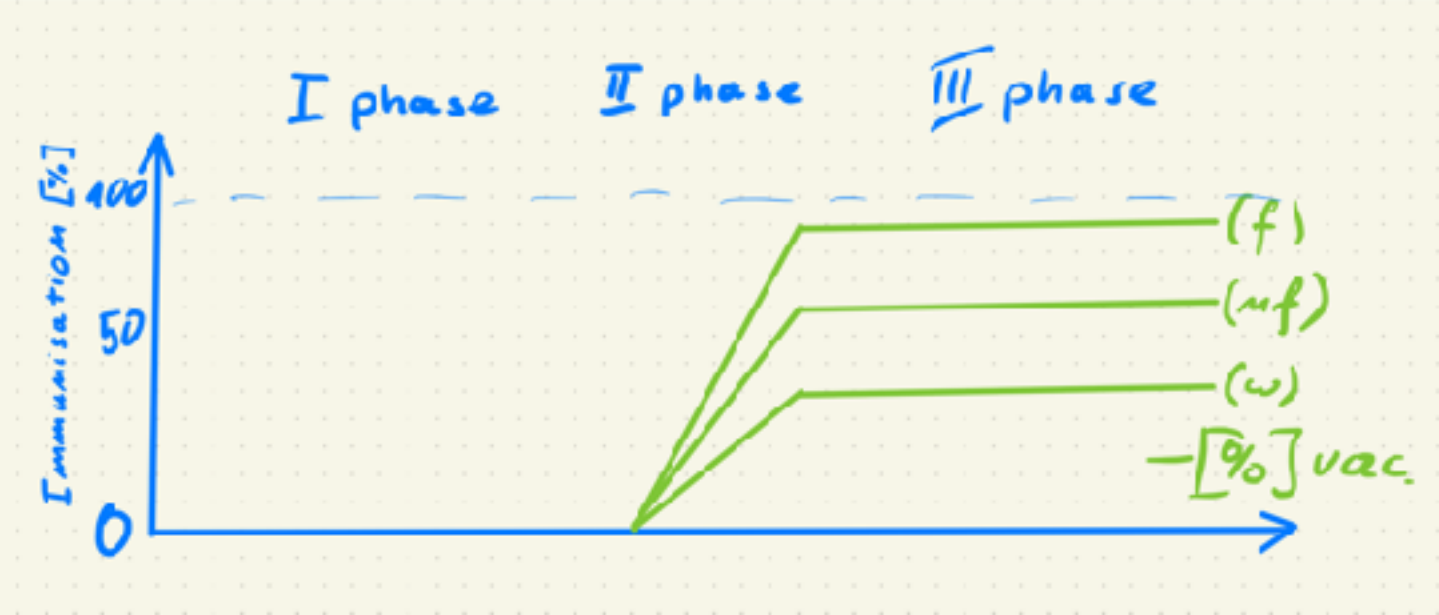
UNIVERSITY OF WARSAW

UNIVERSITY OF WARSAW
Interdisciplinary Centre for Mathematical and Computational Modelling
icm.edu.pl

# Part IV

## How did the Covid-19 epidemic unfold in Poland, Europe? An agent-based model perspective.

# How did the Covid-19 epidemic unfold in Poland, Europe?




In most (every?) country we had three phases of the COVID-19 epidemic:

1. Before appearance and availability of the vaccine
2. Vaccination campaign period
3. Vaccination plateau - those who intended to vaccine, did it and no meaningful increase of vaccination level is observed.

