

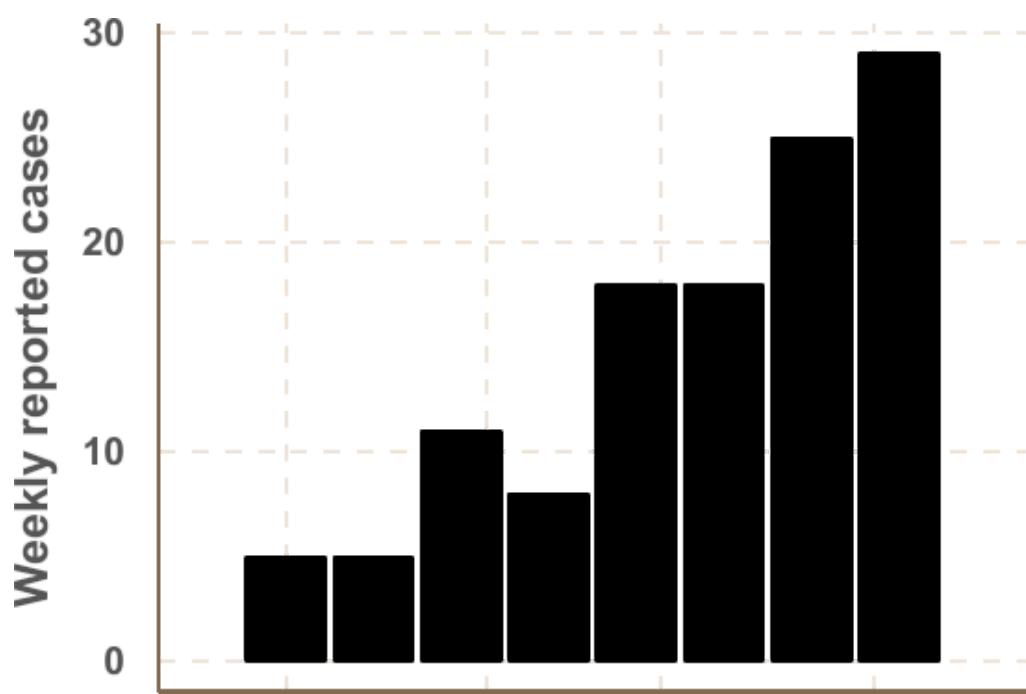
Real-time modelling and forecasting of infectious disease dynamics

