Modeling 101 for Public Health

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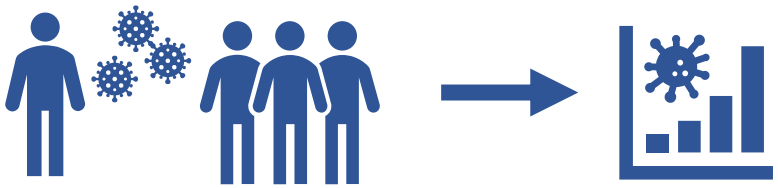
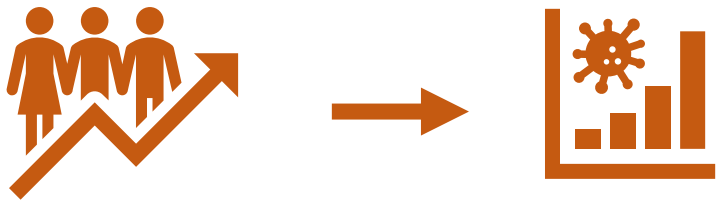


Mechanistic

Describe biological processes that drive disease spread

Statistical

Identify relationships between observed features



Pioneers of Infectious Disease Modeling

Hilda Hudson

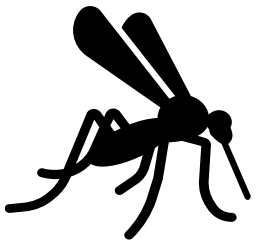
Ronald Ross

1915-17

Anderson McKendrick

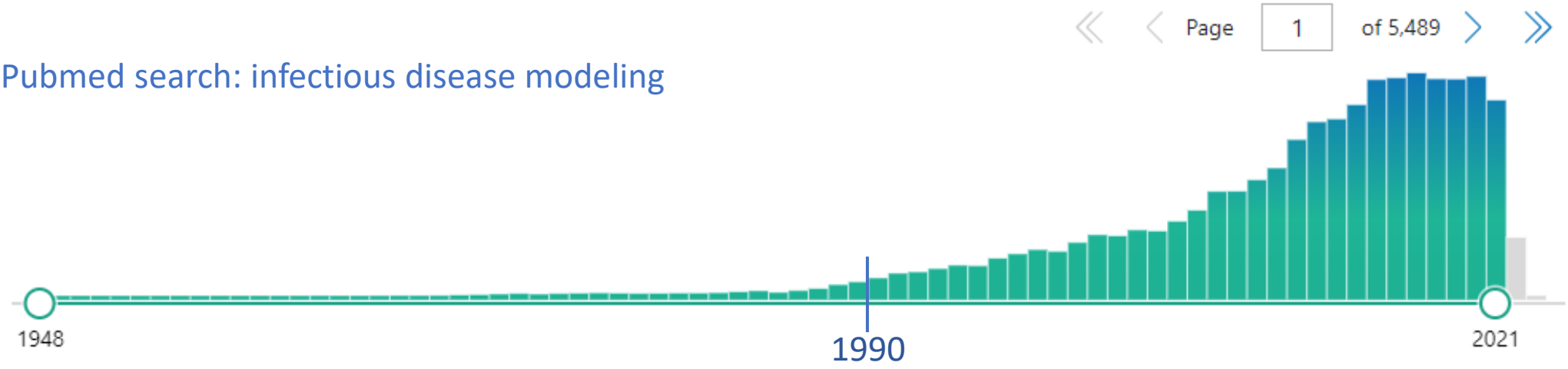
William Kermack

1927-33



Since the 1980/90s the field has been steadily growing

Pubmed search: infectious disease modeling



SCIENCE • CORONAVIRUS

What Are Mathematical Models Of Covid-19?

February 4, 2022
9:17 AM EST
Last Updated 6 months ago

United Kingdom

Britain's pandemic modellers say future large waves of COVID possible

Mathematical model suggests a clue as to when COVID-19 pandemic will turn into an endemic

