

Navigating Epidemics: Accuracy and Utility of Infectious Disease Models

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<https://epiforecasts.io>

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MPI-DS Colloquium

LONDON
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HYGIENE
& TROPICAL
MEDICINE



centre for
mathematical
modelling of
infectious diseases

Acknowledgements

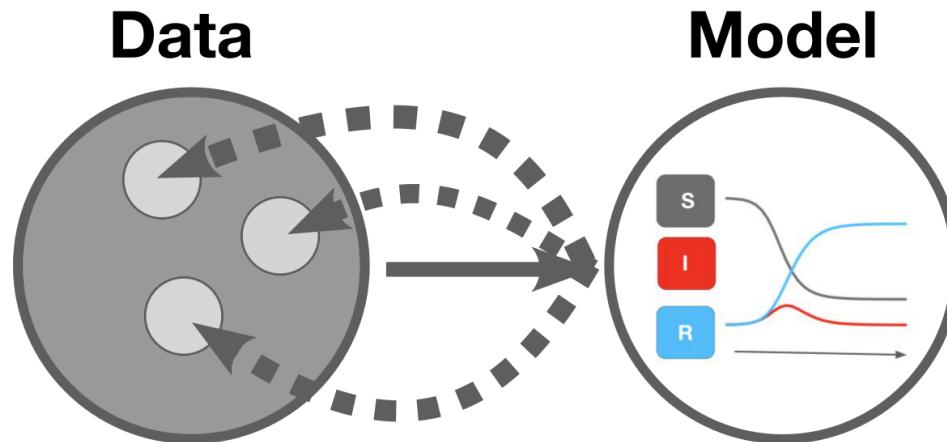
EpiForecasts group (<https://epiforecasts.io>):

Akira Endo, Alexis Robert, Ciara McCarthy, Hannah Choi,
Joel Hellewell, James Azam, James Munday, Kath Sherratt,
Liza Hadley, Manuel Stapper, Nikos Bosse, Sam Abbott,
Sophie Meakin, Toshiaki Asakura

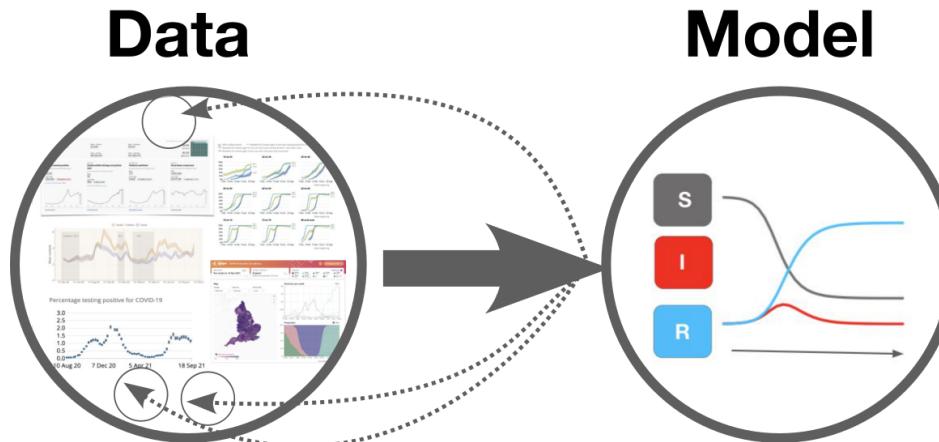
Johannes Bracher, Nick Reich and other collaborators



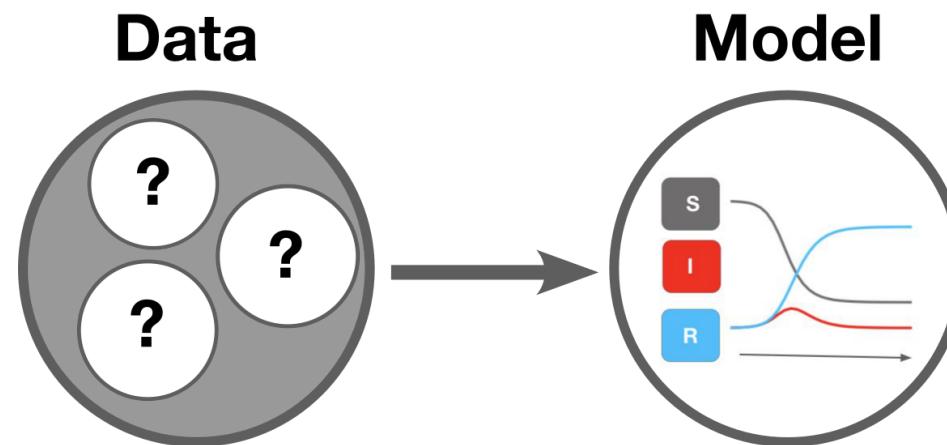
Models are a tool to combine data (what we **know**) with assumptions and theory (what we **think**) to learn about what we **don't know**.



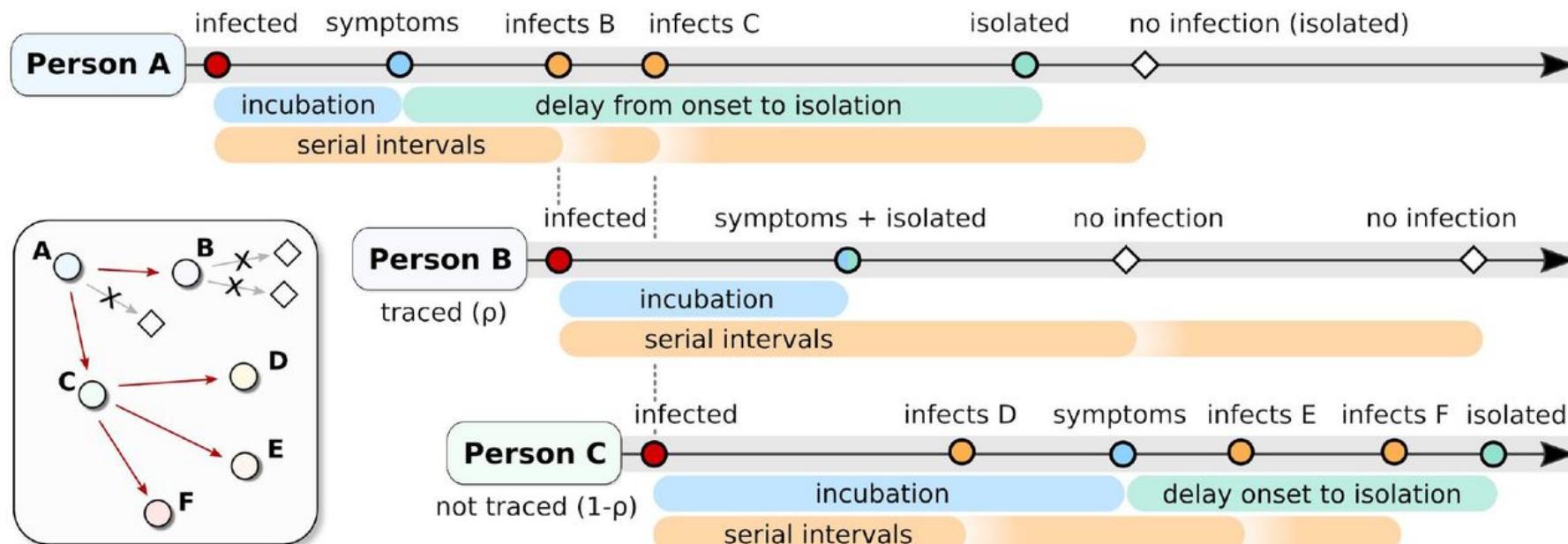
When data is **abundant**, models and analytics can generate insight without many additional assumptions.



When data is **sparse** (e.g. early in an outbreak), modellers need to make more assumptions to generate insights.

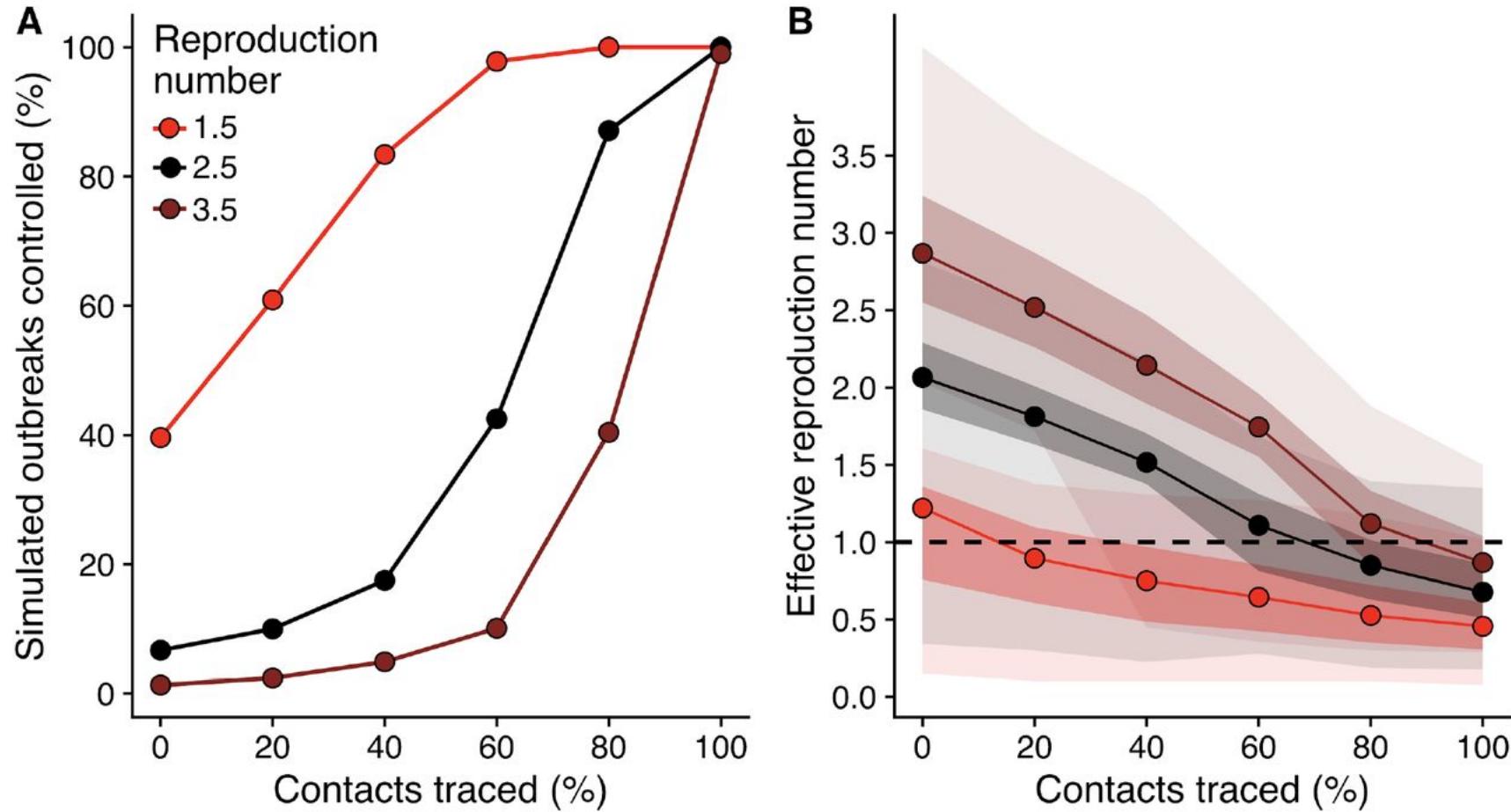


January 2020: Can COVID-19 be controlled by contact tracing?



Hellewell et al., medRxiv, 2020

Probability of control depends on **intensity of transmission** and **contact tracing effort**.