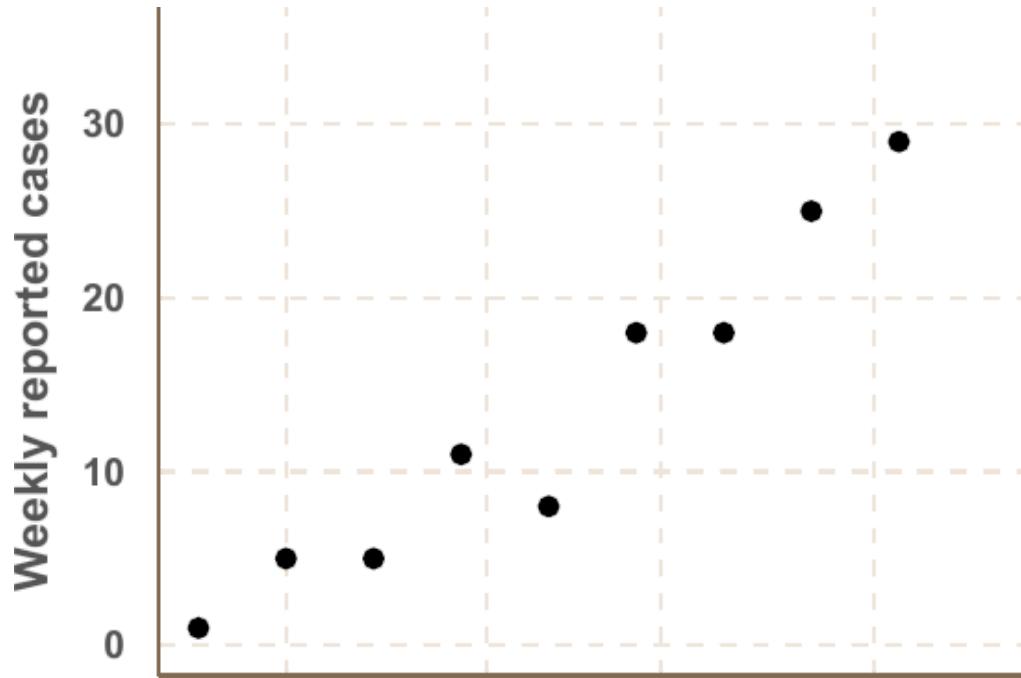
Sebastian Funk

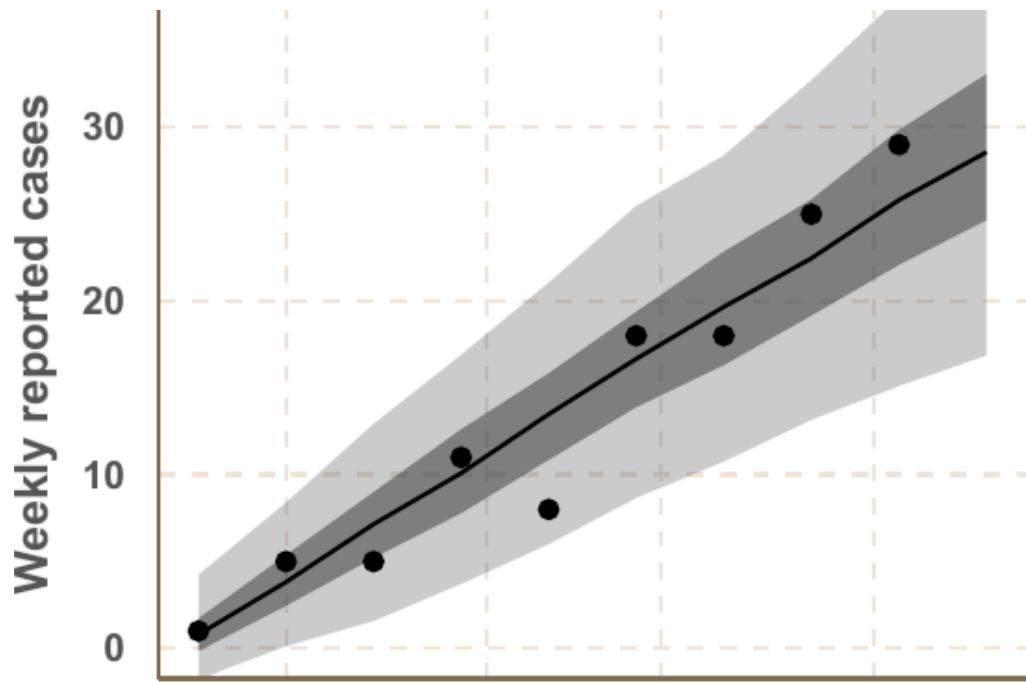
6 March, 2018

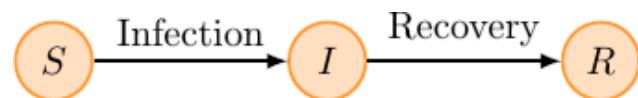
Centre for Complex Systems Studies, Utrecht