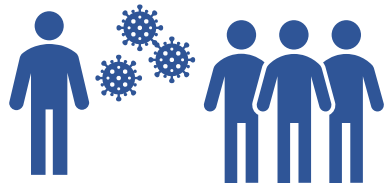
CURRENT EVENTS

The Math of Ending the Pandemic: Exponential Growth and Decay

COVID-19

Exponential growth bias: The numerical error behind Covid-19

Outline



General model framework & examples

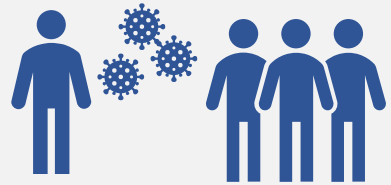
Use cases

Interpreting model uncertainty

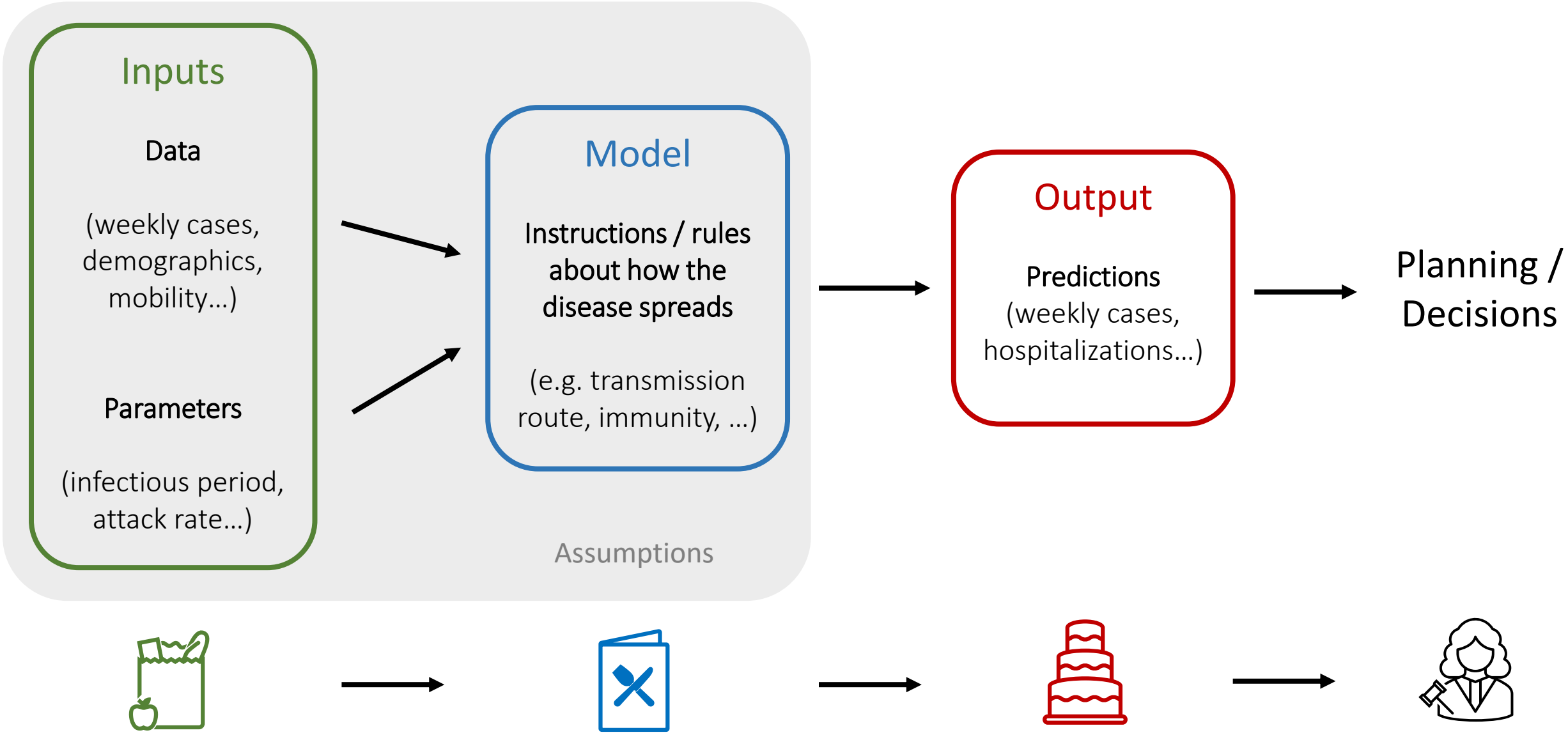
Assessing model utility

Combining multiple models

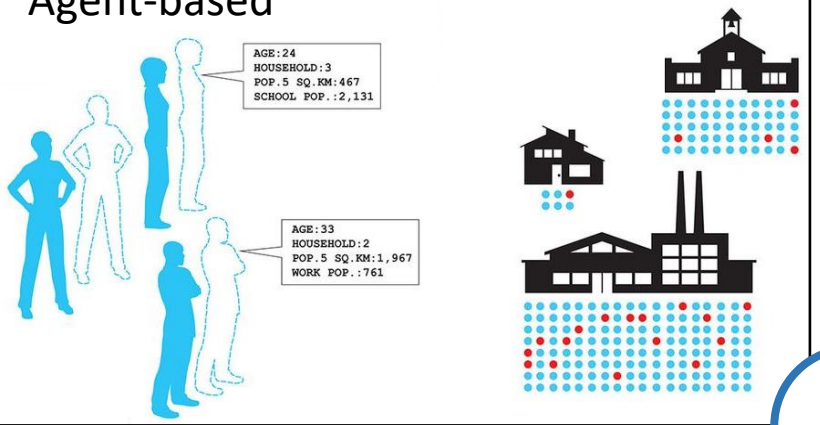
General framework & examples



General model framework



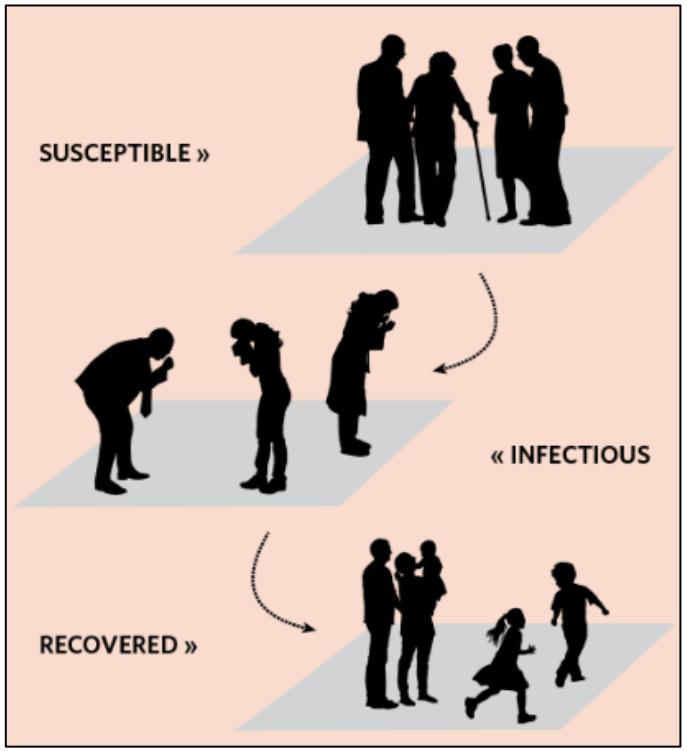
Agent-based



Model

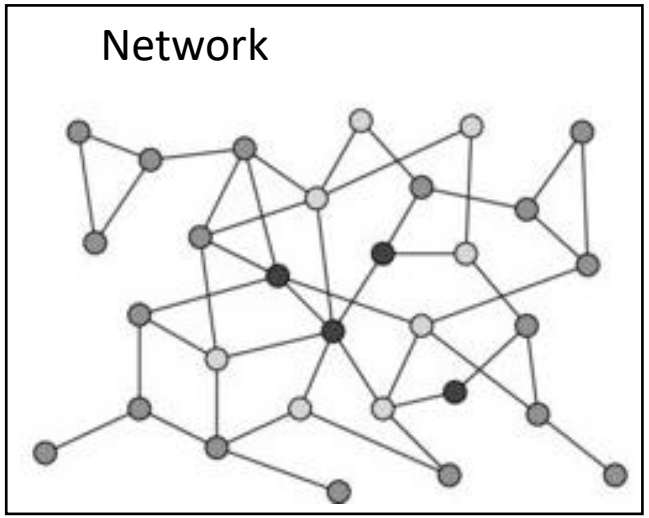
Instructions / rules about how the disease spreads

(e.g. transmission route, immunity, …)



Compartmental

Network



Meta-population

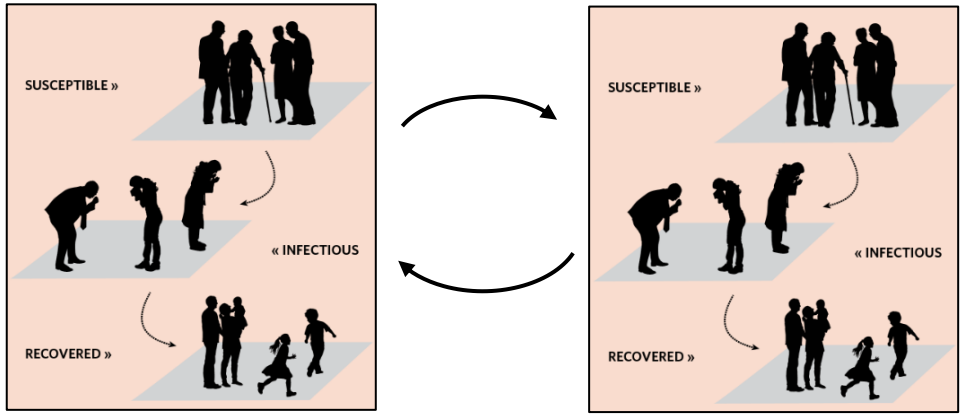
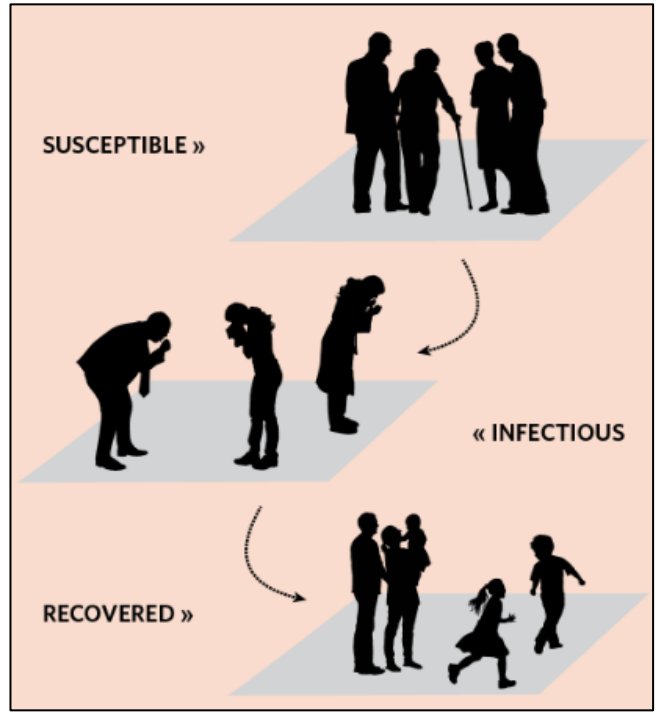


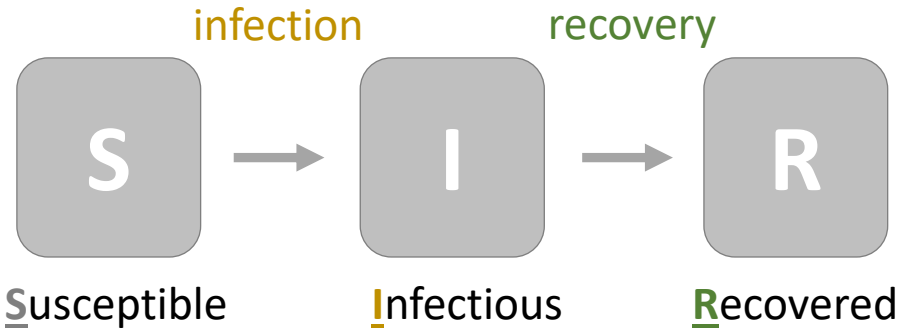
Image sources: The Scientist, Meyers et al 2007, IEEE Spectrum

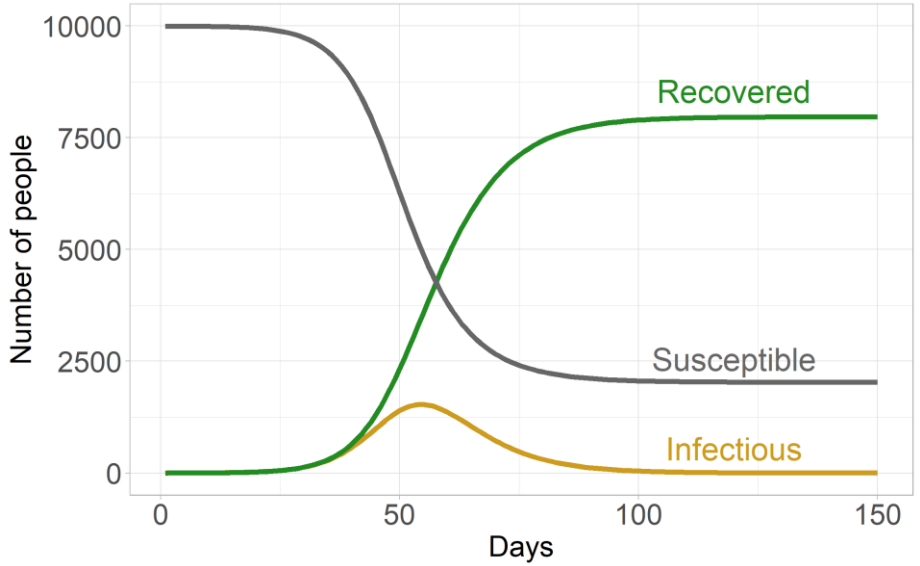
Compartmental models: SIR model

Assumptions

- Health states: susceptible, infectious, recovered
- Parameters: infection rate, recovery rate
- Lifelong immunity