“We illustrate the potential impact that flawed model inferences can have on public health policy with the model described [...] by Joel Hellewell and colleagues, which is part of the scientific evidence informing the UK Government’s response to COVID-19.”

Gudrasani & Ziauddeen, *Lancet Glob Health*, 2020

“All models are wrong, but some are useful”

– George Box

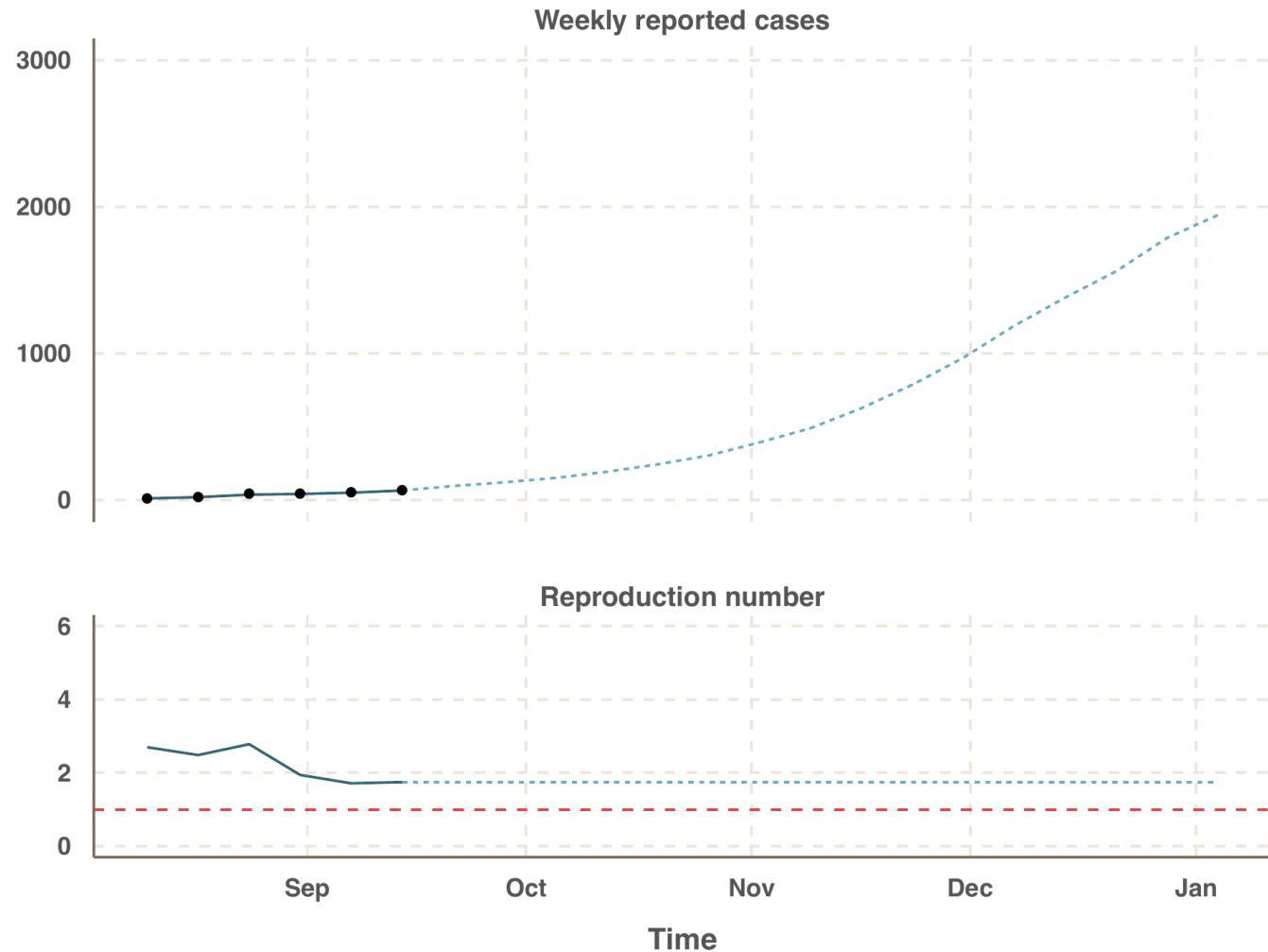
“All models are **wrong**, but **some** are useful”

– George Box

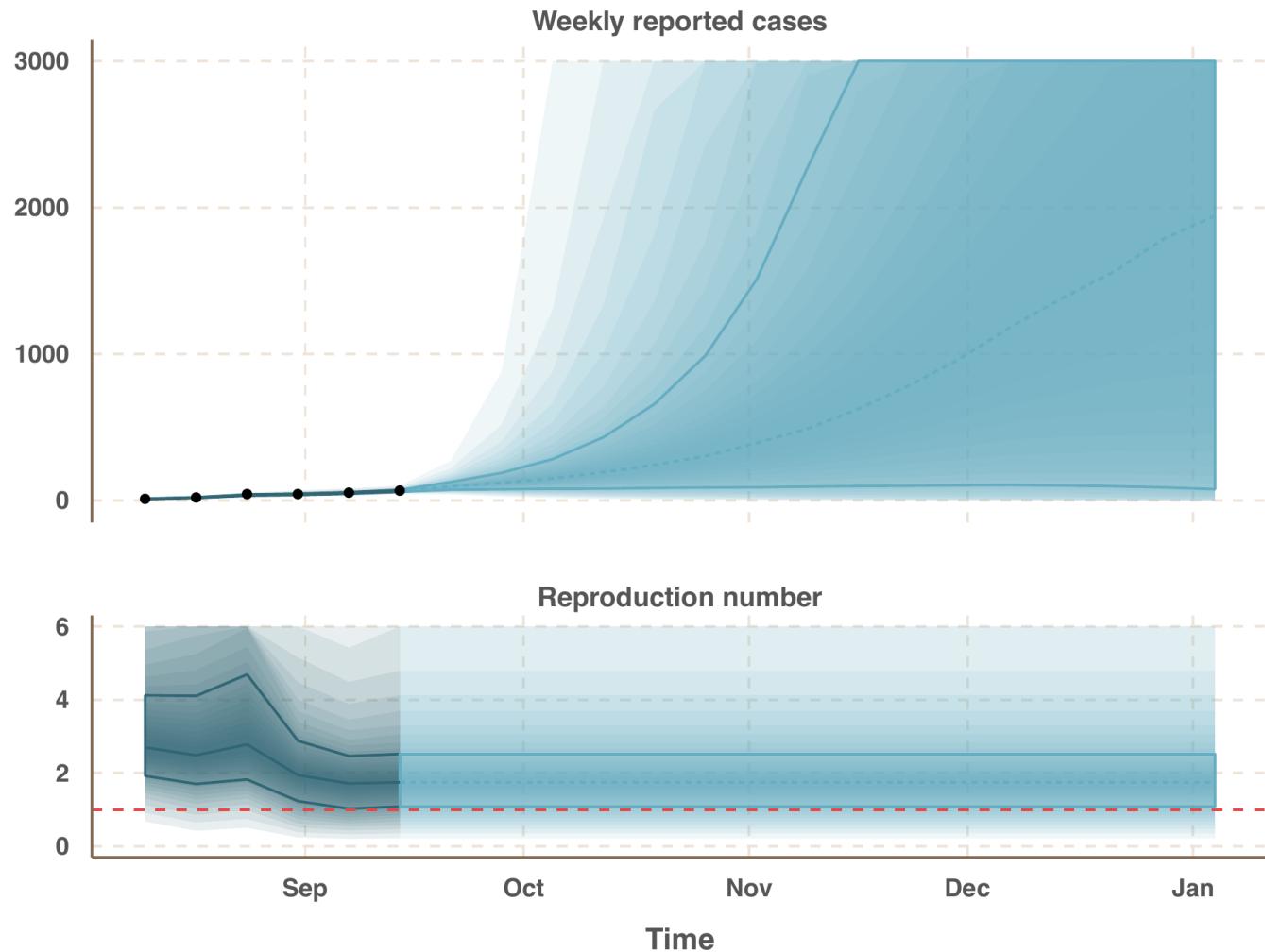
wrong: how wrong?

some: which ones?

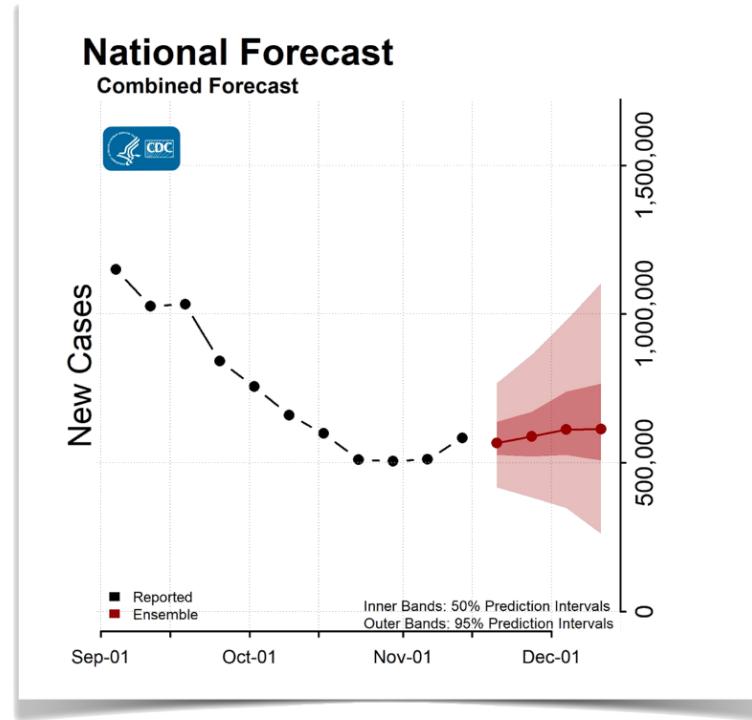
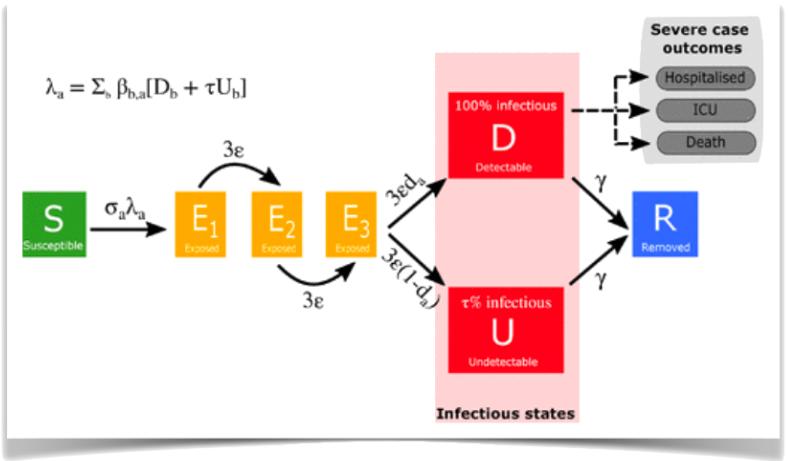
The future as a (particular) data gap