In Europe:

- highest vaccination level was ~ 90% (almost 100% in elder groups)
- middle ~60%
- lowest ~35%

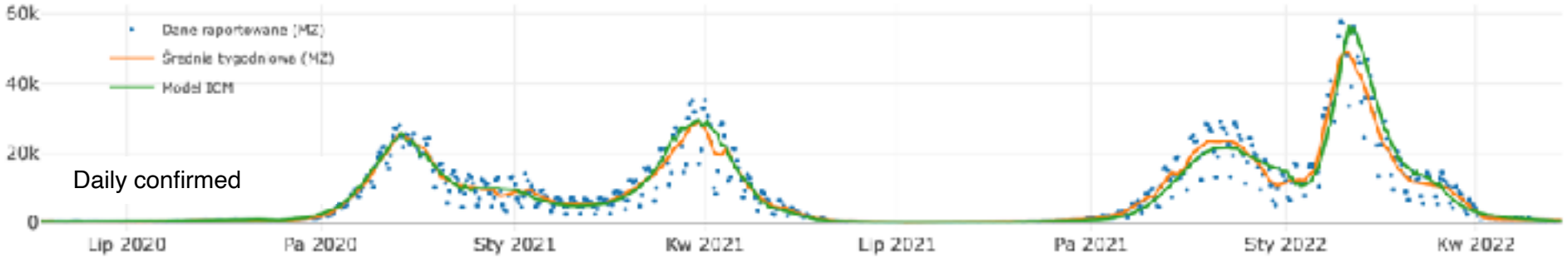
# In Poland:
# real and registered sizes of the waves:
# cases and deaths

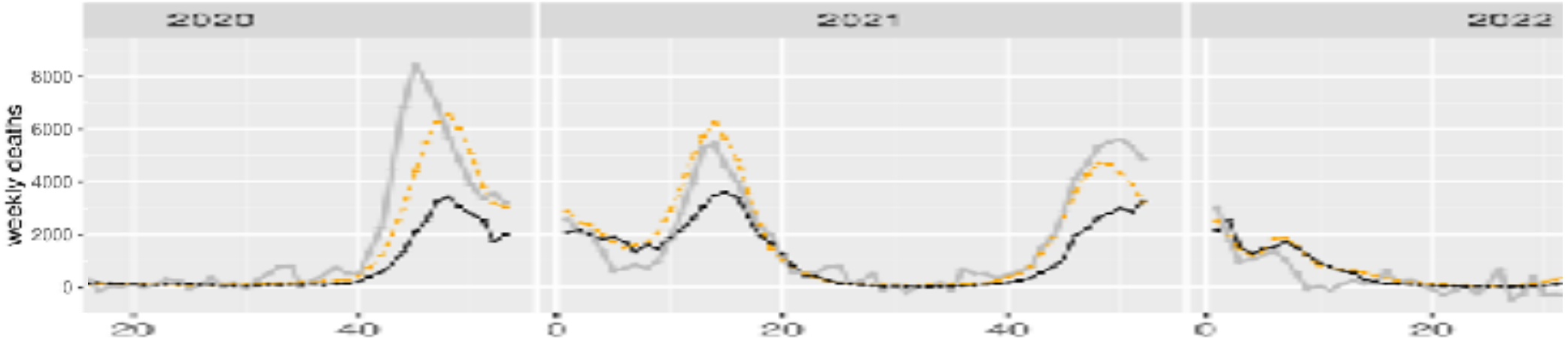
UNIWERSYTET WARSZAWSKI

UNIWERSYTET WARSZAWSKI
Interdyscyplinarne Centrum Modelowania Matematycznego i Komputerowego
icm.edu.pl

*Attack rates in the following waves:*

| | | | | |
|---|---|---|---|---|
| *REAL CASES* | *8.1 M* | *7.6 M* | *11.4 M* | *21.5 M* |
| *CONFIRMED* | *1.5 M* | *1.4 M* | *1.3 M* | *2.0 M* |