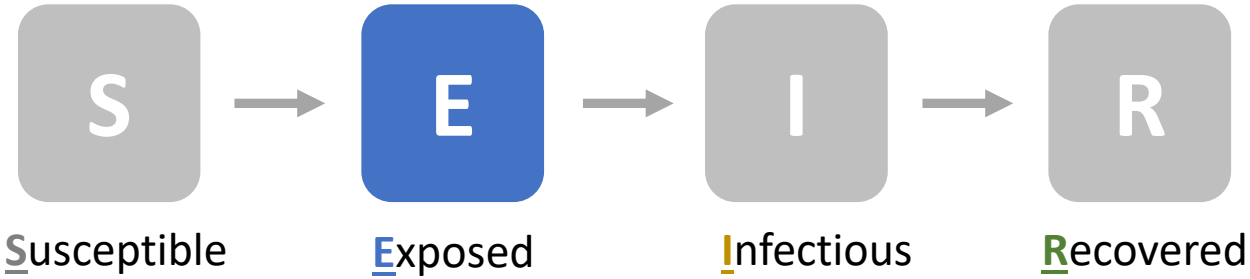




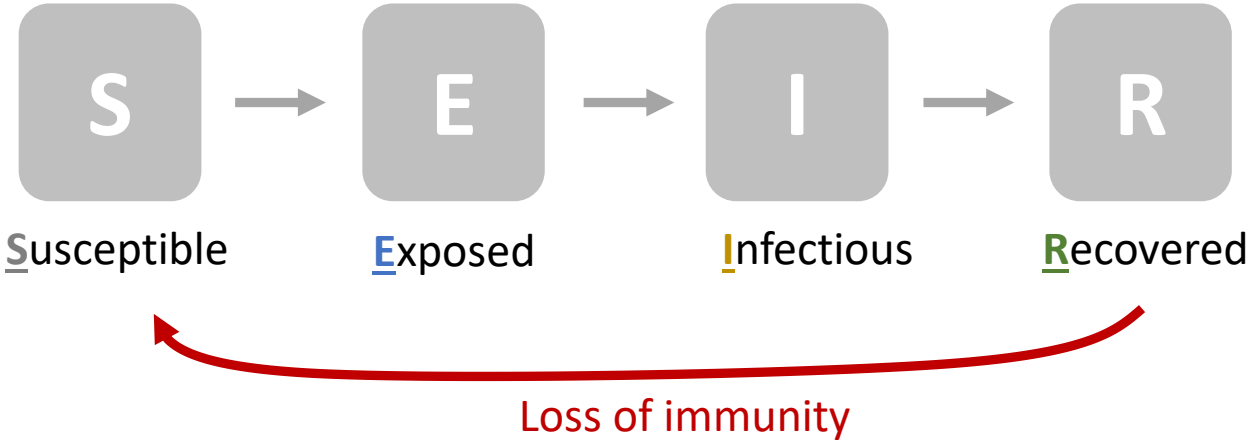


SIR model

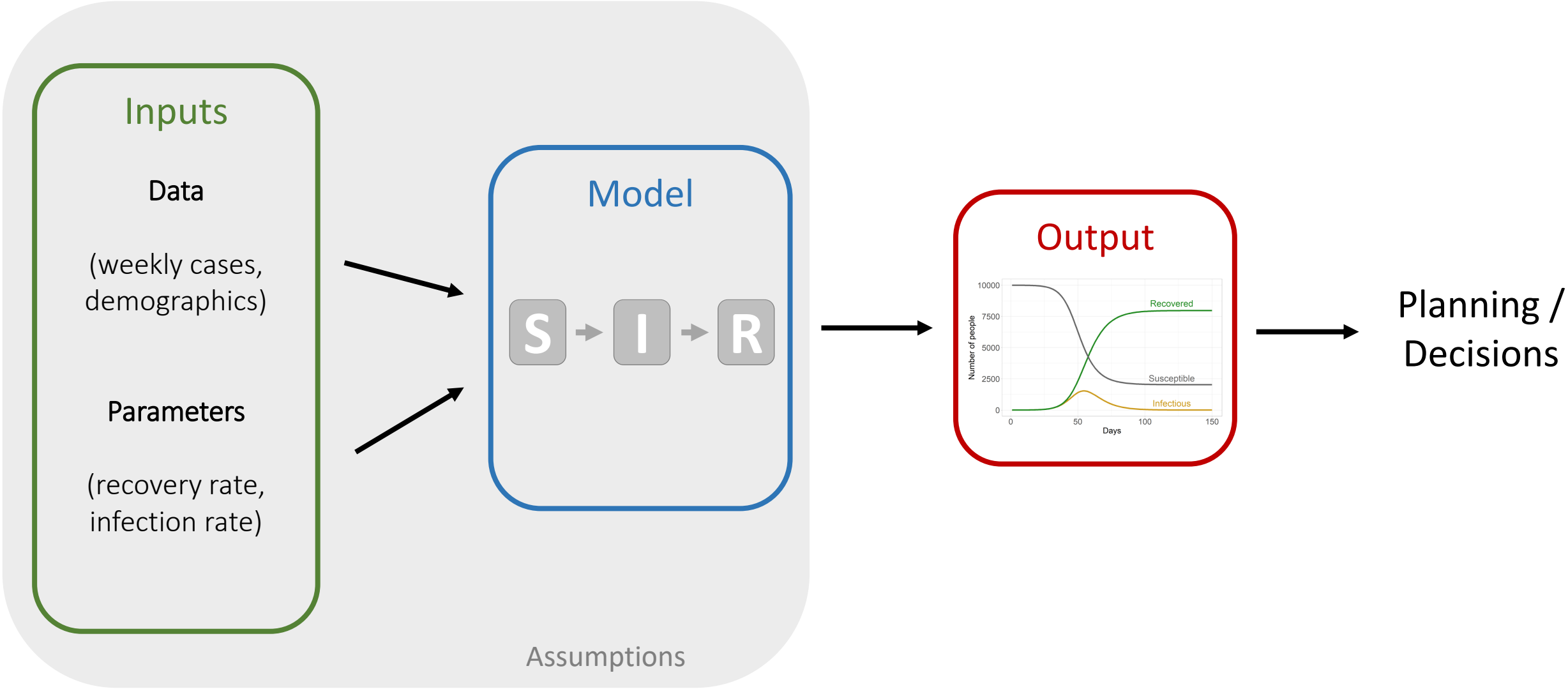
SEIR model



SEIRS model



General model framework

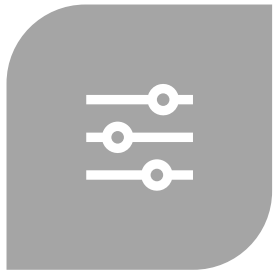


Uses

What can models be used for?