The future as a (particular) data gap

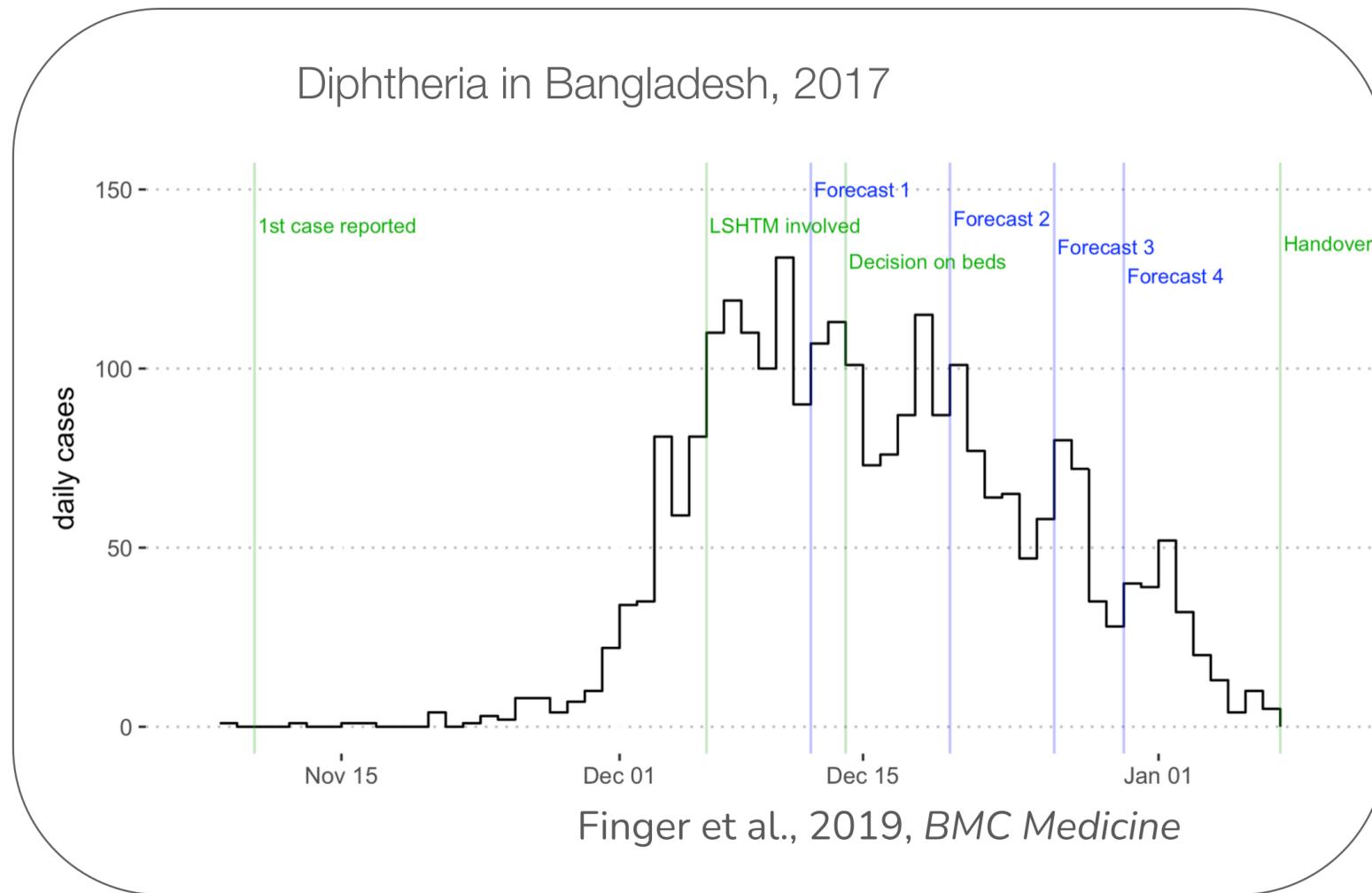


Mechanistic models support causal understanding, but predictions can have value in their own right



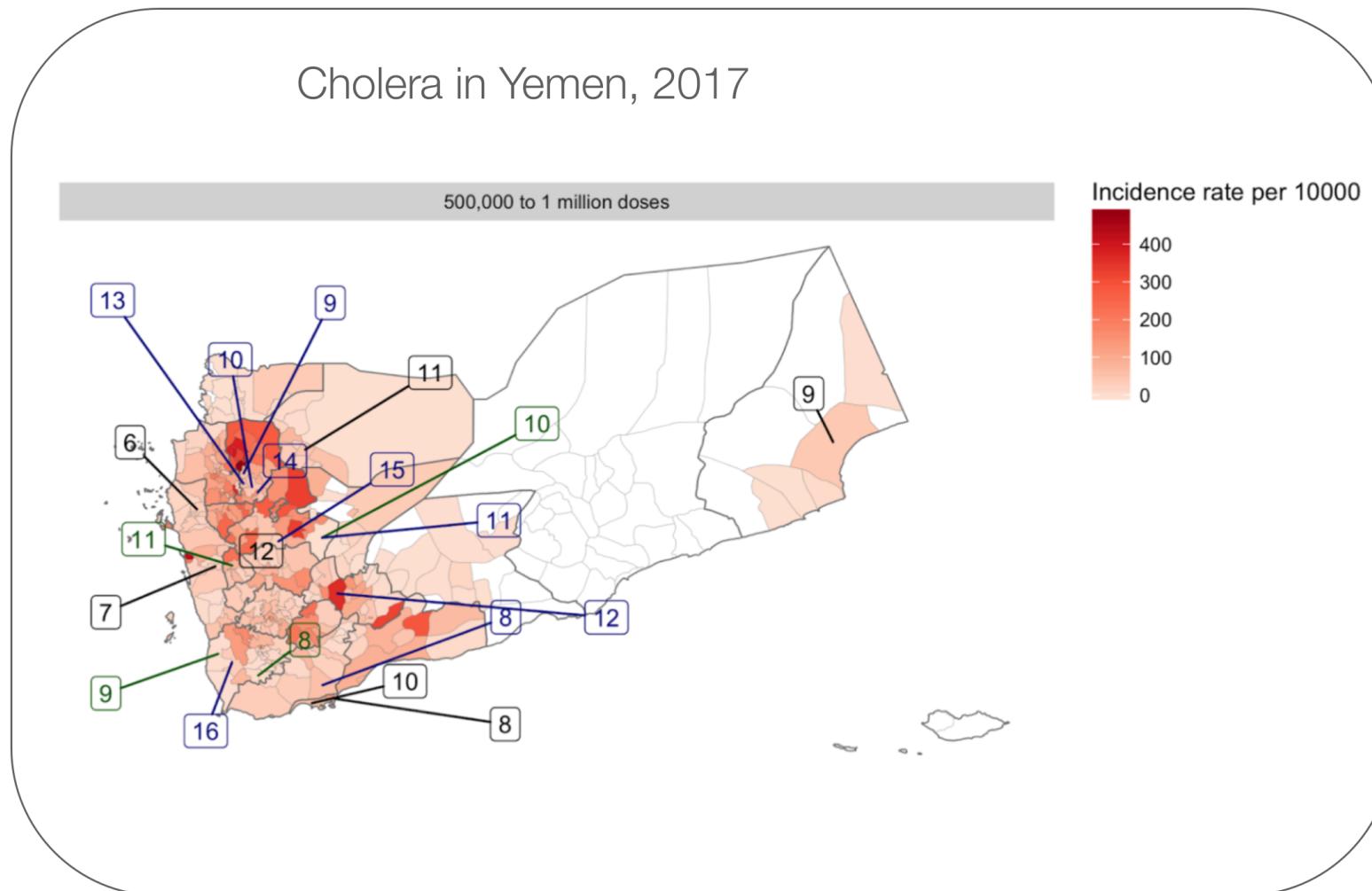
Desai et al., *Health Secur*, 2019
Keeling et al., *Stat Meth Med Res*, 2021
Cramer et al., *Scientific Data*, 2021