Summer 2014





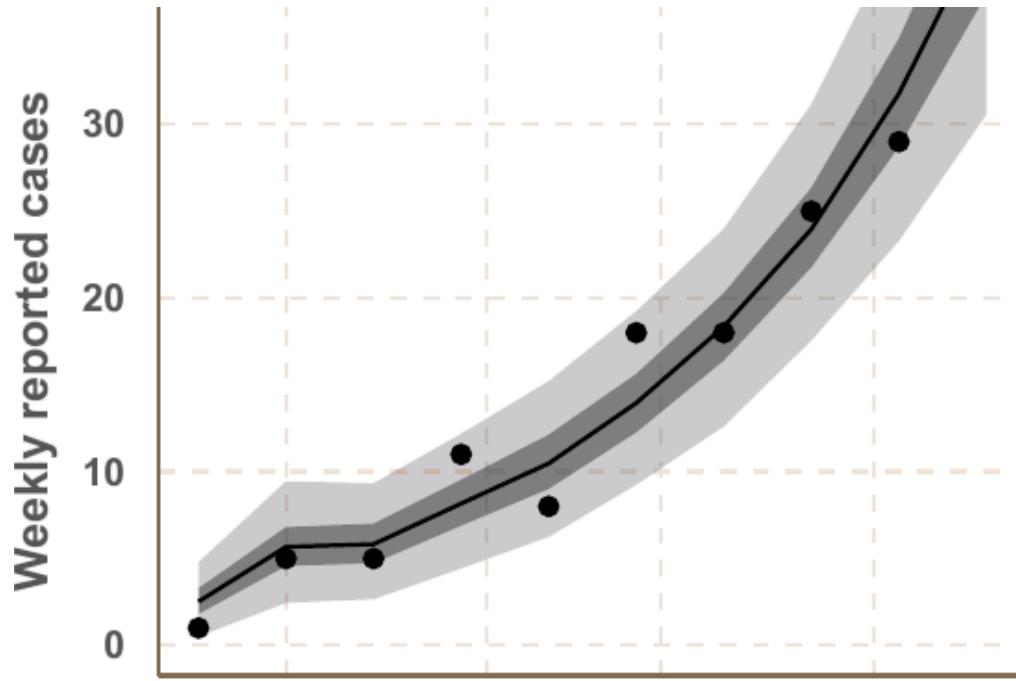


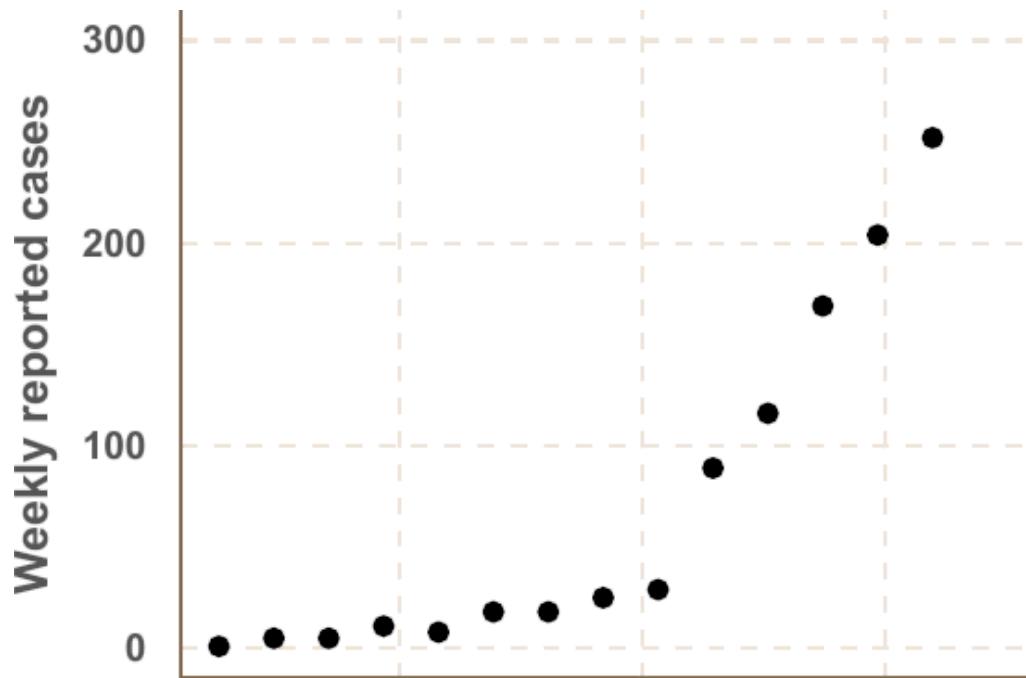


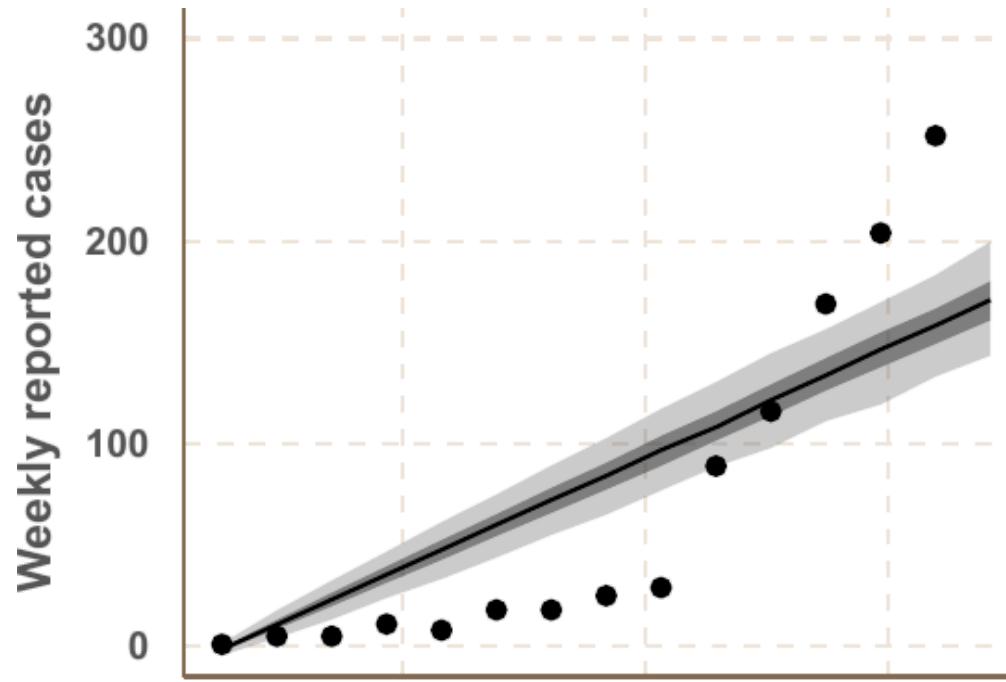