Predicting what could happen in the future

FORECASTING / PREDICTION



Exploring hypotheticals that can't be implemented

SCENARIO ANALYSIS

Gaining information on something that isn't observed

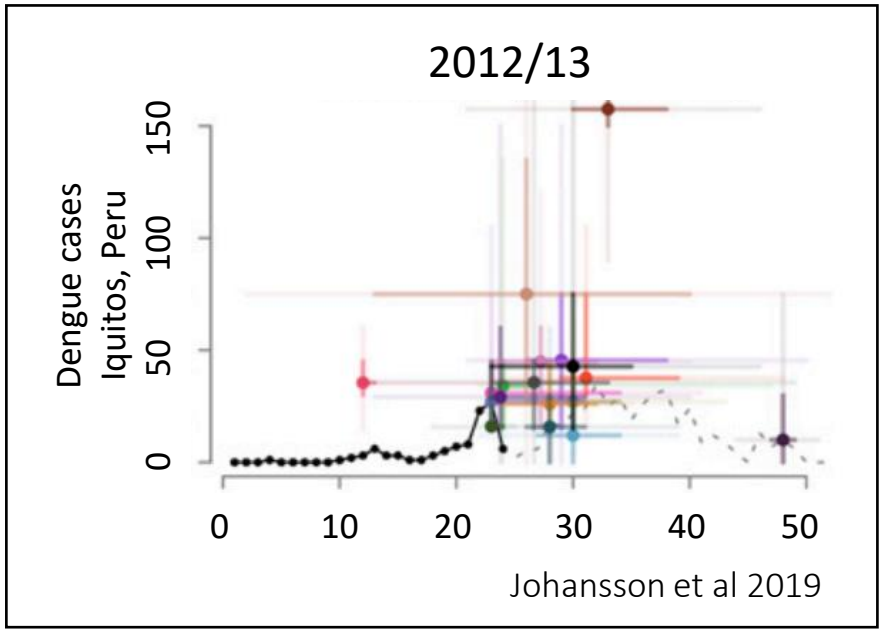
ESTIMATION

Identifying the underlying cause of something

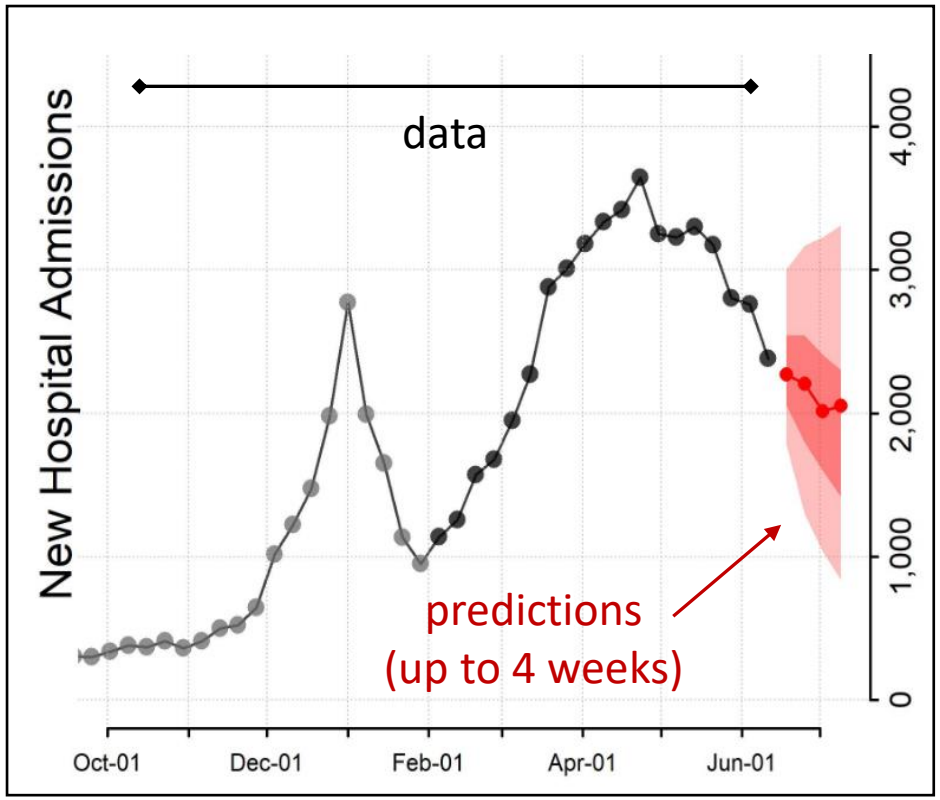
INFERENCE

Forecasting / Prediction

Dengue Forecasting Project, 2015



FluSight Challenge, 2021/22

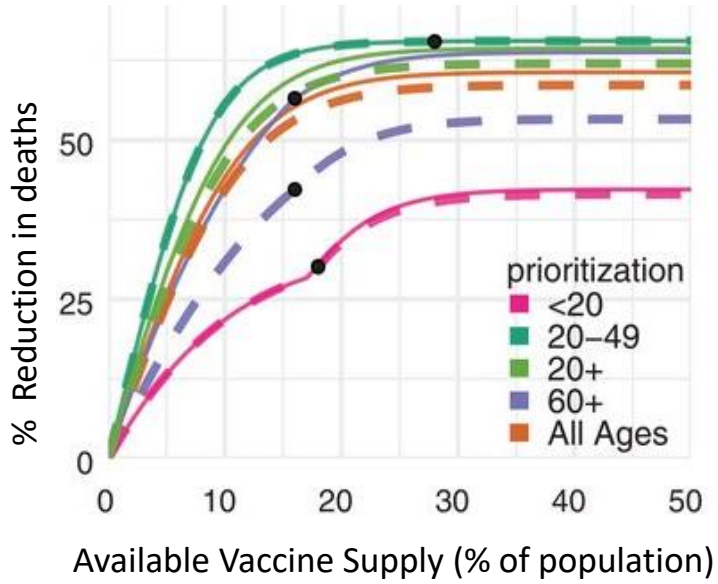


Useful for: Situational awareness
Short-term planning

Scenario Analysis

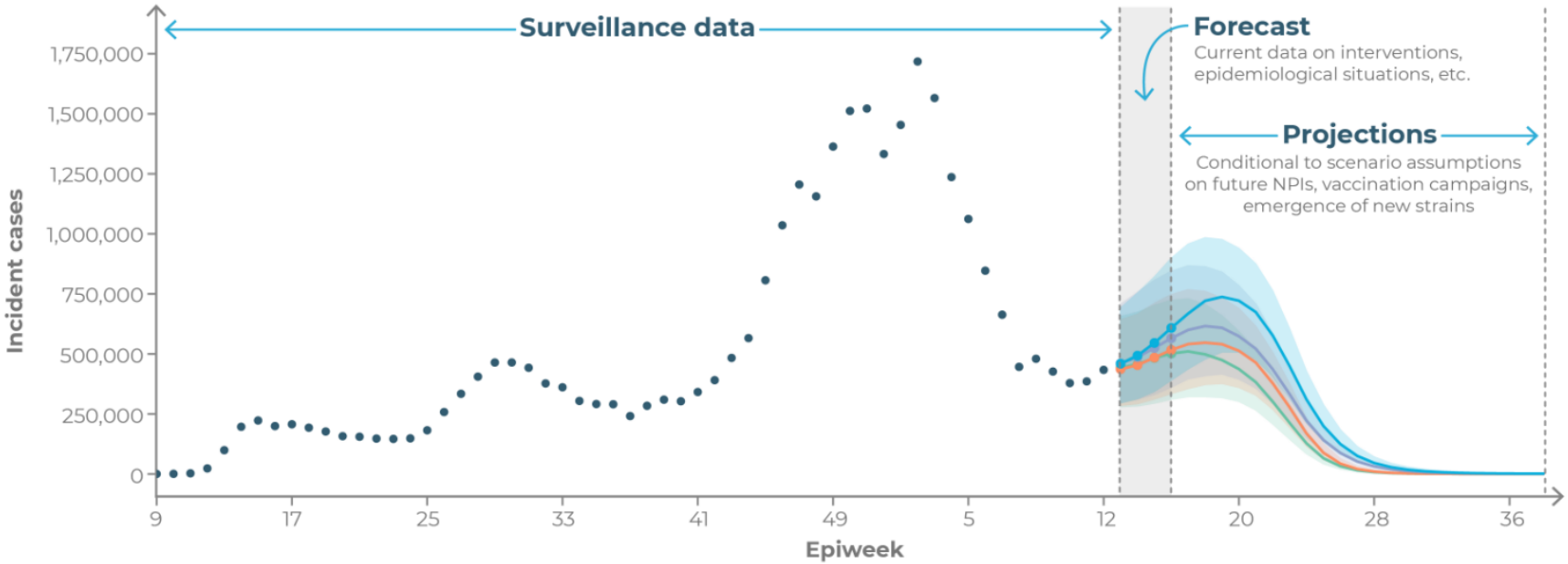
Useful for: Exploring different hypotheses
Longer-term planning / assessment

COVID vax allocation



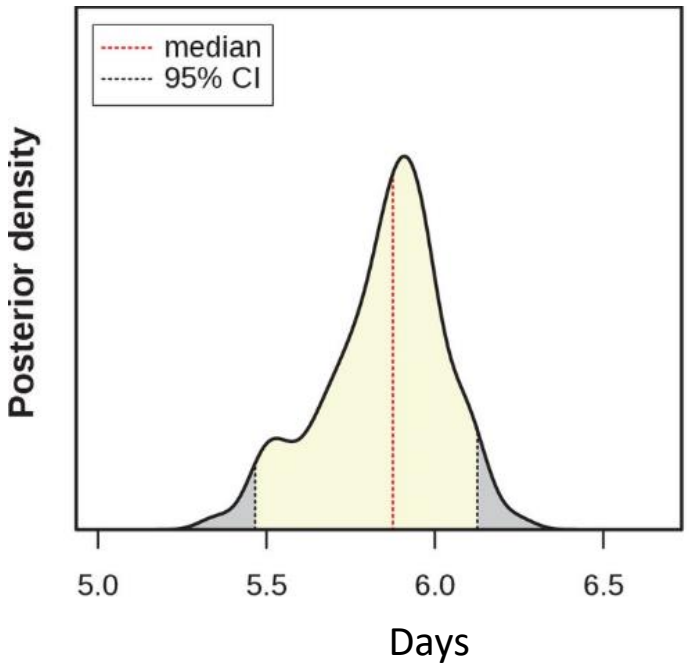
Bubar et al 2021

Scenario Modeling Hub



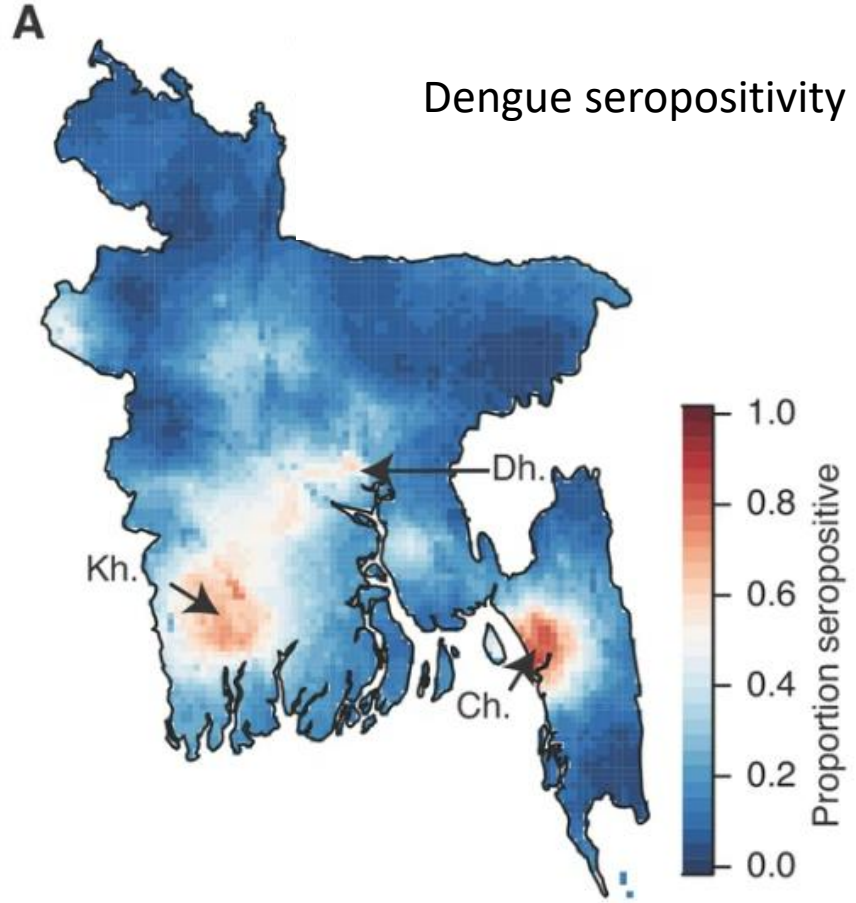
Estimation

Infectious period, Zika



Lourenco et al 2017

Dengue seropositivity

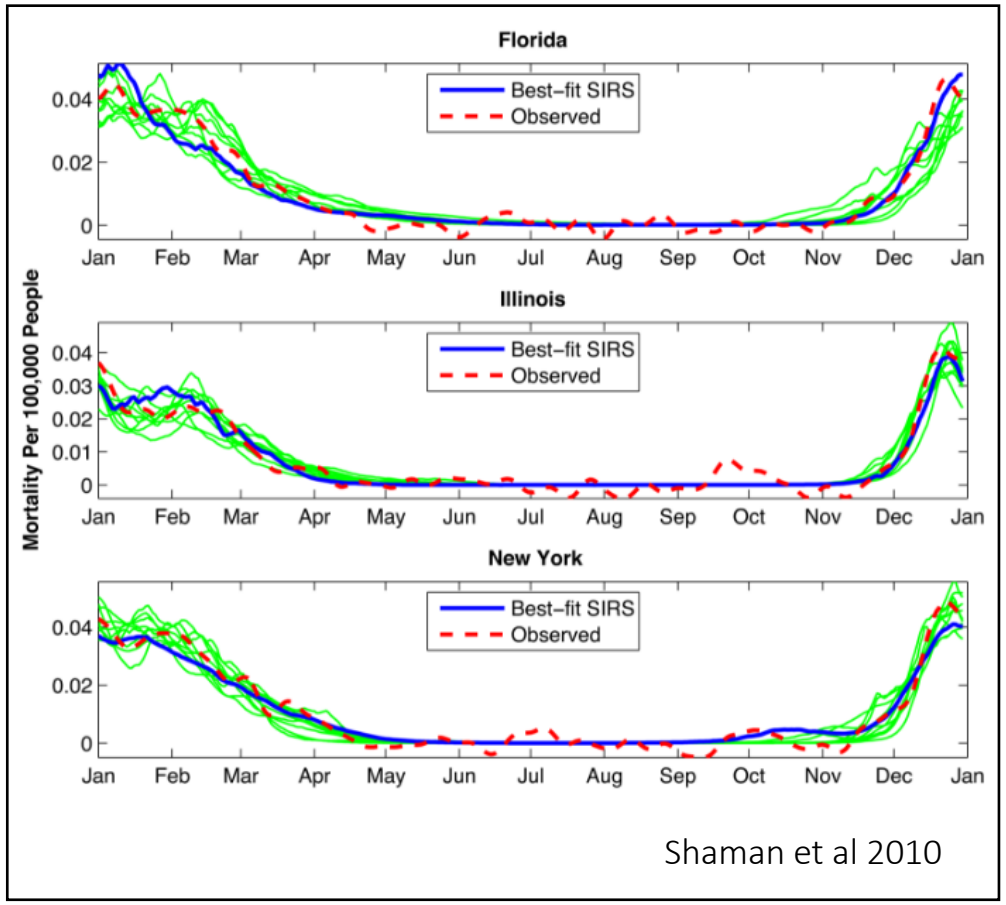


Salje et al 2019

Useful for: Understanding disease (e.g. natural history)
Policy design
Better inputs for future models