| | | | | |
|---|---|---|---|---|
| *EXCESS DEATH* | *70 K* | *50 K* | *46K* | *12K* |

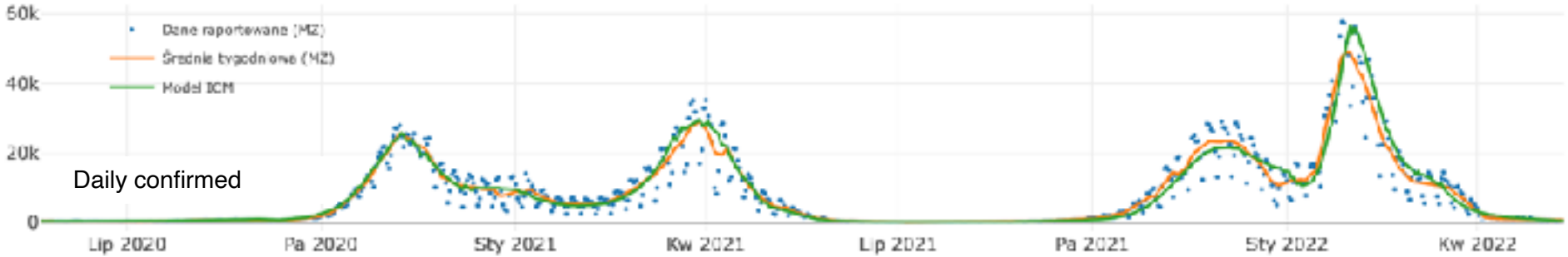
# In Poland:
# real and registered sizes of the waves:
# cases and deaths

UNIWERSYTET WARSZAWSKI

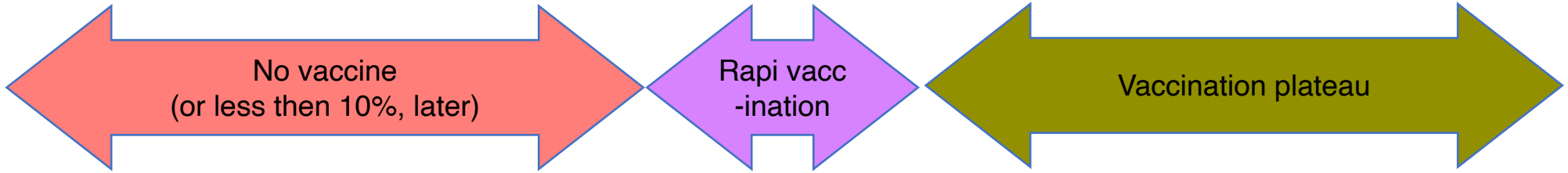
UNIWERSYTET WARSZAWSKI
Interdyscyplinarne Centrum Modelowania Matematycznego i Komputerowego
icm.edu.pl

*Attack rates in the following waves:*

| | | | | | |
|---|---|---|---|---|---|
| *REAL CASES* | *8.1 M* | *7.6 M* | | *11.4 M* | *21.5 M* |
| *CONFIRMED* | *1.5 M* | *1.4 M* | | *1.3 M* | *2.0 M* |




| | | | | | |
|---|---|---|---|---|---|
| ***EXCESS DEATH:*** | ***70 K*** | ***50 K*** | | ***46K*** | ***12K*** |



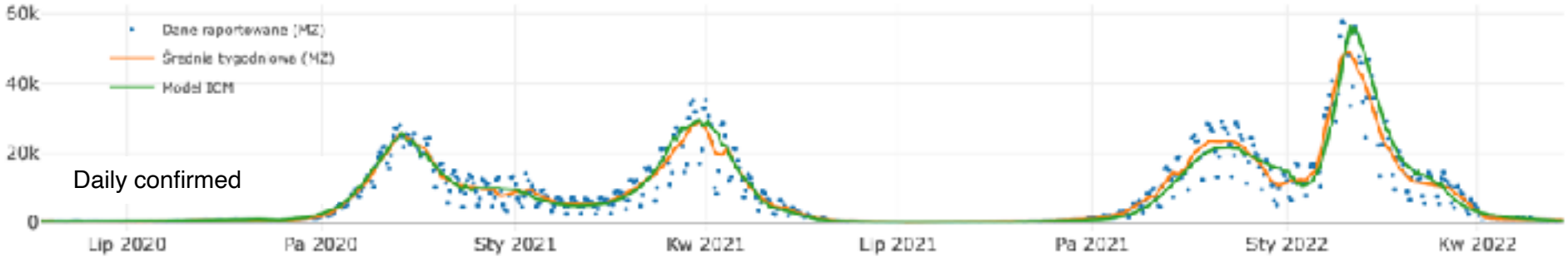
# Hospitalisation needs also differed from the actually occupied beds.