$$\dot{S} = -\beta \frac{S}{N} I$$

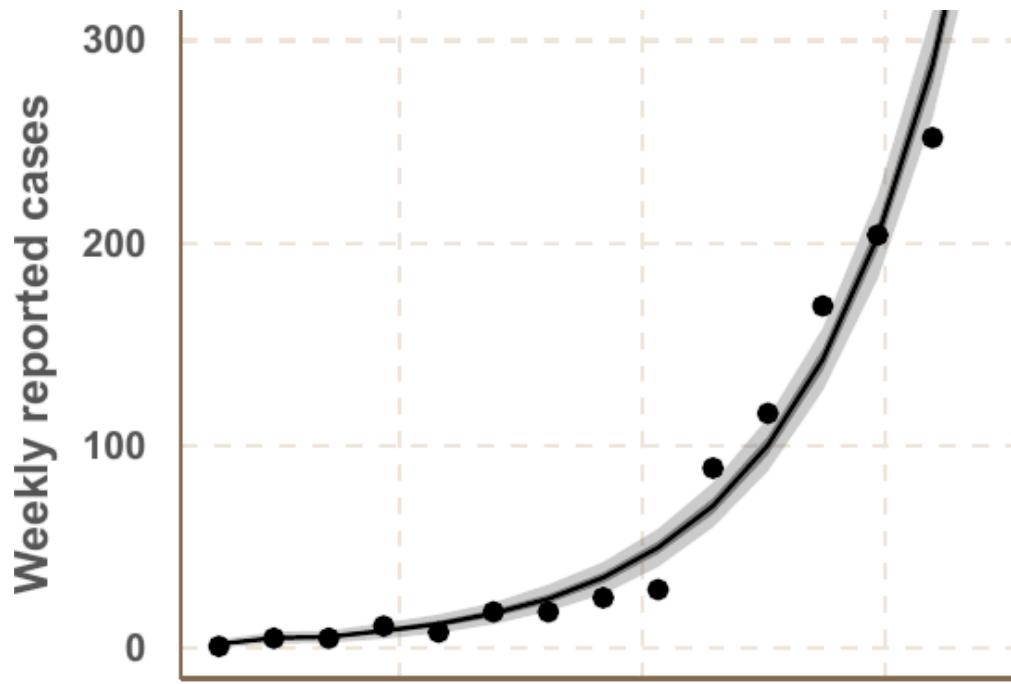
$$\dot{I} = +\beta \frac{S}{N} I - \gamma I$$