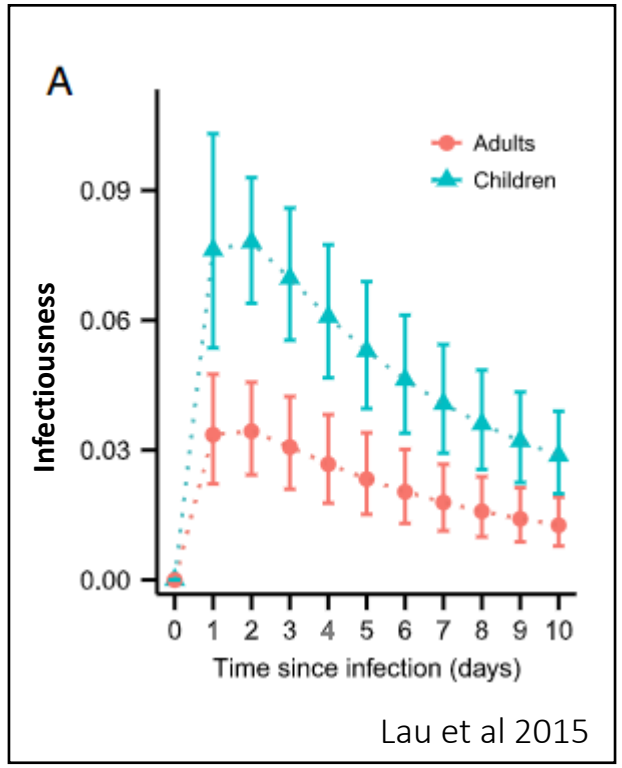
Inference

Absolute humidity a driver of flu seasonality



Shaman et al 2010

Children may be more infectious than adults

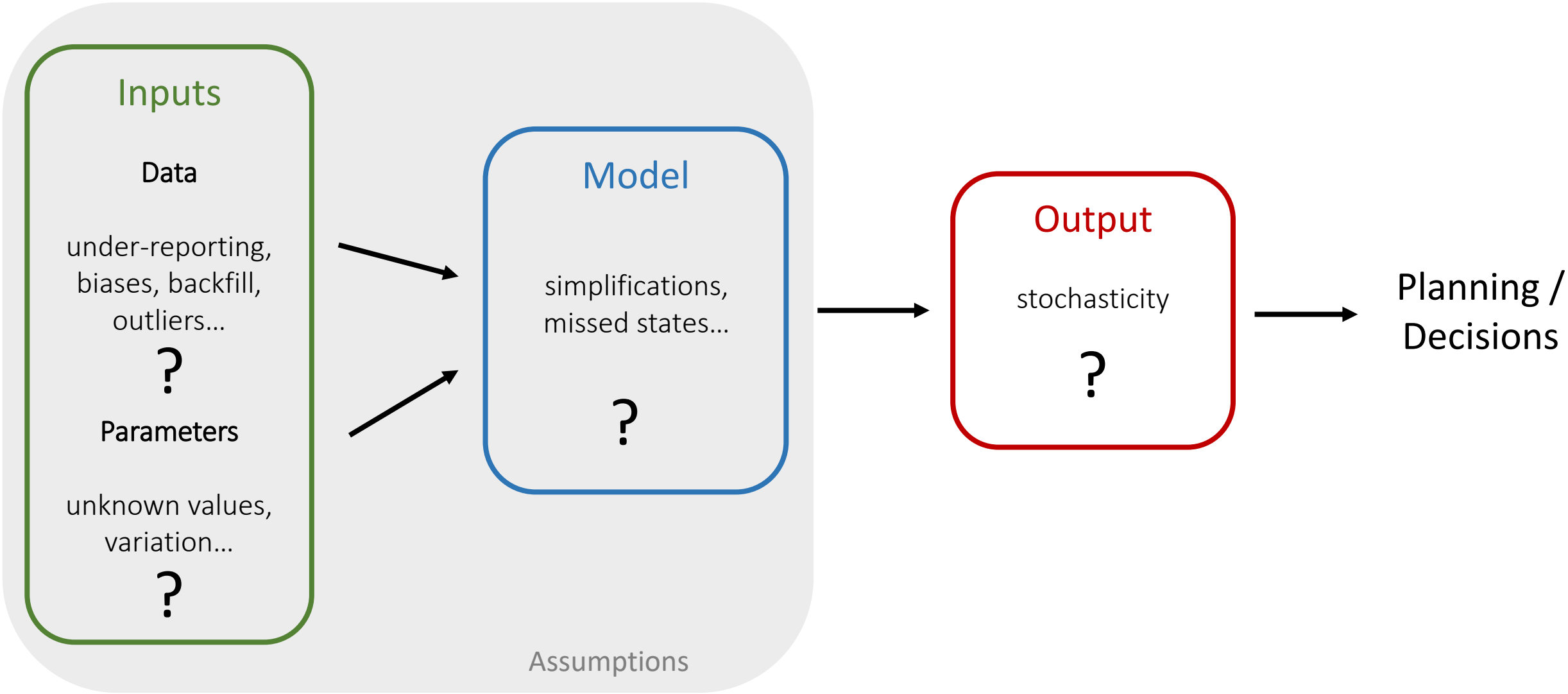


Lau et al 2015

Useful for: Understanding drivers of spread
Policy design
Building more accurate models

Interpreting model uncertainty

How much uncertainty is there?



Sensitivity analysis

Inputs

Data

under-reporting, biases, backfill, outliers…

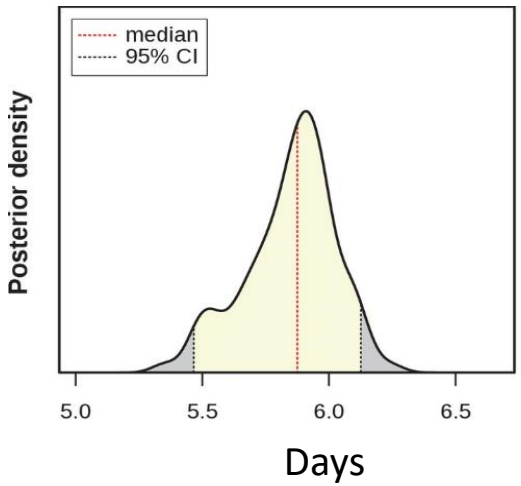
?

Parameters

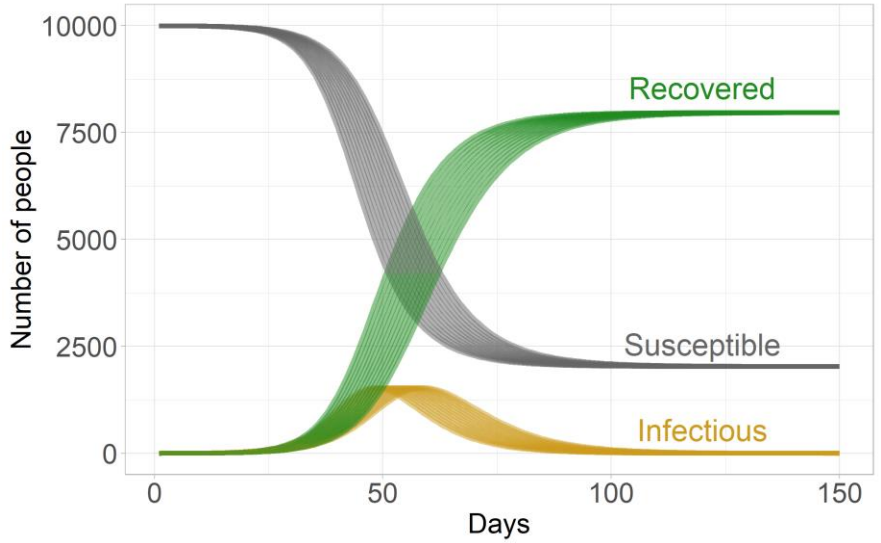
unknown values, variation…

?