Short-term forecasts can inform decision making



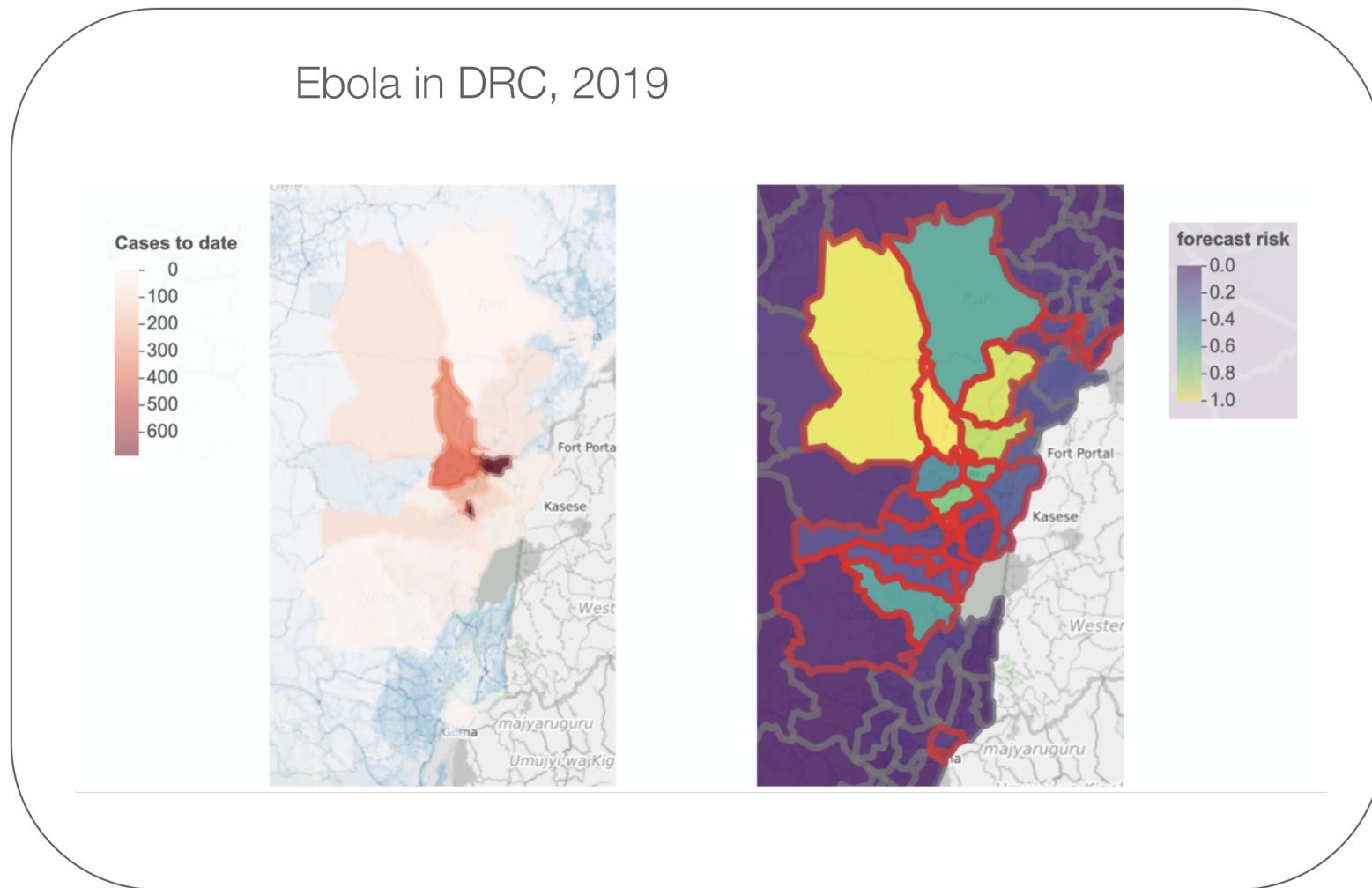
Finger et al., *BMC Medicine*, 2019

Short-term forecasts can inform decision making



Design interventions

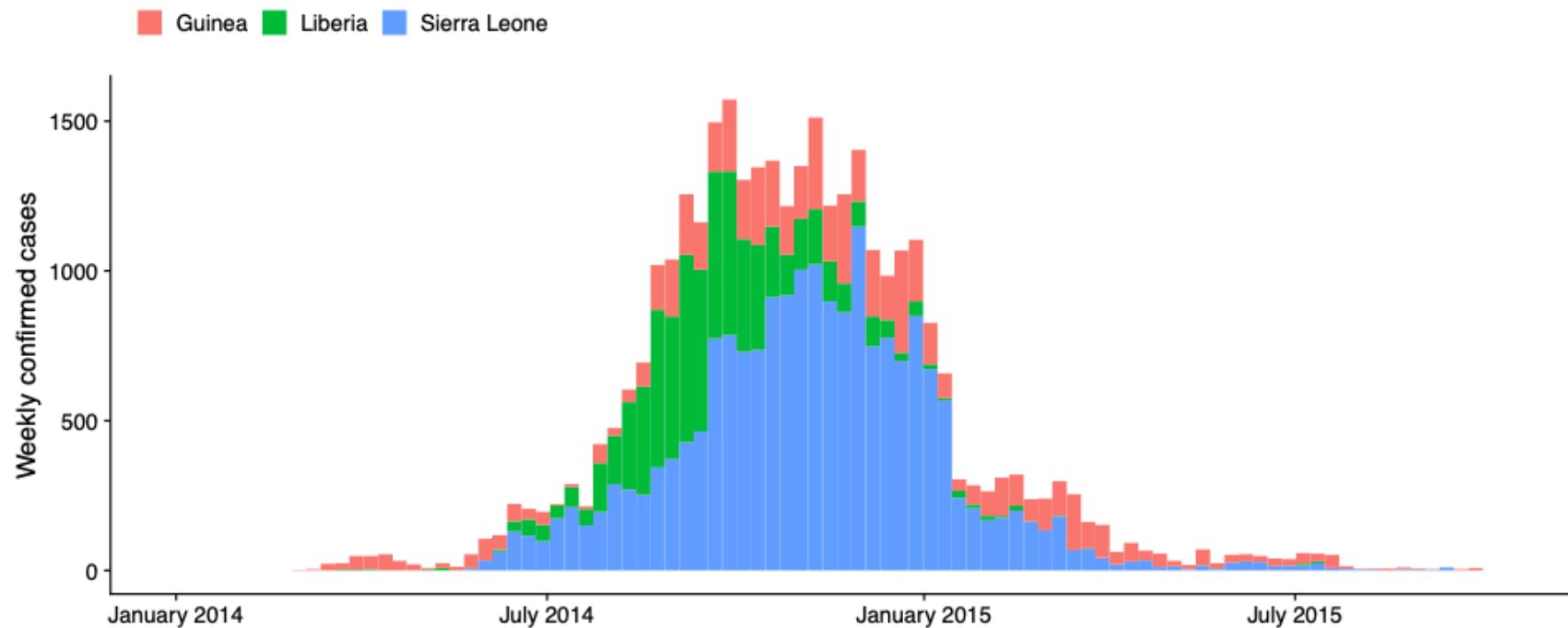
Short-term forecasts can inform decision making



Plan clinical trials

Forecasting Ebola

Ebola in West Africa, 2013-16



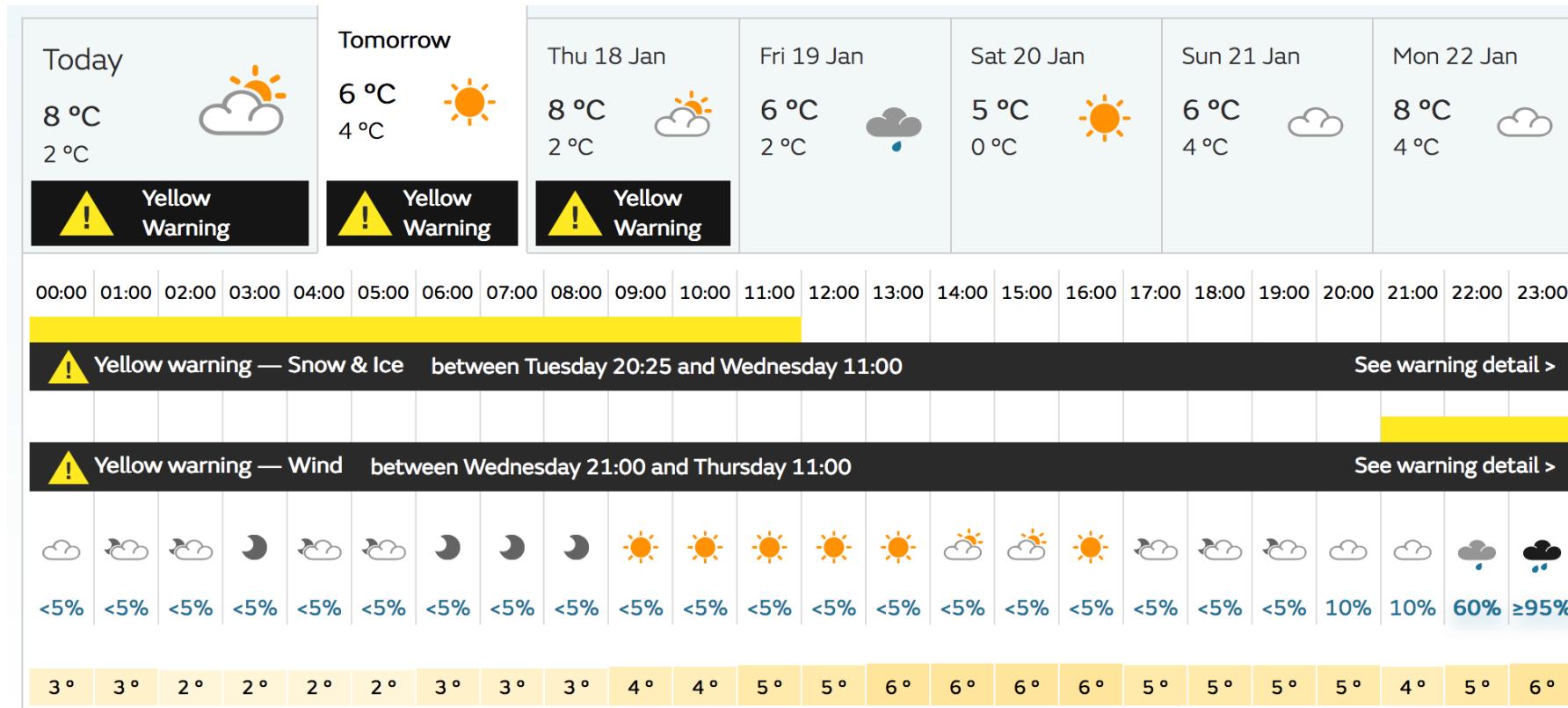
"We were losing ourselves in details [...] all we needed to know is, are the number of cases rising, falling, or levelling off?"

– Hans Rosling, Liberia, 2014



Display a menu

Forecasts can be assessed/validated

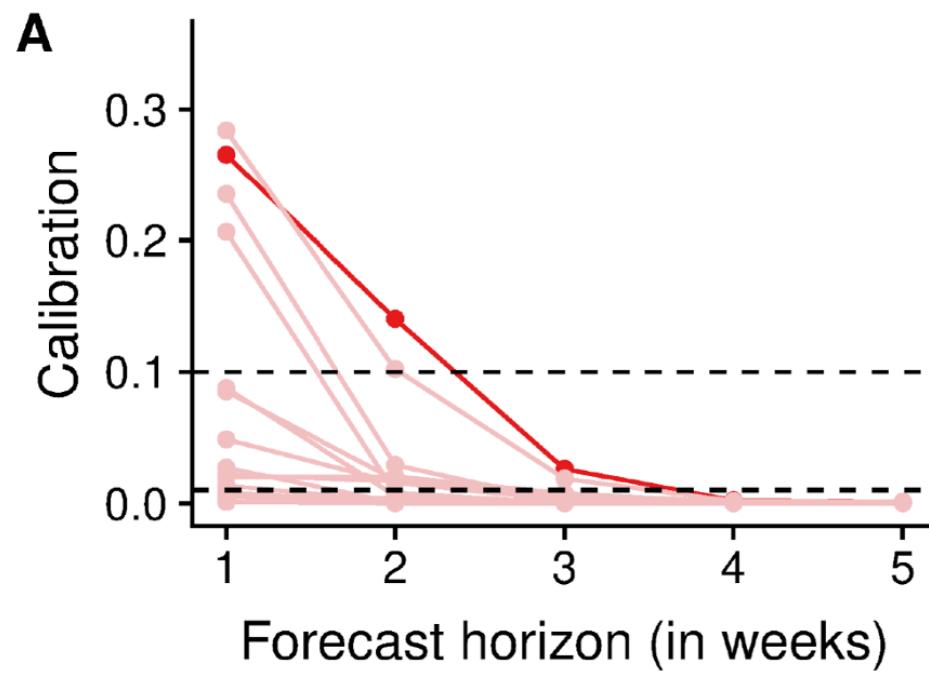


Forecasting paradigm

“maximise **sharpness** subject to **calibration**”

Gneiting, Balabdaoui & Raftery, *J R Stat Soc B*, 2007

Ebola: how wrong were our models?



Funk et al., *PLOS Comp Biol*, 2019

Ebola forecasts could be trusted for up to 2 weeks

Our Ebola forecasts could be trusted for up to 2 weeks

Forecasting COVID-19

Forecasting via the renewal equation

$$\text{New infections } I(t) = R_t \sum_{\tau} g_{\tau} I_{t-\tau}$$

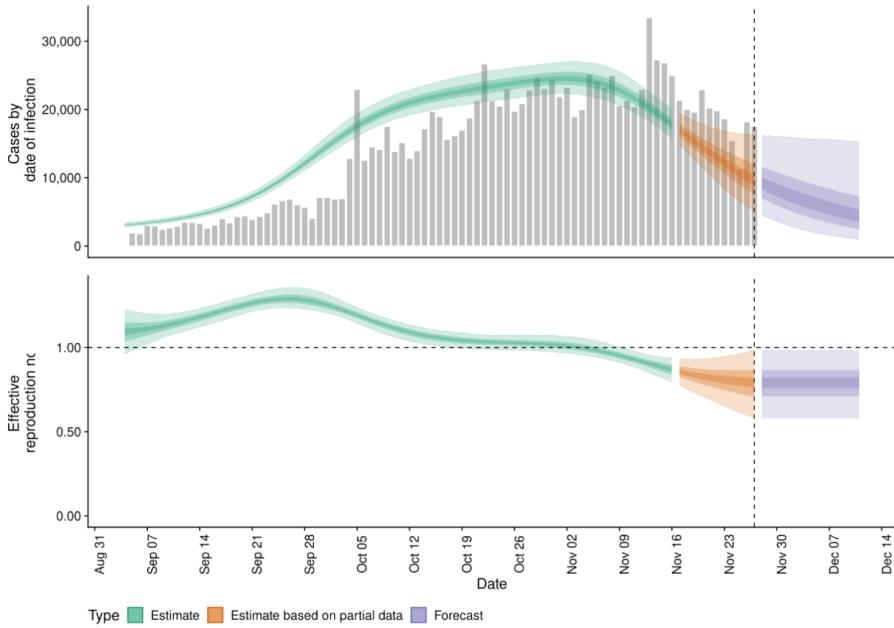
$$\text{Reproduction number } R(t) = R_{t-1} \exp(\text{GP})$$