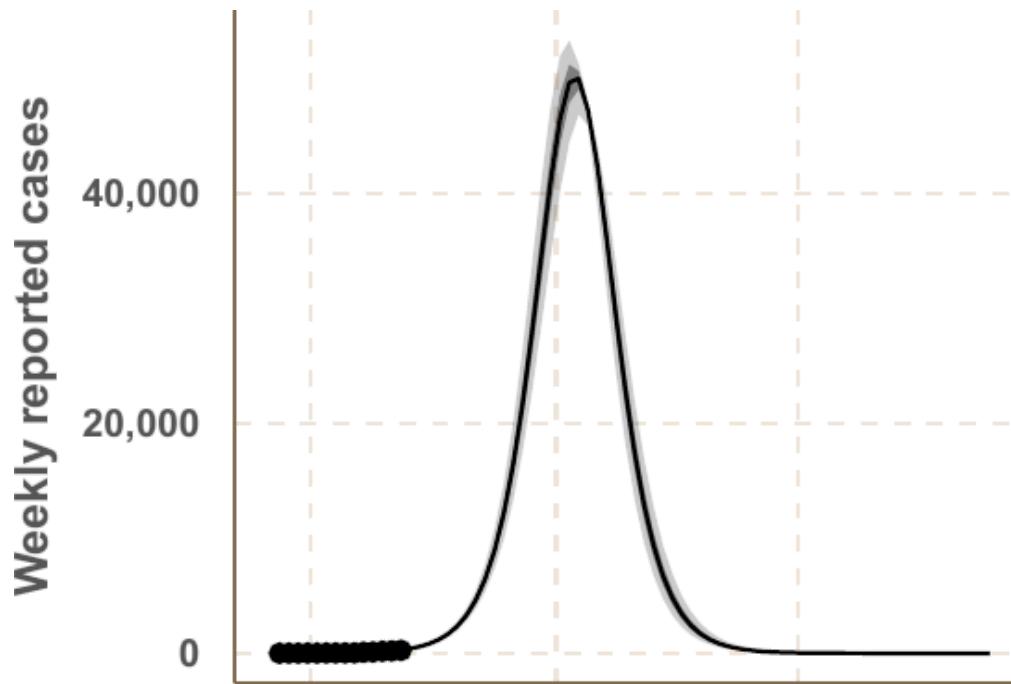
$$\dot{R} = +\gamma I$$

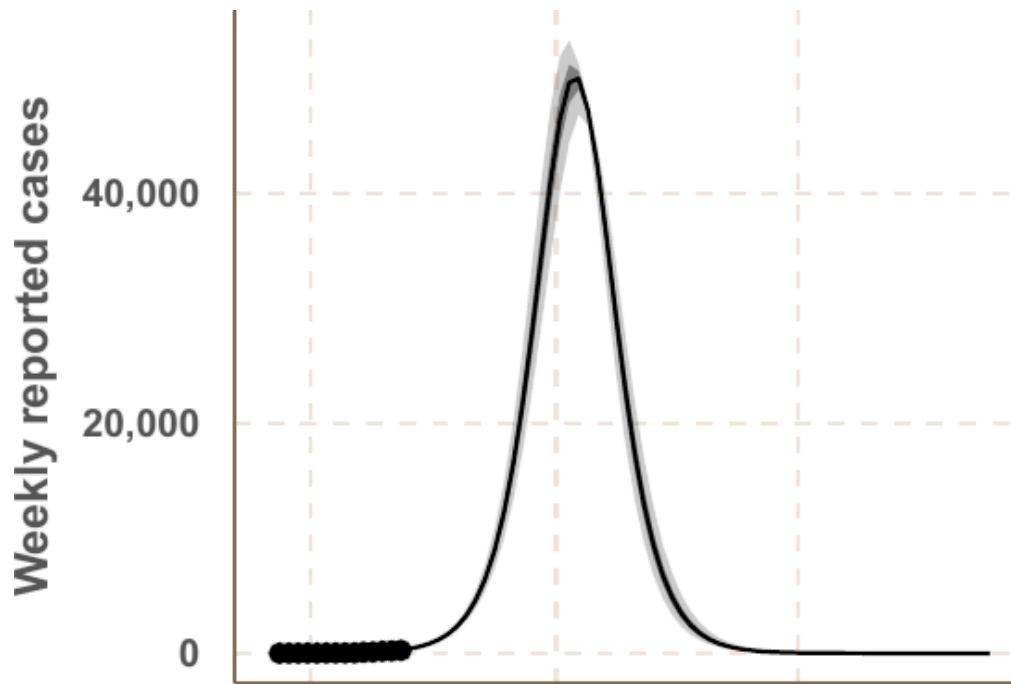