UNIWERSYTET WARSZAWSKI

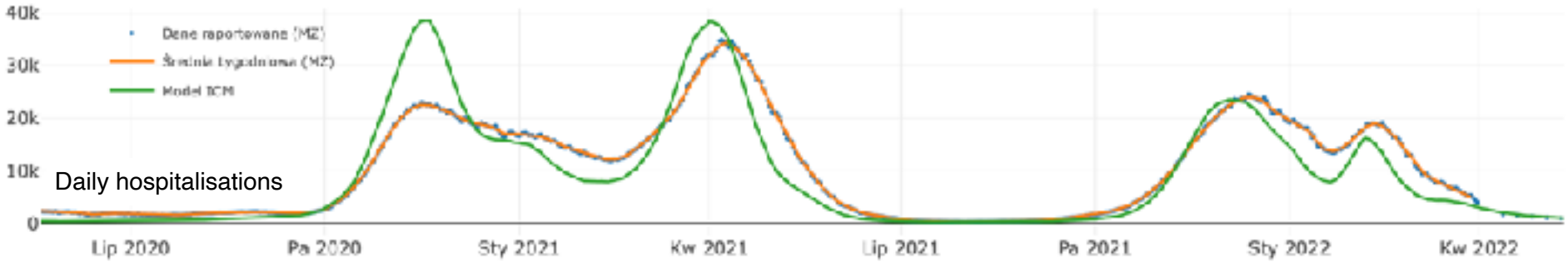
UNIWERSYTET WARSZAWSKI
Interdyscyplinarne Centrum Modelowania Matematycznego i Komputerowego
icm.edu.pl

*Attack rates in the following waves:*

| | | | | |
|---|---|---|---|---|
| *REAL CASES* | *8.1 M* | *7.6 M* | *11.4 M* | *21.5 M* |
| *CONFIRMED* | *1.5 M* | *1.4 M* | *1.3 M* | *2.0 M* |