$$\text{Delayed reporting } D(t) = \sum_{\tau} \xi_{\tau} I_{t-\tau}$$

$$\text{Observations } C(t) = \text{NegBin}(D_t \omega_{(t \bmod 7)}, \phi)$$

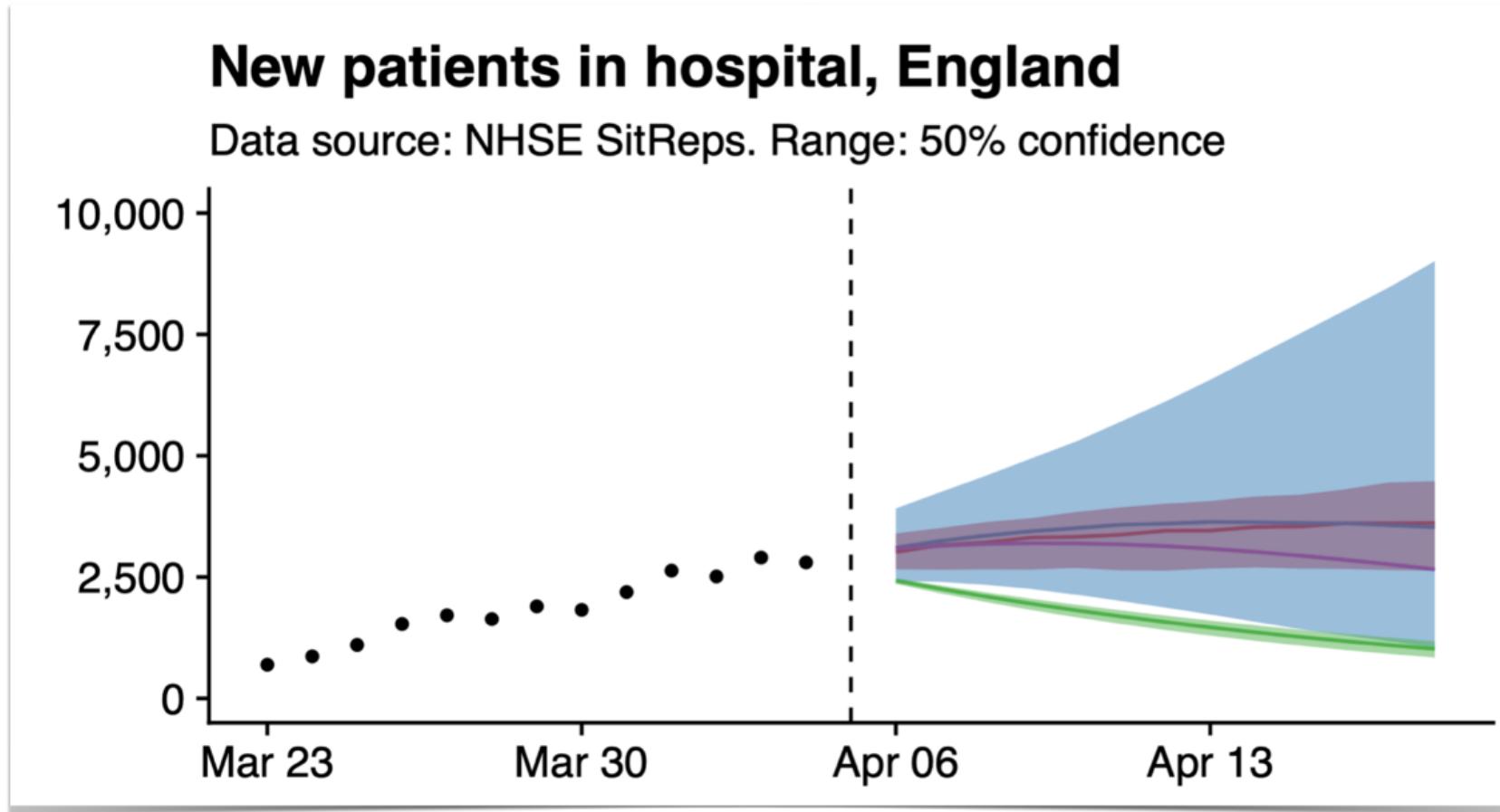
<https://epiforecasts.io/EpiNow2/>

Global COVID case forecasts via the renewal equation

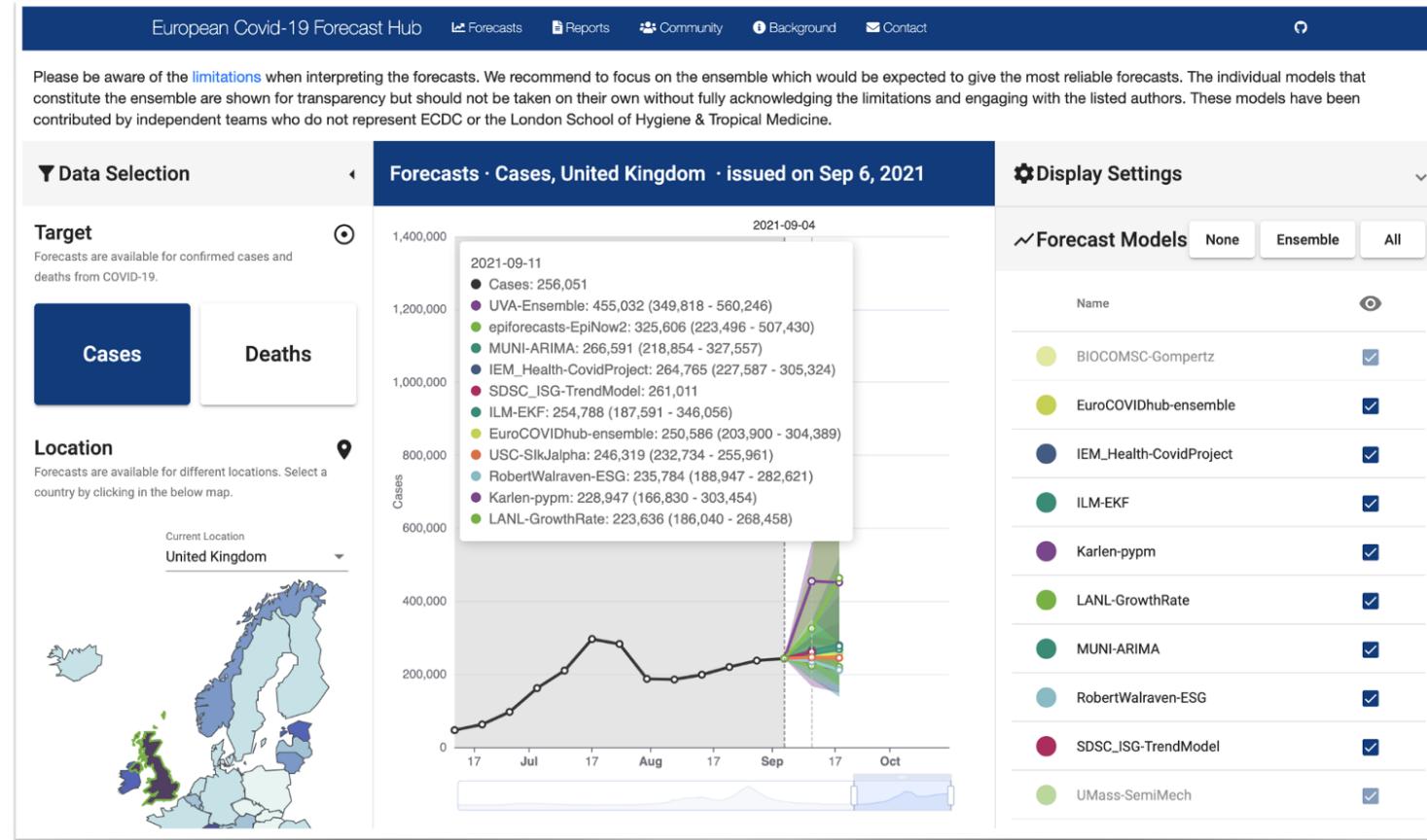


Abbott et al., *Wellcome Open Res*, 2020
Gostic et al., *PLoS Comp Biol*, 2021
<https://epiforecasts.io/posts/2022-03-25-rt-reflections>

Forecasting to inform policy in the UK



European COVID-19 Forecast Hub



Reich et al., *Am J Public Health*, 2022
<https://covid19forecasthub.org>
<https://covid19forecasthub.eu>

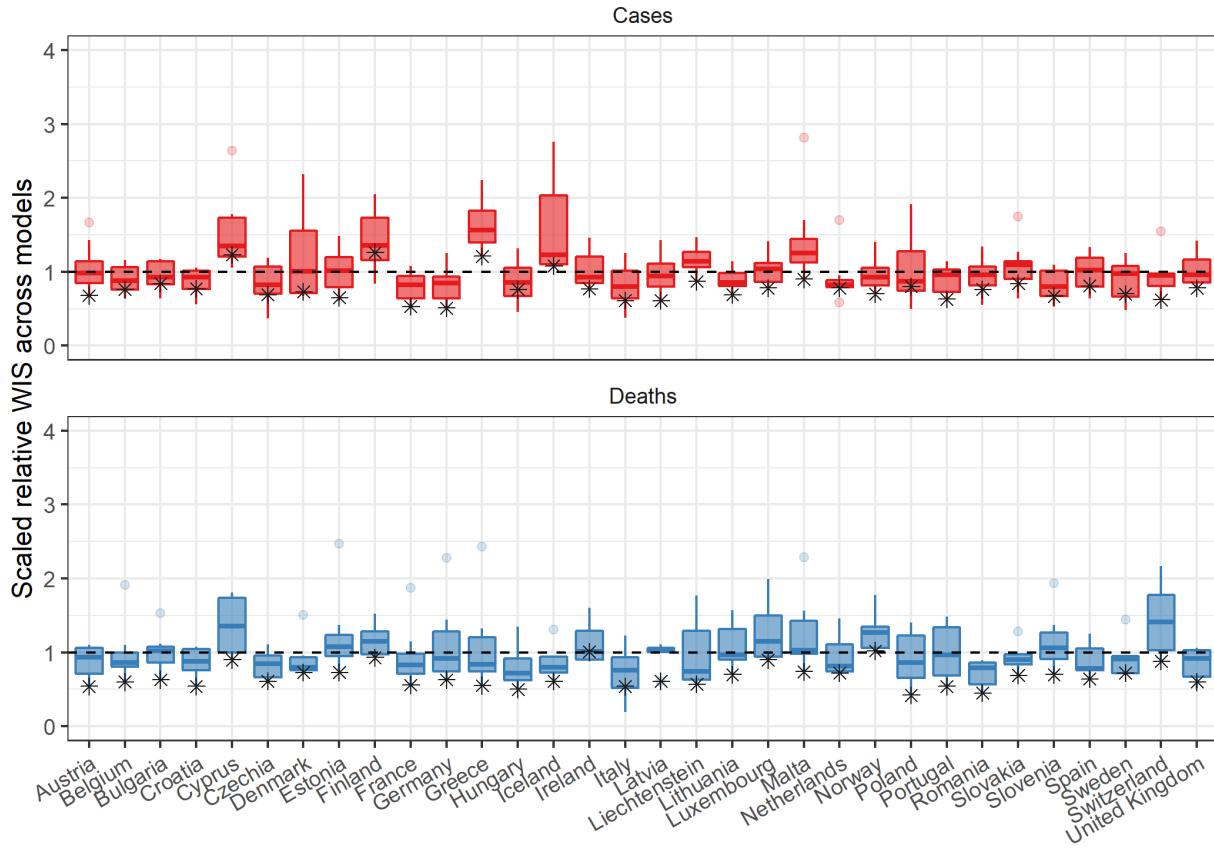
How good were COVID forecasts?