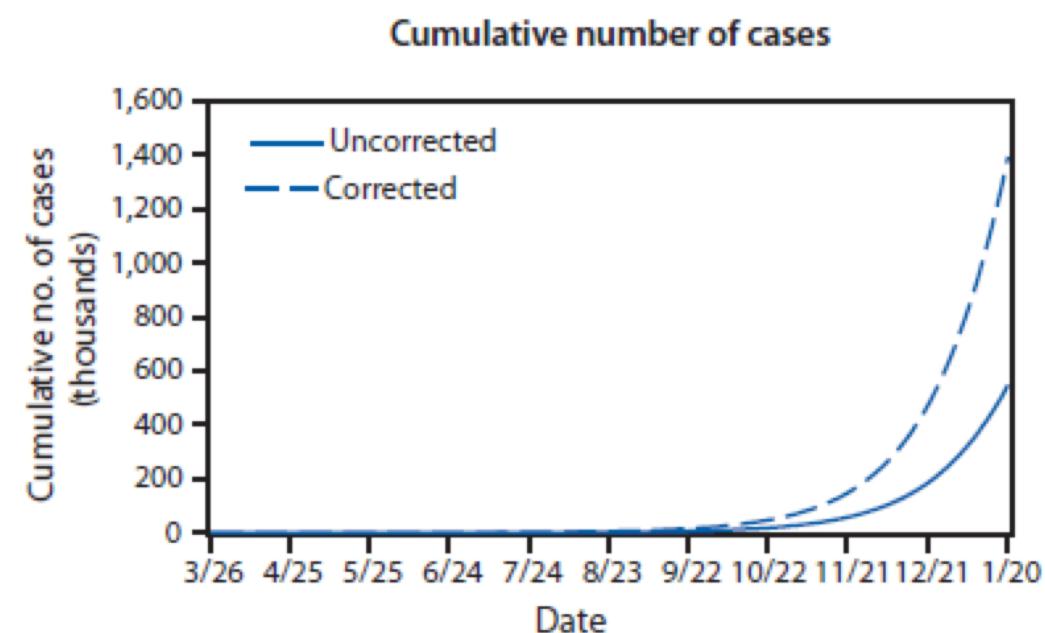


Figure 3. Unbiased and Corrected cumulative cases over time since 1st case.