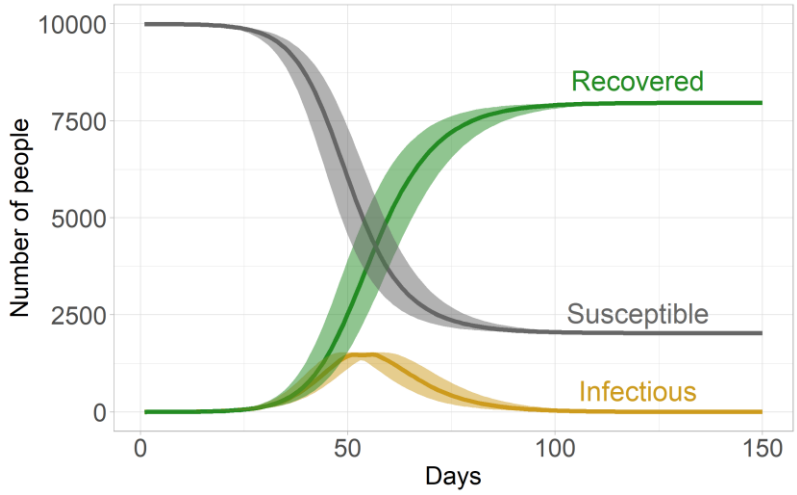
Infectious period



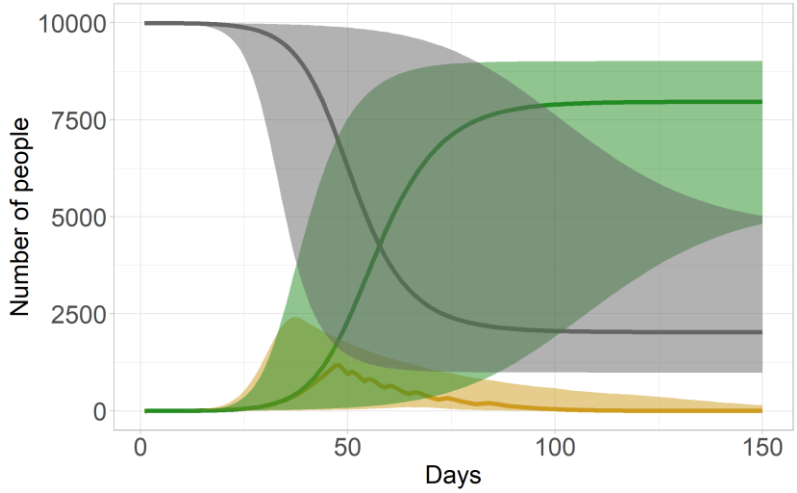
range



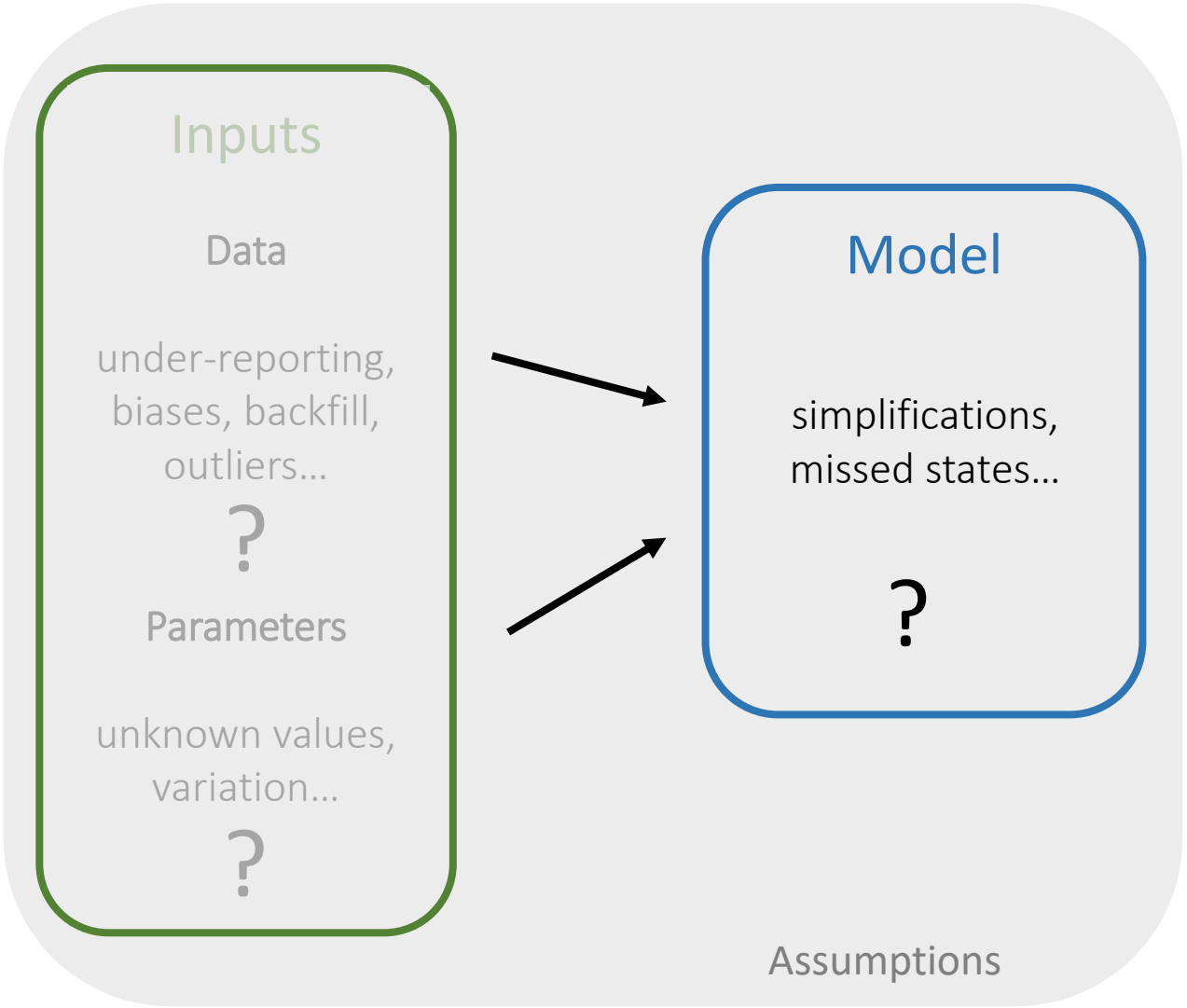
Infectious period: **small** uncertainty

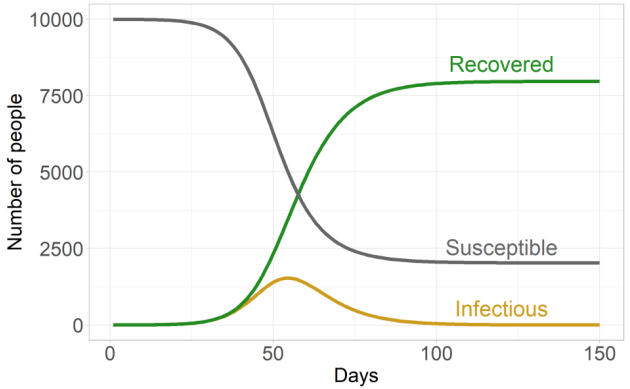


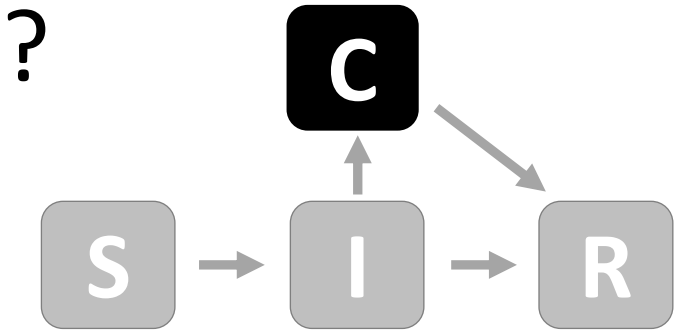
Infection rate: **large** uncertainty

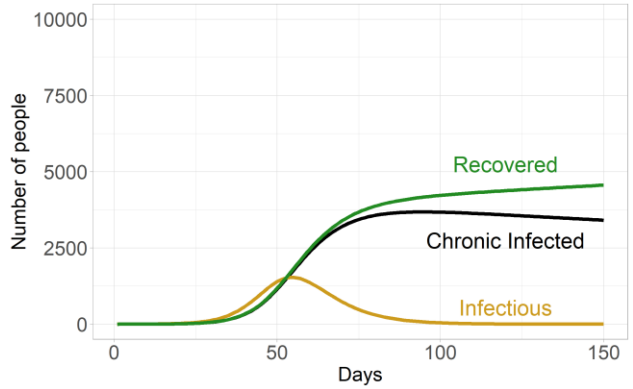


How much uncertainty is there?









How much uncertainty is there?

Inputs

Data

under-reporting, biases, backfill, outliers…

?

Parameters

unknown values, variation…

?

Model

simplifications, missed states…

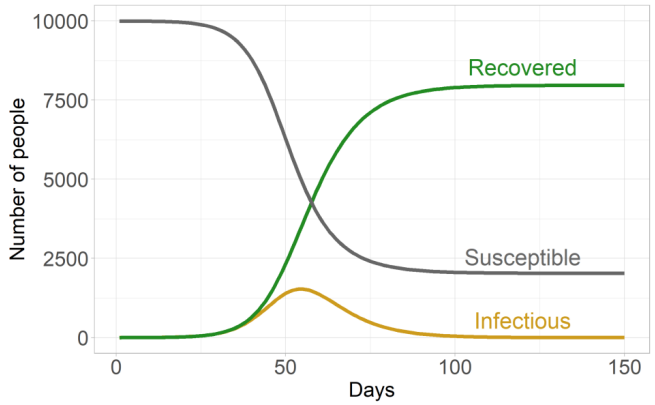
?

Assumptions

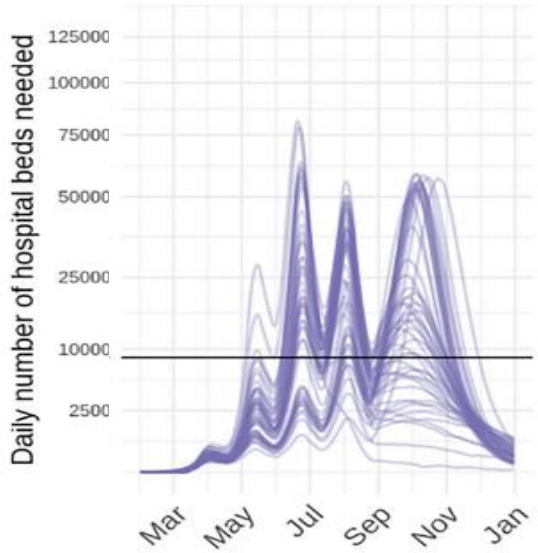
Output

stochasticity

Deterministic model



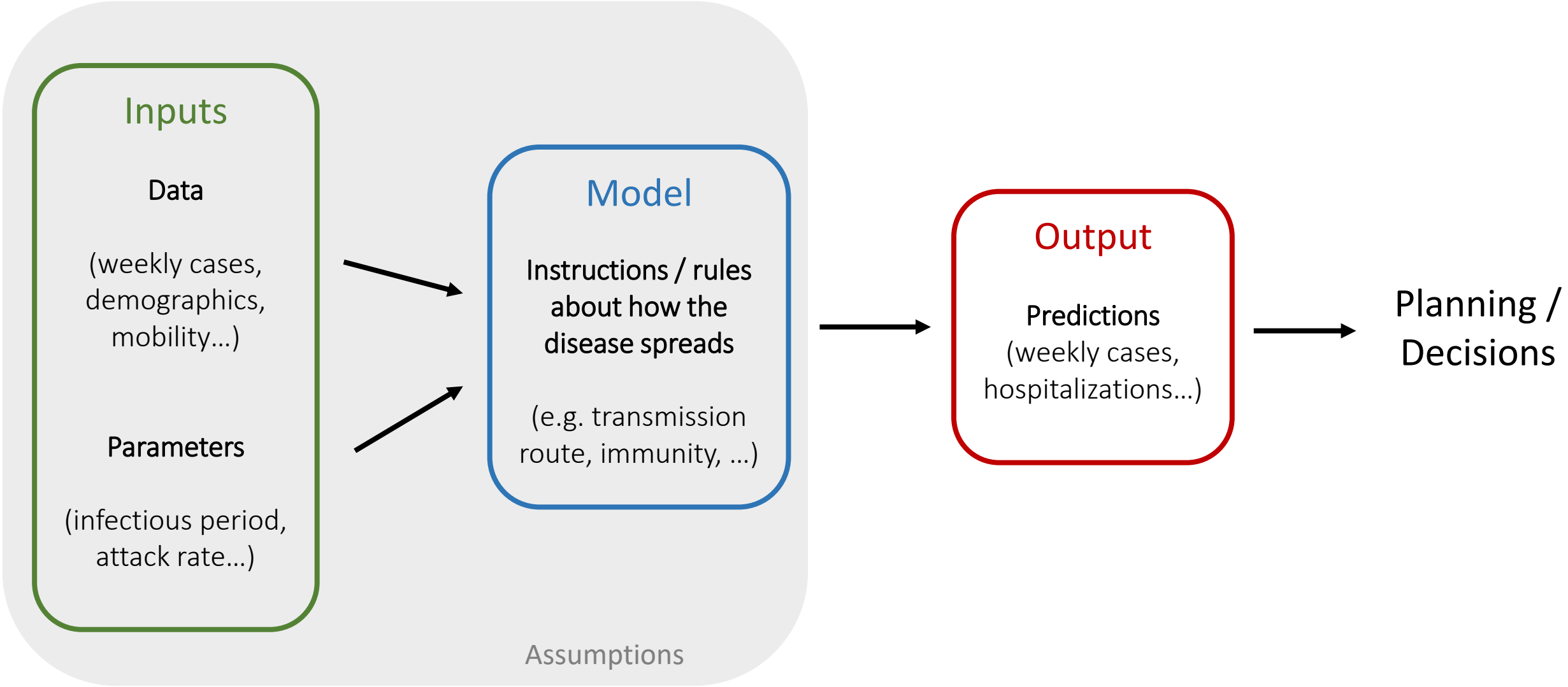
Stochastic model



Lemaitre et al 2021

Assessing model utility

How ‘good’ is this model?