We can compare forecasts using
proper scoring rules

$$\text{CRPS}(F, x) = \mathbb{E}|X - x| - \frac{1}{2}\mathbb{E}|X - X'|$$

Gneiting and Raftery, *J R Statist Soc B*, 2007

Median ensemble outperforms individual models

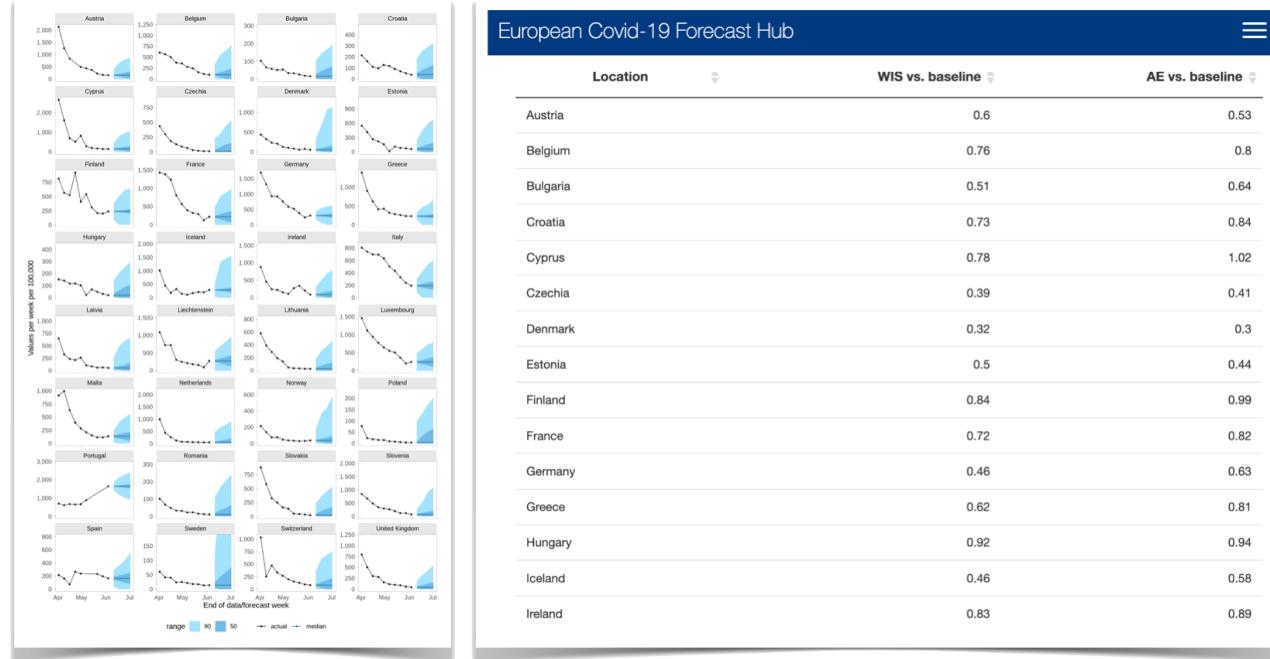


We can compare forecasts using *proper scoring rules*

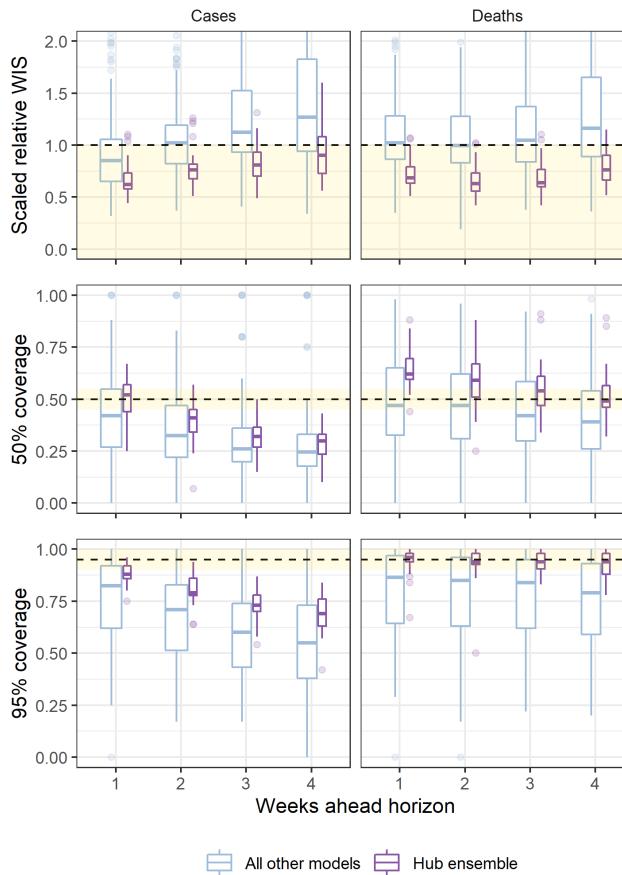
$$\text{CRPS}(F, x) = \mathbb{E}|X - x| - \frac{1}{2}\mathbb{E}|X - X'|$$

but these only tell us about *relative* quality of forecasts

Absolute quality of forecasts #1: baseline models



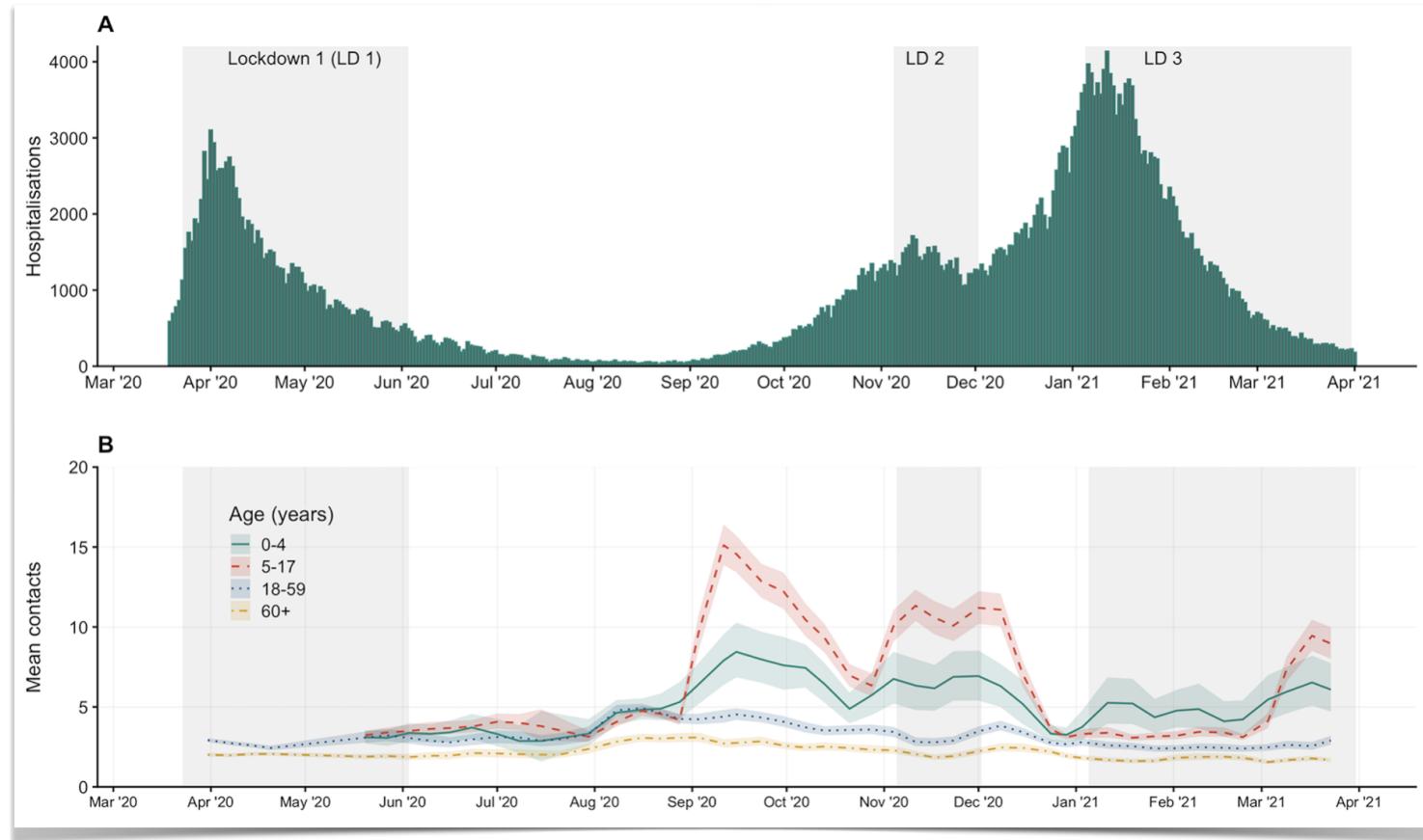
Absolute quality of forecasts #2: calibration



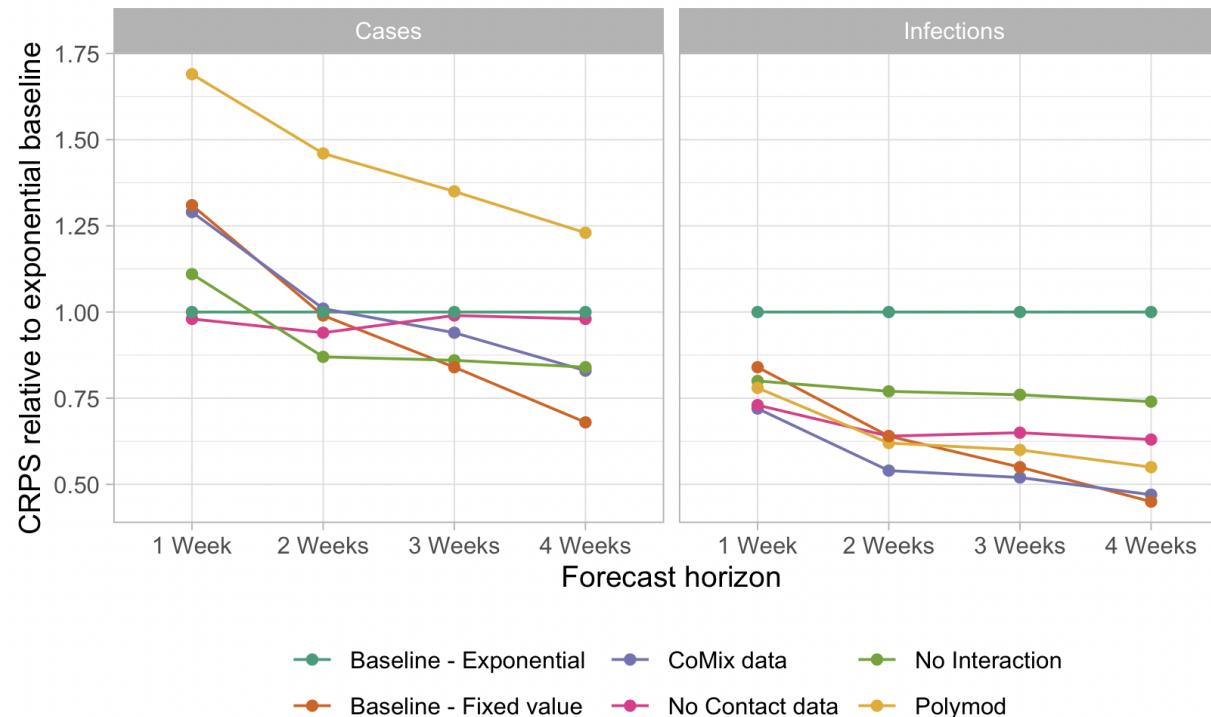
What limits predictive ability?