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[middle east](#) [cities](#) [development](#) [europe](#) [US](#) [americas](#) [≡ all](#)

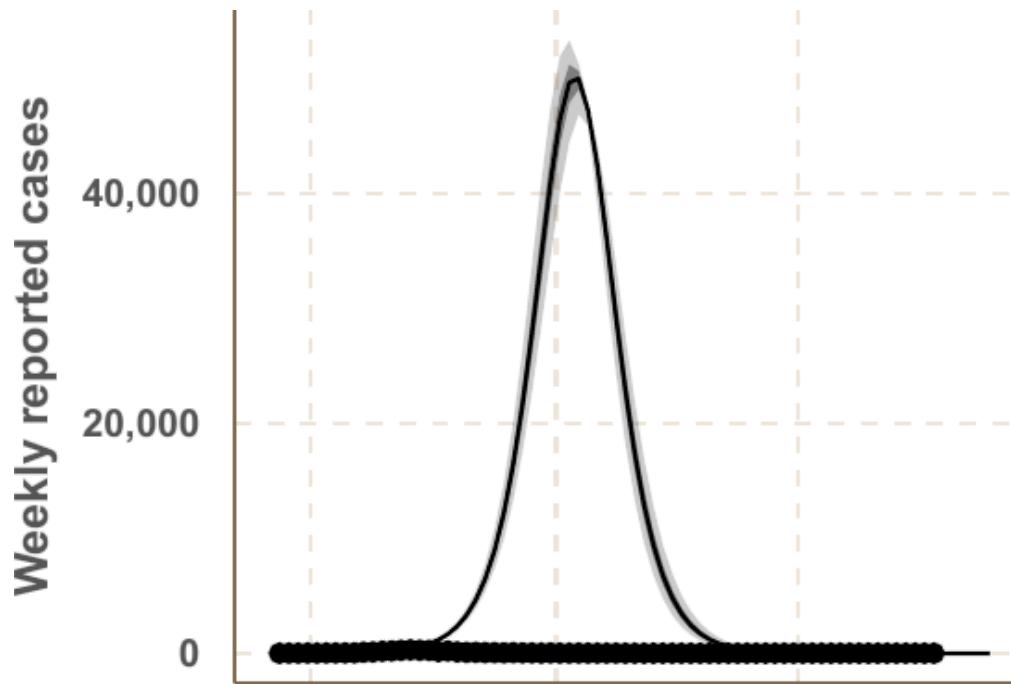
Ebola

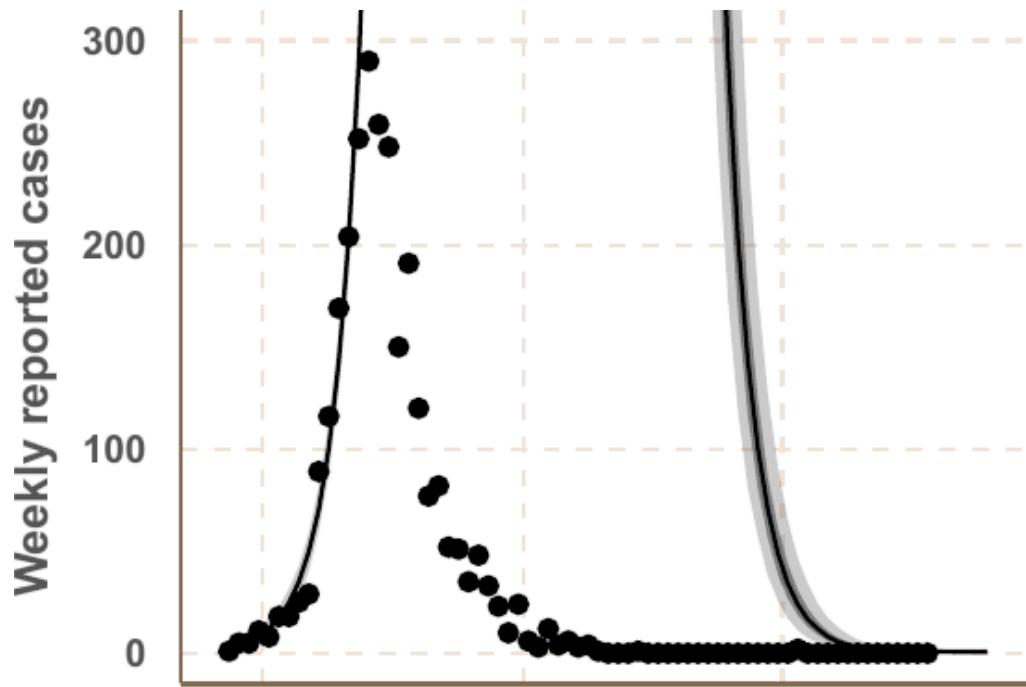
Up to 1.4m people could be infected with Ebola by January, CDC warns

US doctors warn that without immediate action to quarantine and change burial practices, epidemic will spread