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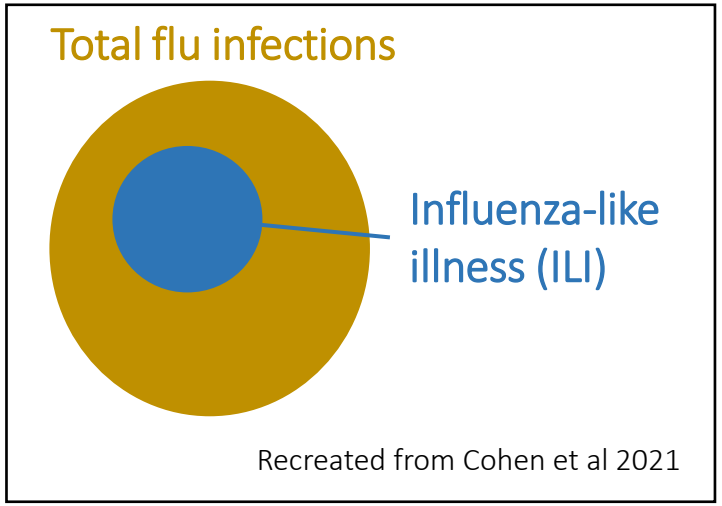


Inputs

Data

(weekly cases, demographics, mobility…)

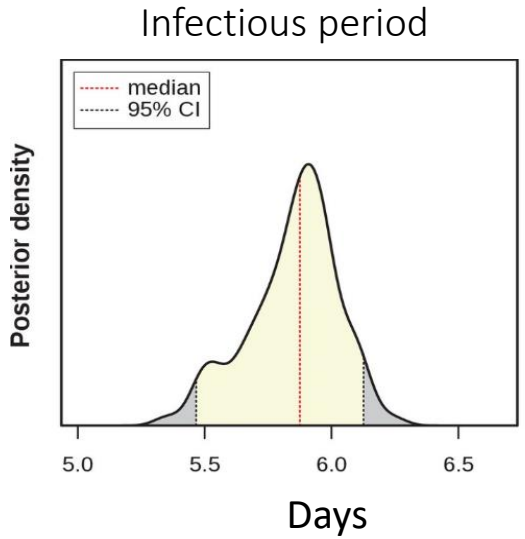
Parameters

(infectious period, attack rate…)

What data are being used?
- What are they being used to inform?
- Are there biases / limitations to take into account?

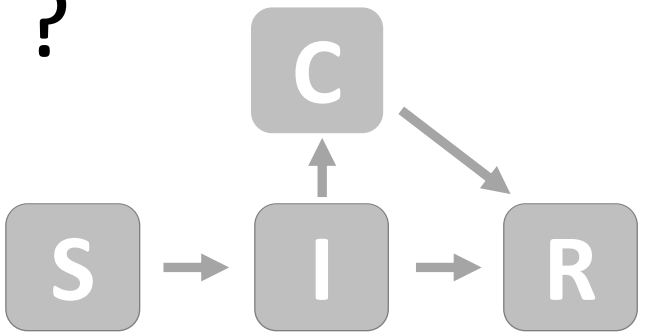
How were parameter values chosen?
- Are they reasonable?
- How (un)certain are we?

Do we expect values to change with time, place…?



How ‘good’ is this model?

?



Inputs

Data

(weekly cases, demographics, mobility…)

Parameters

(infectious period, attack rate…)

Model

Instructions / rules about how the disease spreads

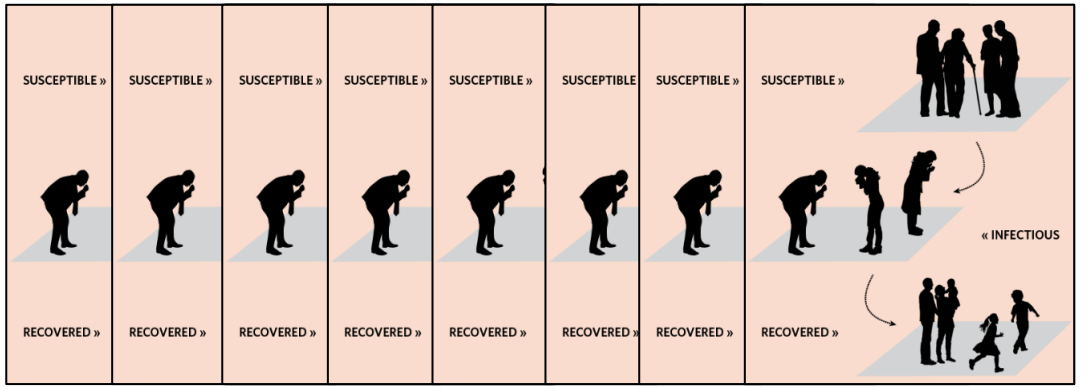
(e.g. transmission route, immunity, …)

Assumptions

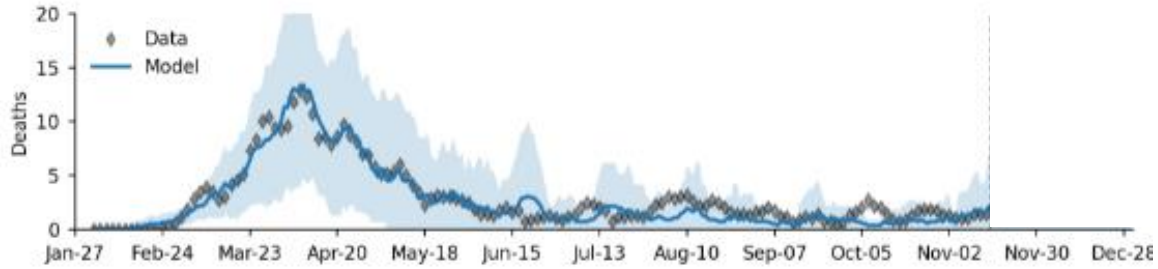
How confident are we in the model structure? Are there others that should be considered?

Is the model too complex / not complex enough?

Meta-population?



How ‘good’ is this model?



Kerr et al 2021

Inputs

Data

(weekly cases, demographics, mobility…)

Parameters

(infectious period, attack rate…)

Model

Instructions / rules about how the disease spreads

(e.g. transmission route, immunity, …)

Assumptions

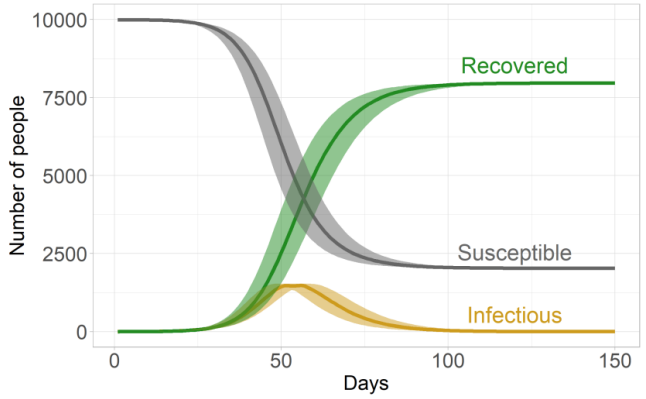
Output

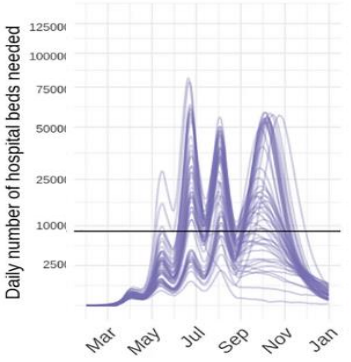
Predictions
(weekly cases, hospitalizations…)

How good is the fit?

Are trends captured?

Is there uncertainty?





Lemaitre et al 2021

How ‘useful’ is this model?

Relevance: is the model addressing the right Q?

Inputs

Data

(weekly cases, demographics, mobility…)

Parameters

(infectious period, attack rate…)

Model

Instructions / rules about how the disease spreads

(e.g. transmission route, immunity, …)

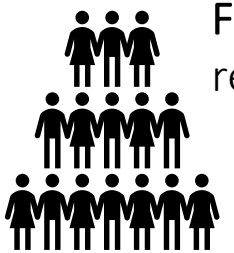
Output

Predictions

(weekly cases, hospitalizations…)

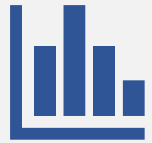
Planning / Decisions

Assumptions



Feasibility: what resources are needed?

Combining models for decision-making



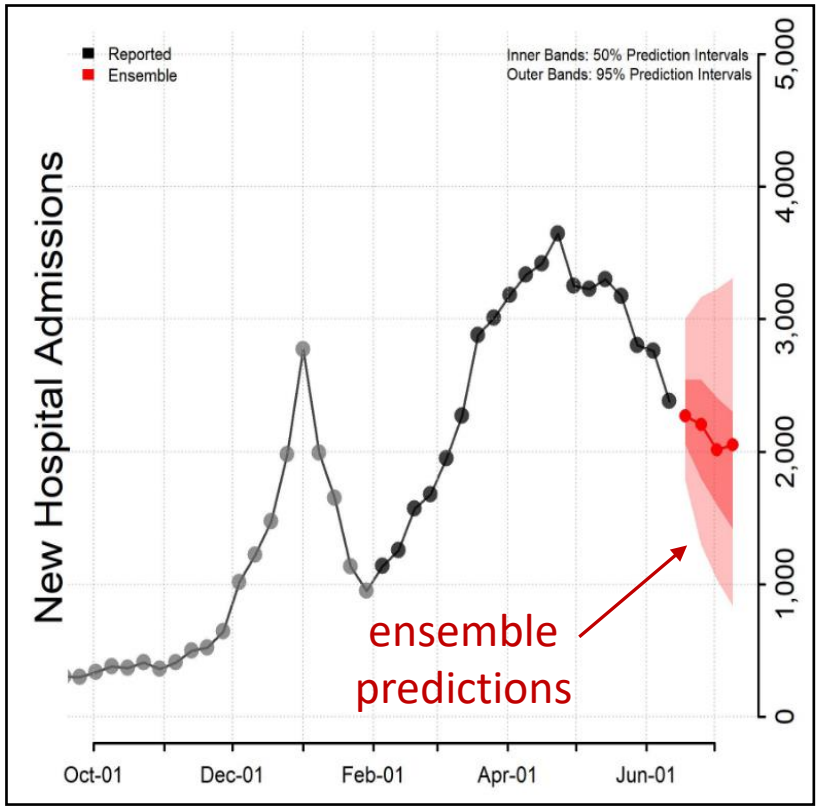
Ensemble models

Models can differ by inputs
structure
deterministic vs stochastic
mechanistic vs statistical