1. Unpredictable human behaviour?
2. Unpredictable pathogen biology?
3. Bad models?

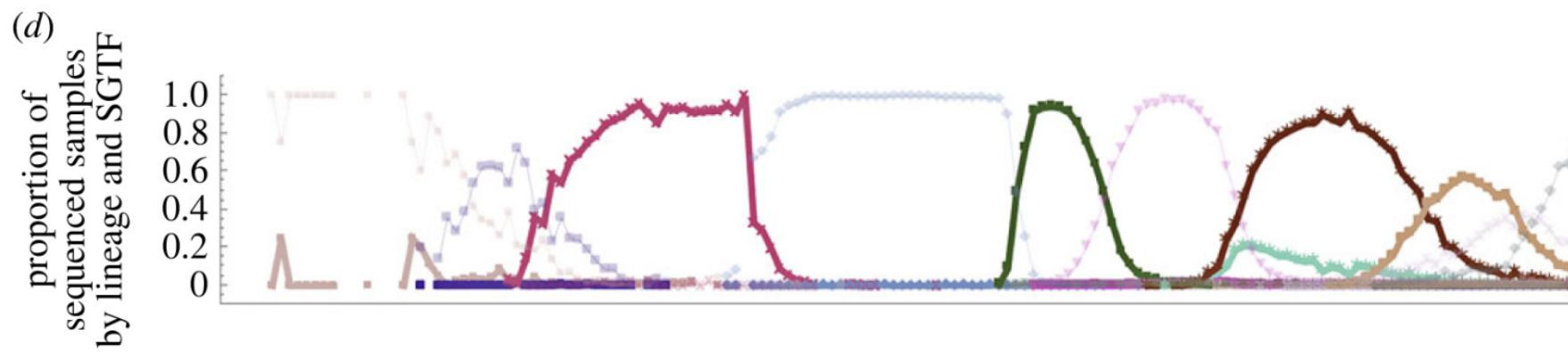
Unpredictable human behaviour?



Observed behaviour as predictor: improvement of forecasts, but only once **age-specific reporting** is taken into account.

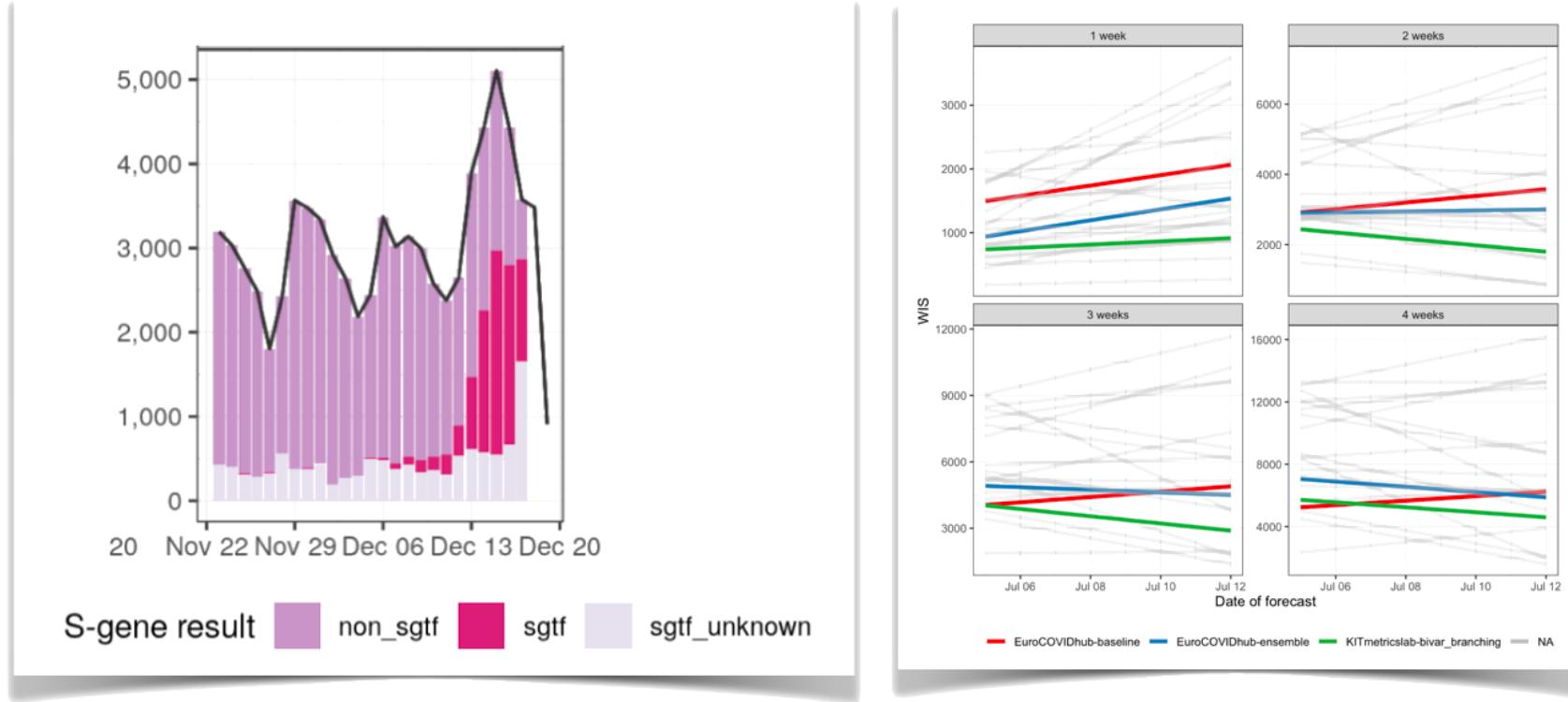


Unpredictable biology?



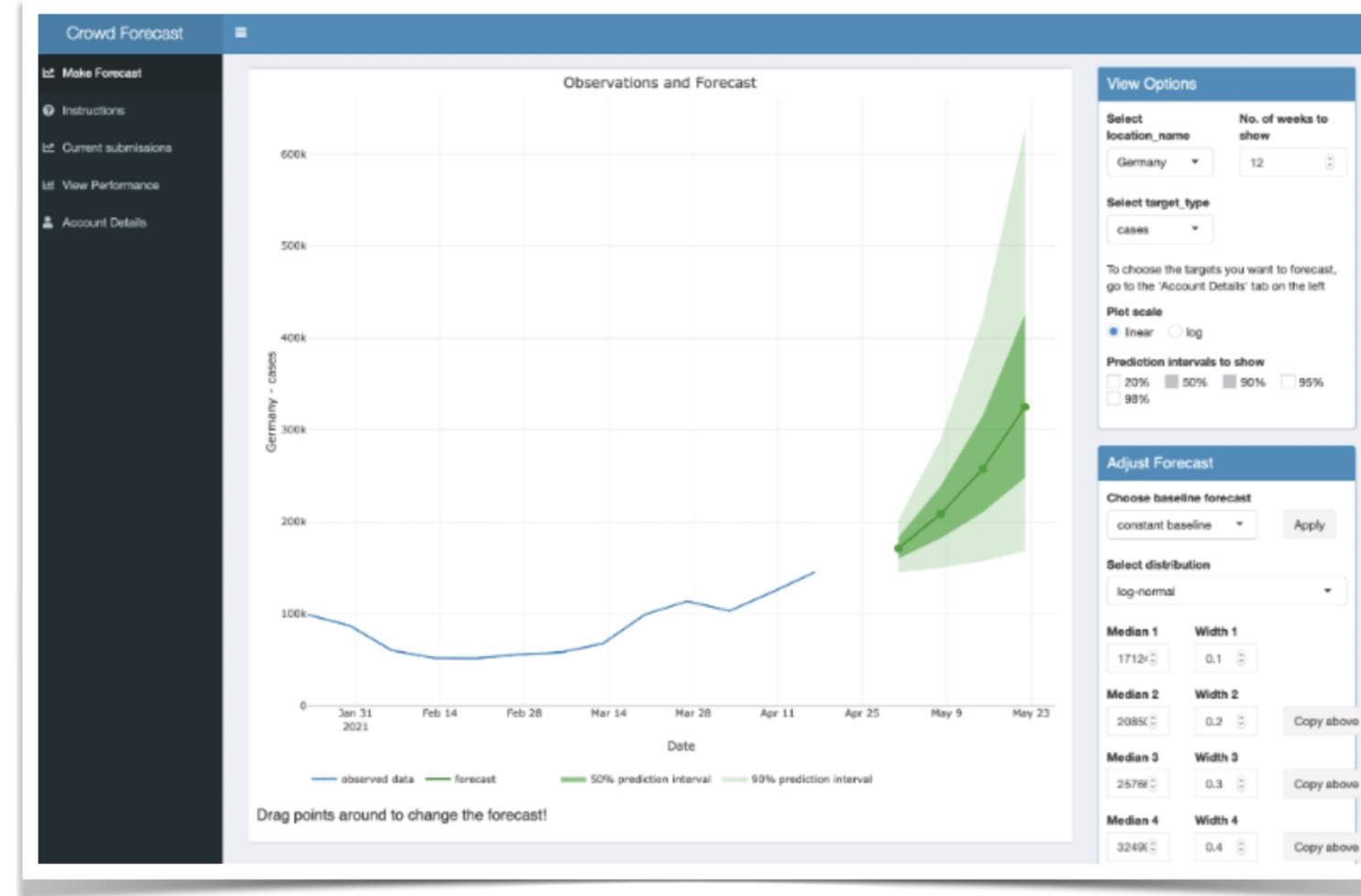
Lythgoe et al., *Proc Roy Soc B*, 2023

Variants as predictor: improvements of forecasts during transitions

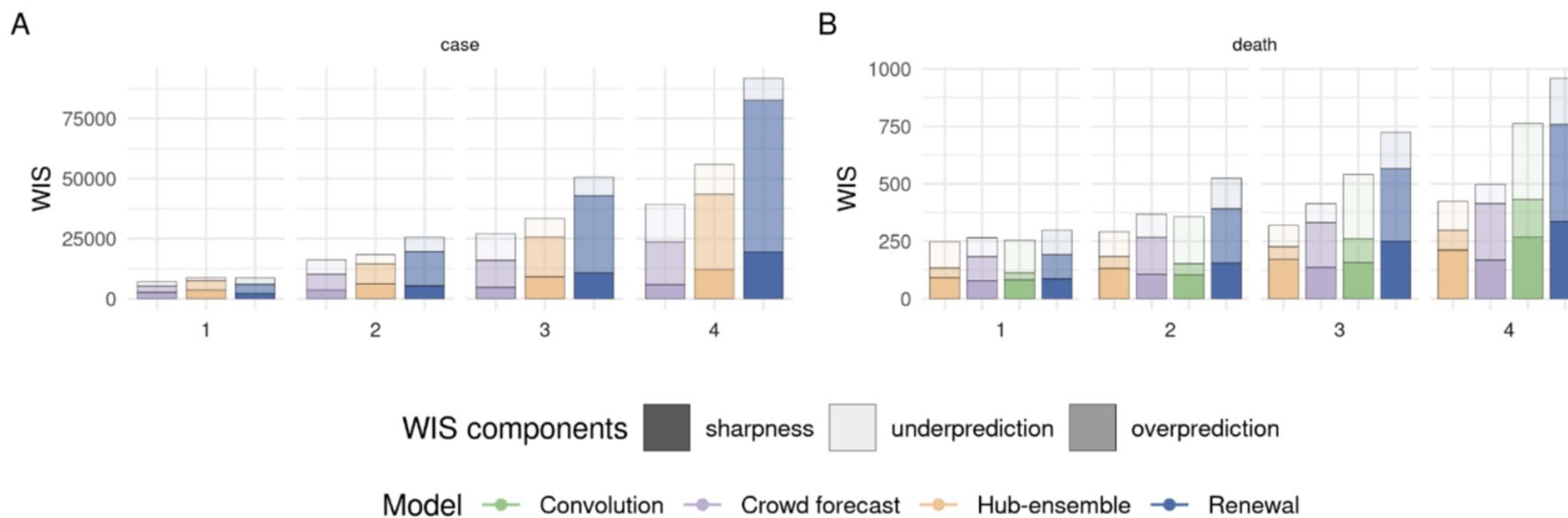


<https://github.com/epiforecasts/forecast.vocs>
https://github.com/jbracher/branching_process_delta