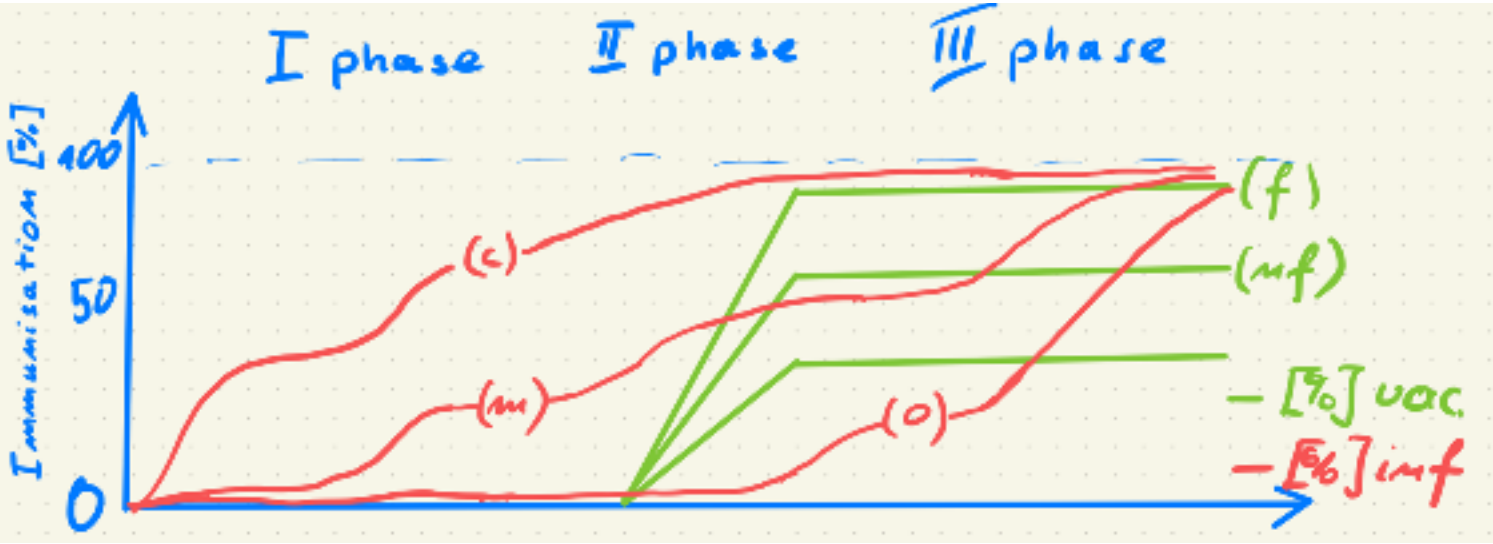



| | | | | |
|---|---|---|---|---|
| *REQUIRED HOSPITALISATIONS* | *192 K* | *152 K* | *146 K* | *97 K* |



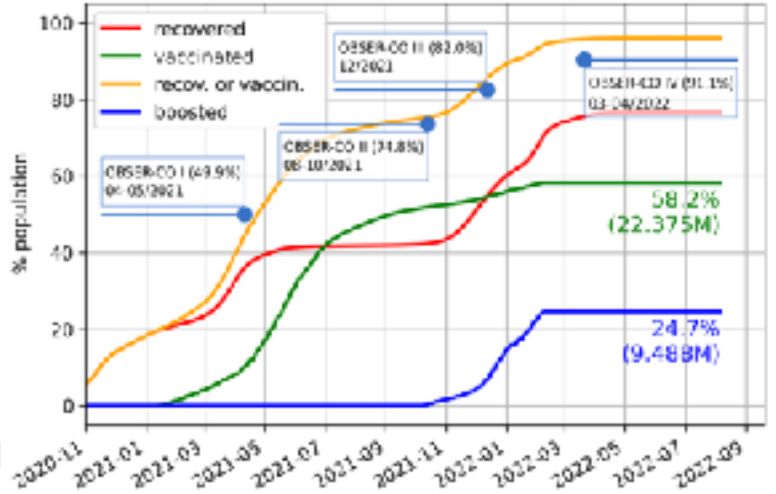

| | | | | |
|---|---|---|---|---|
| ***EXCESS DEATHS*** | ***70 K*** | ***50 K*** | ***46K*** | ***12K*** |

# How did the Covid-19 epidemic unfold in Poland, Europe?



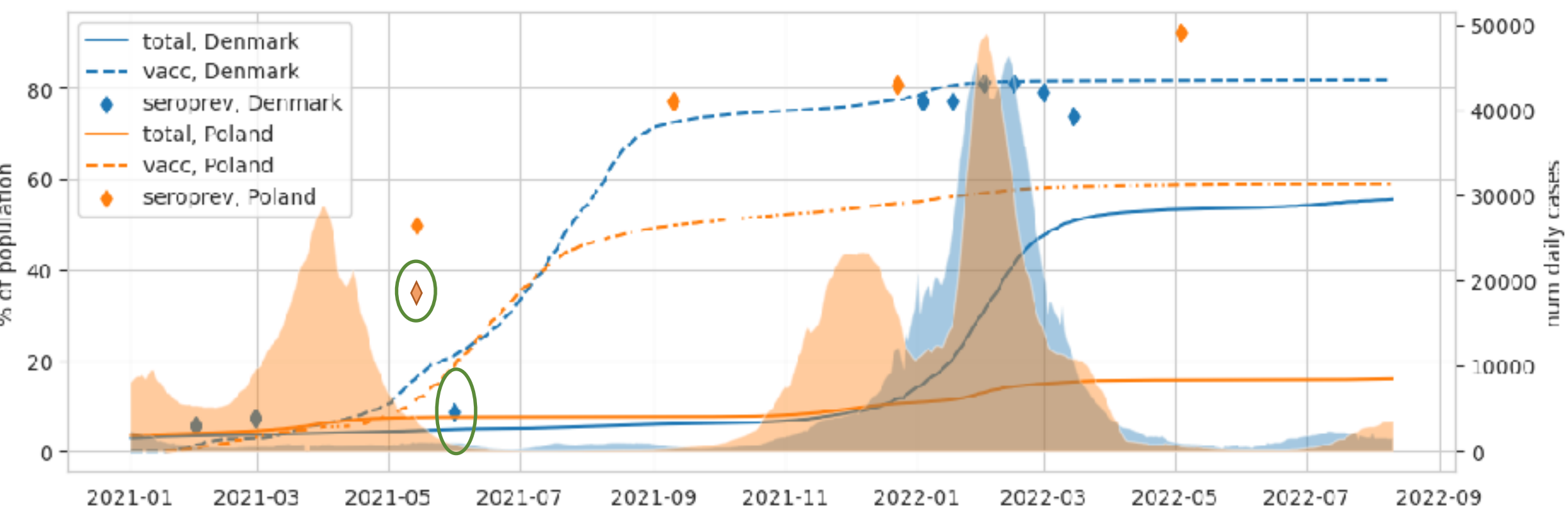

- A key point for understanding the excess death in each country is to analyse immunisation progress in those three phases.
- The less natural immunisation, being the derivative of infections, in the first phase the better
- Assuming that pre-vaccination age-stratified IFR is comparable across countries, is possible to perform rough calculations excess death number in three phases and in total.

| Total population of Poland ~ 38 millions | Phase I and Phase II | Phase III Vaccination at plateau (delta + omicron waves) |
|---|---|---|
| confirmed cases | 2,9 mln | 3,3 mln |
| real cases | 15,5 mln | 33 mln (with reinfections) |
| excess deaths | 124 000 | 55 000 |
| | | |
| Deaths: Ideal way + vac ~60% | 0 | 60 000 |
| Deaths: Ideal way + full vac | 0 | 30 000 |
| Deaths: the worst scenario | 305 000 | 20 |