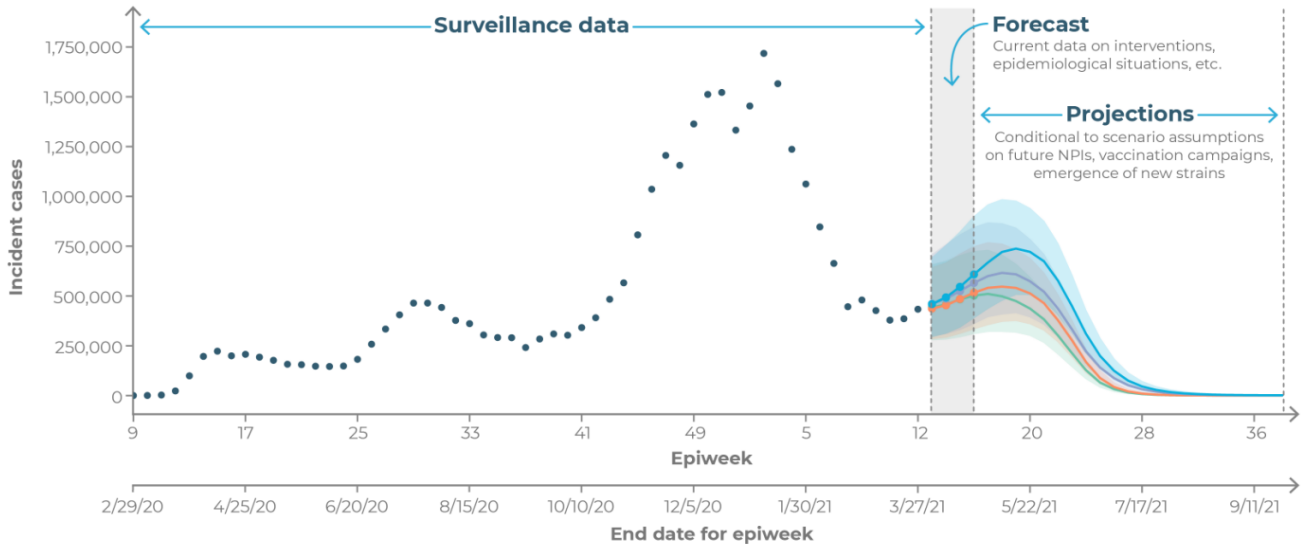
Ensembles combine output from multiple models

Mitigate risks of relying on one model

FluSight Challenge



Scenario Modeling Hub

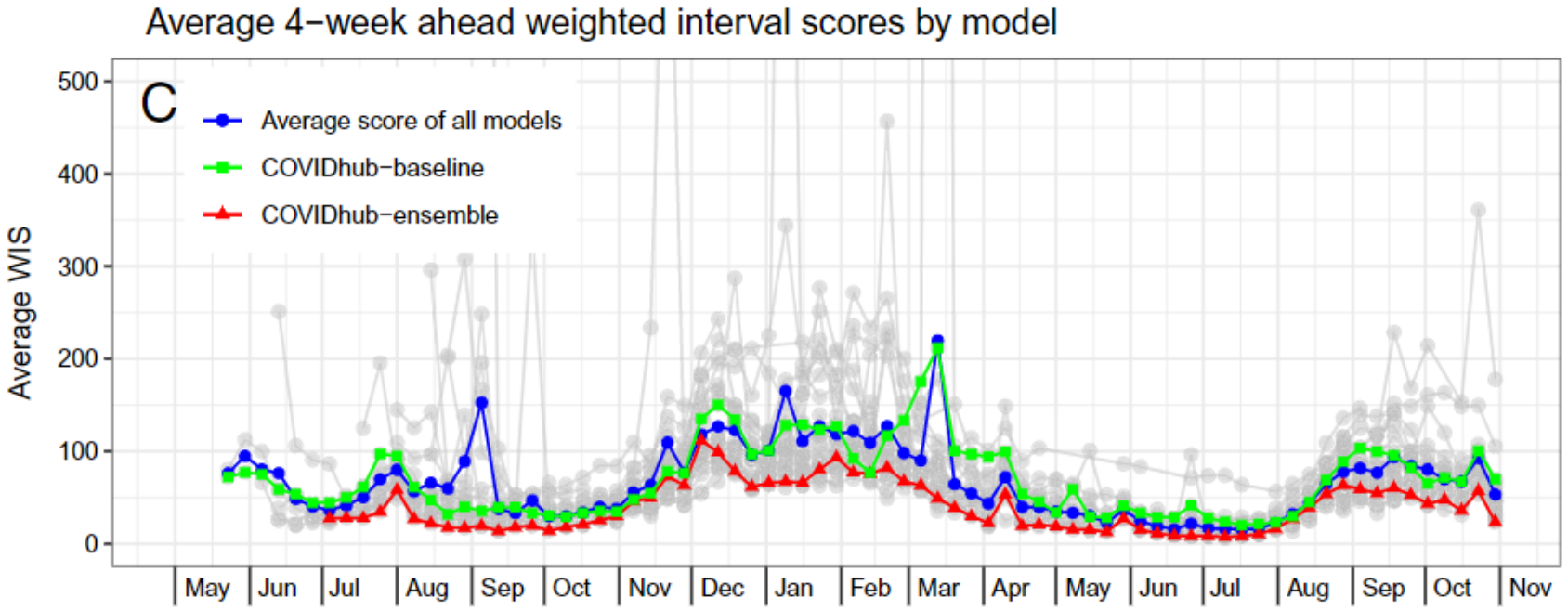


Ensemble models

Example: COVID-19 forecasts

Ensemble consistently among best performing models, across all states

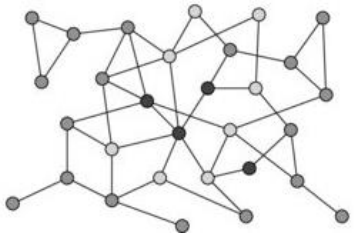
lower = better



Cramer et al 2022

Caveat: resource intensive

Summary



Models come in many flavors

- mechanistic vs statistical
- compartmental, network, agent-based, …
- stochastic vs deterministic

Models have many uses

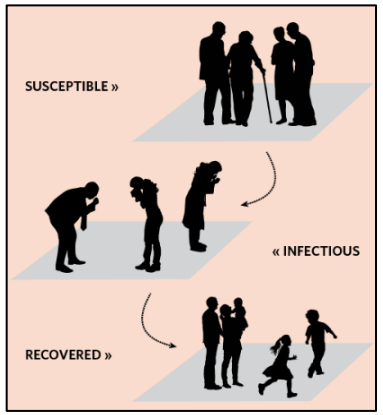
- forecasting
- scenario analysis
- estimation & inference

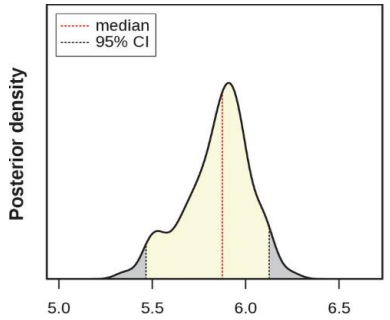
There are ways to assess model uncertainty

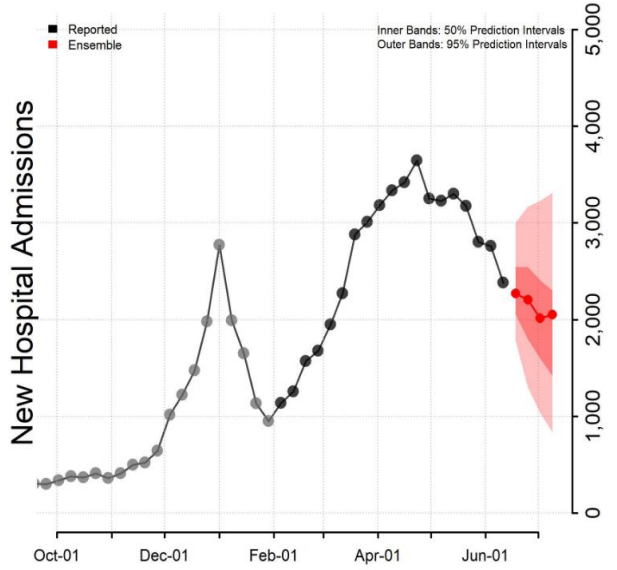
- sensitivity analysis
- alternative structures
- role of stochasticity

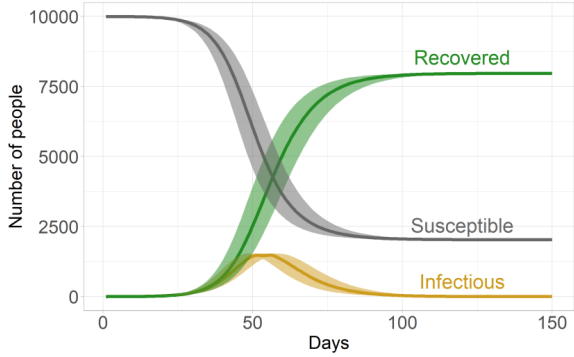
… and utility

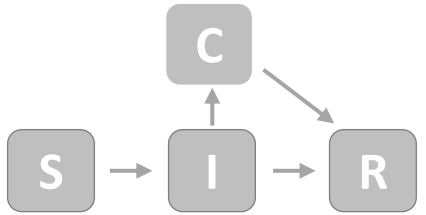
Ensemble models combine multiple models

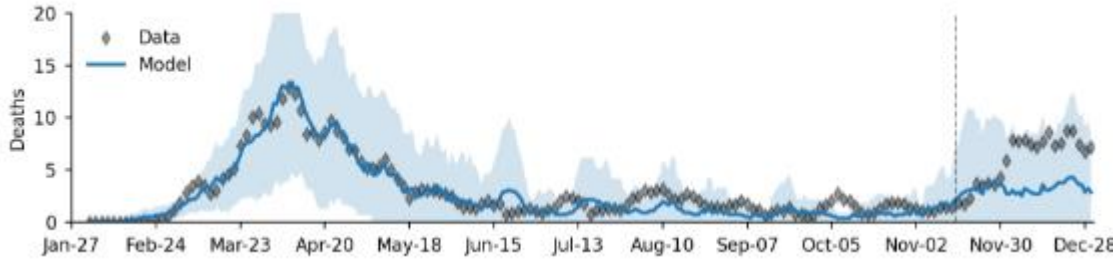












Questions?

Resources:

COVID / Flu Scenario Modeling Hubs
FluSight Challenge

Gurley & Wesolowski, Infectious Disease Transmission Models for Decision Makers, Coursera Online (free)

Acknowledgements: Matt Biggerstaff, Rebecca Borchering

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