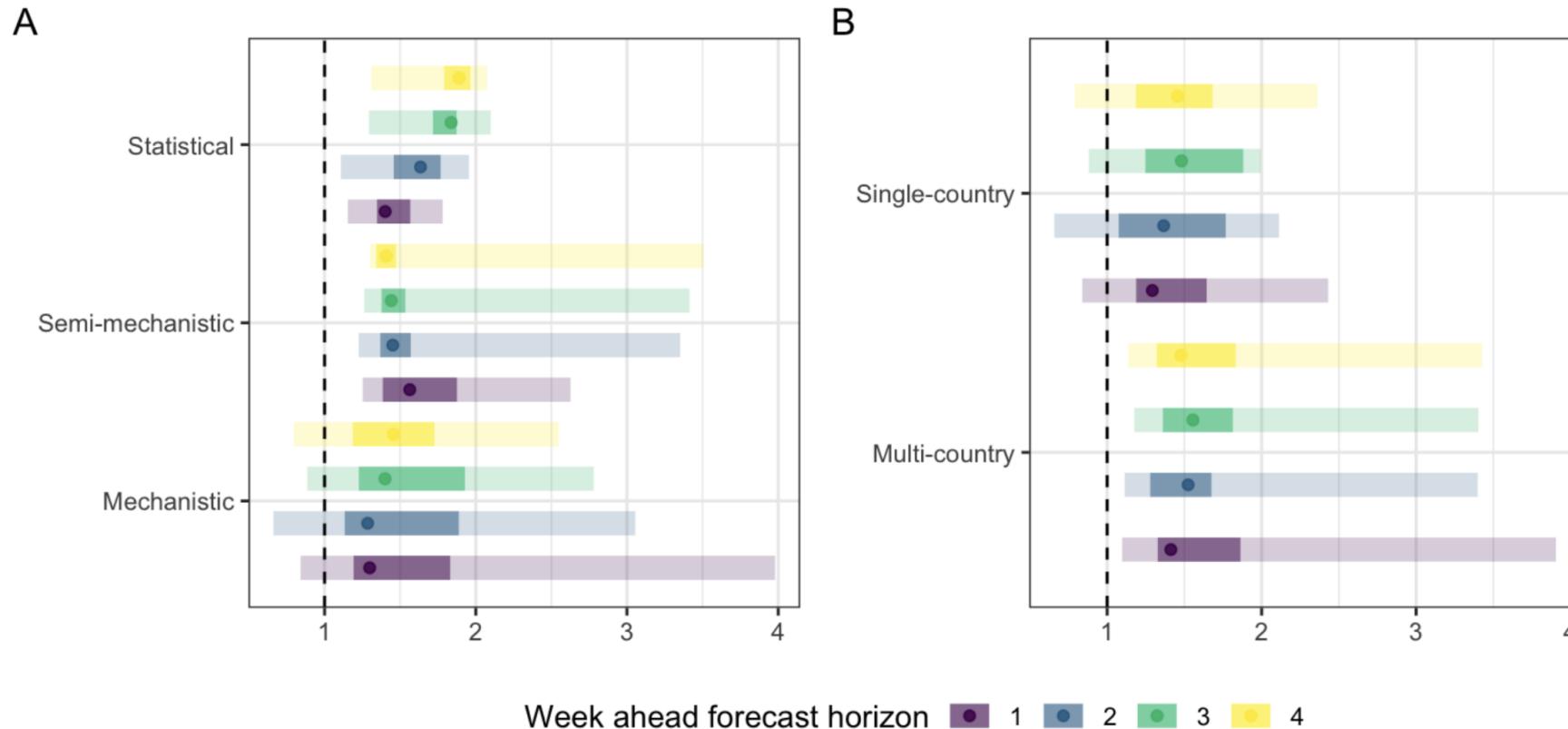
Bad models? Human vs. machine.



Humans better than models at predicting **cases**, but
not **deaths**



Amongst models, ones that focus on a **single country** tended to do better



Inherent limits?

ARTICLE

<https://doi.org/10.1038/s41467-019-08616-0>

OPEN

On the predictability of infectious disease outbreaks

Samuel V. Scarpino^{1,2,3,4,5,6} & Giovanni Petri^{6,7}

Information Bottlenecks in Forecasting COVID-19

David Gamarnik, *† Muzhi Ma, ‡

Reliable short term and long term forecasting of the number of COVID-19 incidences is a task of clear importance. Numerous attempts for such forecasting have been attempted historically since the onset of the pandemic. While many

Scarpino & Petri, *Nat Comm*, 2019
Gamarnik & Ma, *medRxiv*, 2024

What can we conclude for the next
pandemic?

Summary

- Covid-19 forecasts have been relatively poor further than one or two generations ahead
- Ensembles perform best, but can be difficult to interpret

Open questions:

- Can predictive performance be improved?
- Are we measuring predictive performance in the right way?

Alternative ways of measuring predictive performance change the ranking of models.

Evaluating infectious disease forecasts
with allocation scoring rules

Aaron Gerdin*, Nicholas G. Reich, Benjamin Rogers, and Evan L. Ray

RESEARCH ARTICLE

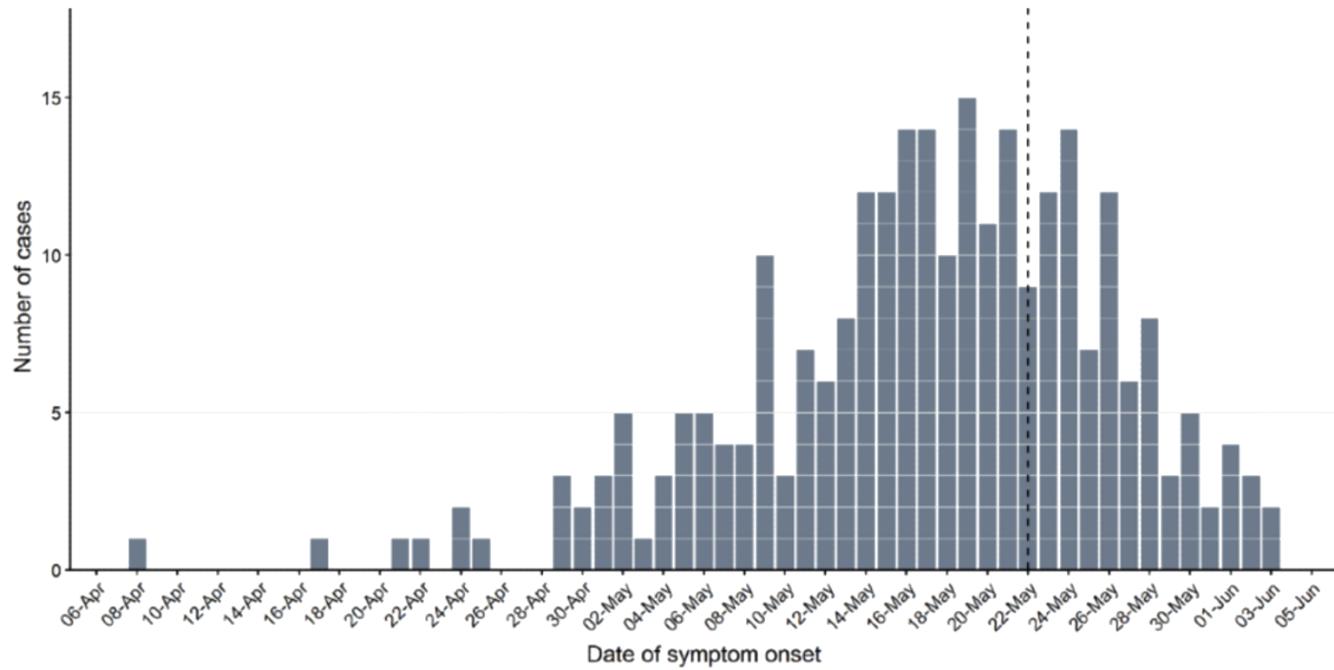
Scoring epidemiological forecasts on
transformed scales

Nikos I. Bosse^{1,2,3*}, Sam Abbott^{1,2}, Anne Cori⁴, Edwin van Leeuwen^{1,3,5},
Johannes Bracher^{6,7}, Sebastian Funk^{1,2,3}

Gerdin et al., *arXiv*, 2024// Bosse et al., *PLOS Comp Biol*, 2023

Forecasting and nowcasting remain relevant

Figure 1. Incidence of confirmed monkeypox cases by day of symptom onset in England as of 8 June 2022



New initiatives

data.org

INITIATIVE

Epiverse: The Global Epidemic Response of the Future

We are launching a global consortium to design and build open software tools enabling privacy-preserving distributed analysis of data to power pandemic response.

WHO Hub for Pandemic and Epidemic Intelligence



A new understanding of pandemic and epidemic risks

The COVID-19 pandemic has given us a shared experience that shows how interconnected our lives are and how public health depends on each one of us. The World Health Organization (WHO) envisions a world where 1 billion more people are better protected and safe from health emergencies, no matter of where they live. It strives to increase equity in access to health care. To better address pandemic and epidemic risks, the WHO Hub for Pandemic and Epidemic Intelligence will strengthen

FAQs >

EPI-BRAIN >

Strategy paper >

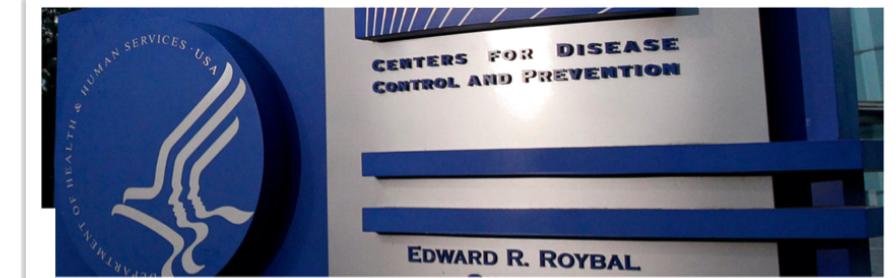
The ROCKEFELLER FOUNDATION

Covid-19 Response Our Commitments Collaborations What's New

Pandemic Prevention Institute



See the signals. Speed the response. Stop outbreaks.
That's the goal of the Pandemic Prevention Institute.
Working towards a #PandemicFreeFuture. Watch this



CDC launches new forecasting center for future pandemics

Health Apr 19, 2022 5:26 PM EDT

A new U.S. government center aims to become the National Weather Service for infectious diseases — an early warning system to help guide the response to COVID-19 and future pandemics.

European respiratory hub

The screenshot shows the RespiCast website homepage. At the top, there is a dark blue header bar with the RespiCast logo on the left, which includes a stylized virus icon and the text "RESPICAST" and "EUROPEAN RESPIRATORY DISEASES FORECASTING HUB". To the right of the logo are five navigation links: "Forecasts", "Evaluations", "Background", "Community", and "Get in touch". On the far right of the header is a GitHub icon. The main content area has a dark blue background with a faint map of Europe and a white COVID-19 virus icon. To the right of the icon, the text "RESPICAST" is written in large, bold, white capital letters, followed by "EUROPEAN RESPIRATORY DISEASES" and "FORECASTING HUB" in smaller white capital letters. Below this, a paragraph of white text describes the hub's purpose: "RespiCast, the European Respiratory Diseases Forecasting Hub, combines multiple forecasting hubs for several respiratory disease indicators, including influenza-like-illness (ILI), acute respiratory infection (ARI), and indicators related to COVID-19." At the bottom of the main content area is a blue button with the white text "View forecasts".

<https://respicast.ecdc.europa.eu/>

Evaluating conditional forecasts (“scenarios”)

Article

<https://doi.org/10.1038/s41467-023-42680-x>

Evaluation of the US COVID-19 Scenario Modeling Hub for informing pandemic response under uncertainty

Received: 7 July 2023

A list of authors and their affiliations appears at the end of the paper

Accepted: 17 October 2023

Howerton et al., *Nat Comm*, 2023

We need **collaborative** efforts, using
standardised datasets to compare
methods and generating sustainable **tools**

“We were losing ourselves in details [...] all we needed to know is, are the number of cases rising, falling or levelling off?”

– Hans Rosling, Liberia, 2014

Slides at