Seroprevalence study in Poland: Obser-Co (PZH), ICM Model

# Did anyone succeed to go the optimal way?
# [zero-covid in pre-vac. epoch and full vaccination when possible]

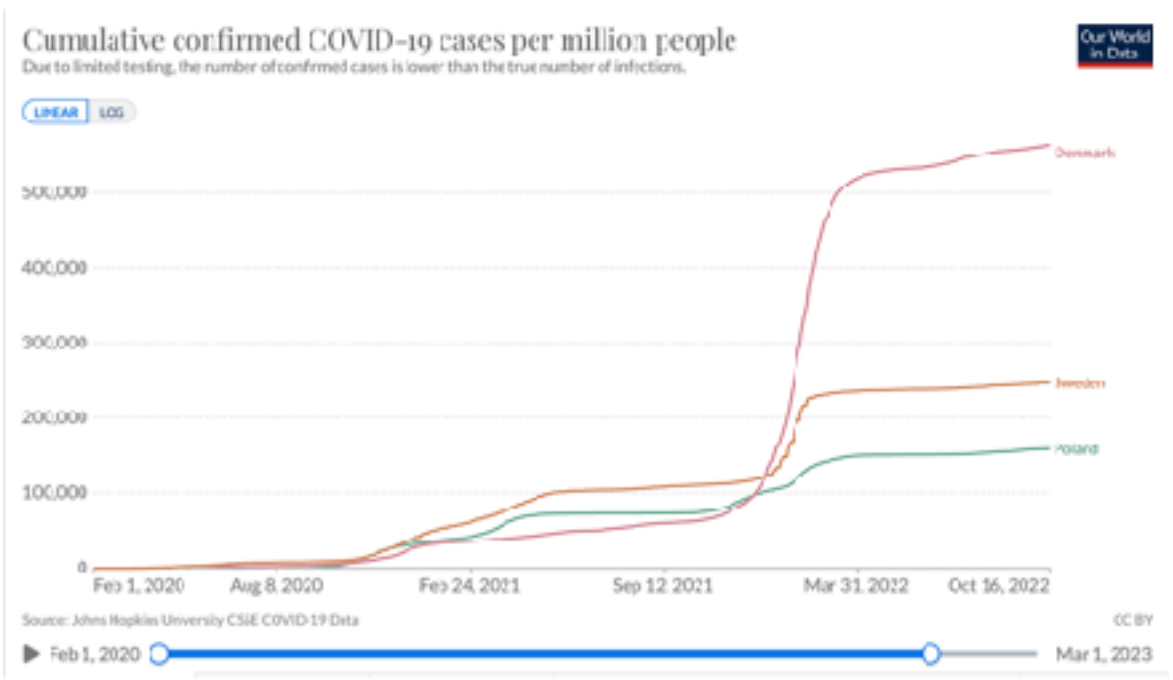


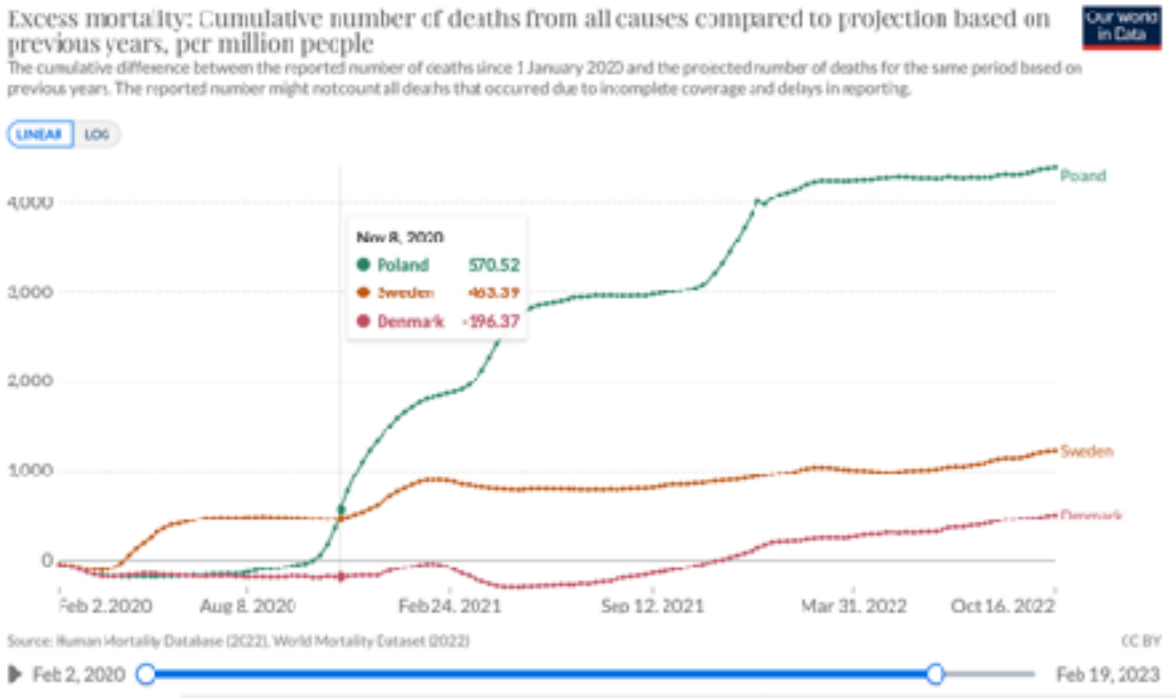

Yes! Some countries did it. Denmark, Norway, …

# Warning:
# “numbers, them selfs, do not know what they mean”

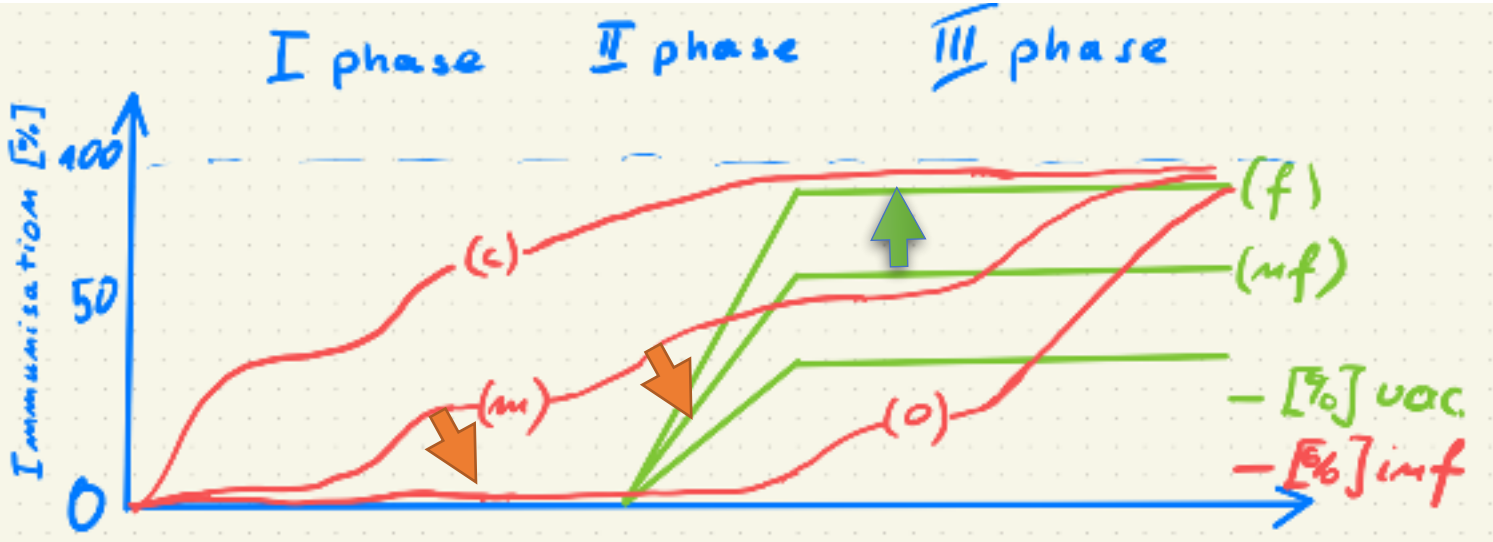
UNIWERSYTET WARSZAWSKI

UNIWERSYTET WARSZAWSKI
Interdyscyplinarne Centrum Modelowania Matematycznego i Komputerowego
icm.edu.pl



# The challange: getting closer to the optimal way…




We hope,
that at least, a bit of the movement along the arrow's directions was done due to the understanding coming from the model and the model based predictions.

There are many reasons of different origin, why some countries didn't go the optimal way.
The list is long, and still should be a subject of intensive and sincere research. The named factors are:

- specific social structure (e.g. sizes of households)
- limited discipline in the population in a thread situation
- limited knowledge on the epidemic processes (both in society and among decision makers)
- not efficiently deployed  targeted methods of transmission suppression (like quarantine, contact tracing app's)
- limited (low) social trust to the state administration
- others..

# Q&A

Why Poland did not go the optimal way?

Our non-mutable structural and social conditions are not favourable regarding the epidemic thread:

- Firstly, our social structure: population density and house hold size distribution is not favourable. In contrary to e.g. Scandinavian countries.

- Secondly, expected and observed social behaviour: low discipline, limited level of trust (to administration and mutual trust), intentions to vaccine intake, also elevate the level of epidemic thread.

Therefore, in such a circumstances of **higher level of risk** the public health policy, including restrictions and case detection system should be **very precise, stronger and timely applied** in comparison to the countries of the more favourable social structure and expected behaviour.
But it were not.

UNIVERSITY OF WARSAW

UNIVERSITY OF WARSAW
Interdisciplinary Centre for Mathematical and Computational Modelling
icm.edu.pl

# Thank You

The ICM Team:
Magda, Jędrzej, Karol, Antoni,
Maciej, Rafał, Jan, Marcin, Bartłomiej,
Artur, Dominik, Grzegorz, Filip