● Experimental drugs to be rushed to Africa

What really happened





nature

International weekly journal of science

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Volume 515

Issue 7525

News

Article

NATURE | NEWS



Models overestimate Ebola cases

Rate of infection in Liberia seems to plateau, raising questions over the

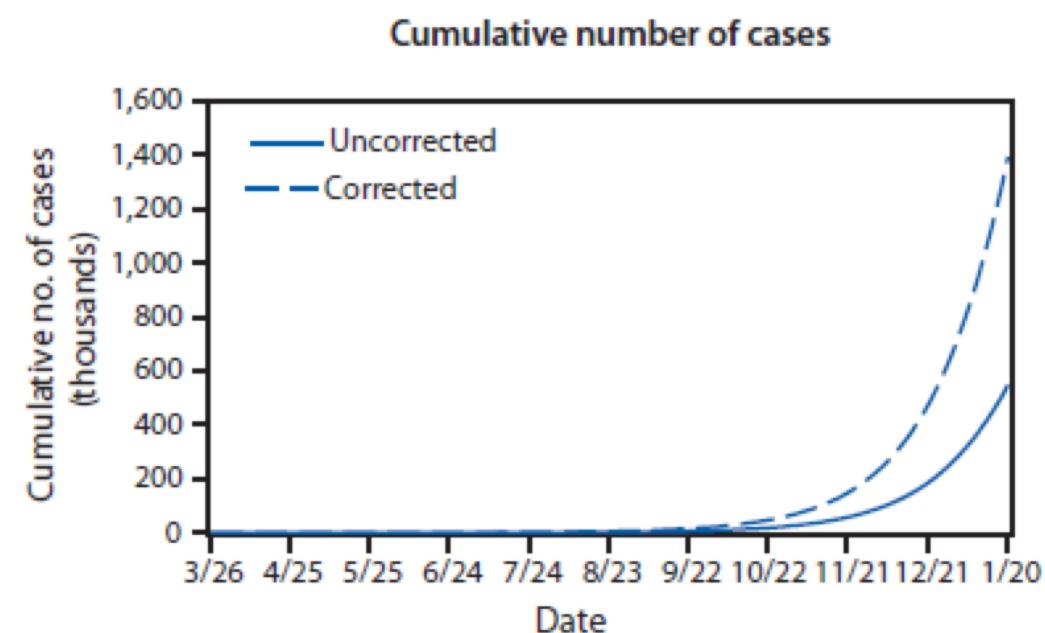
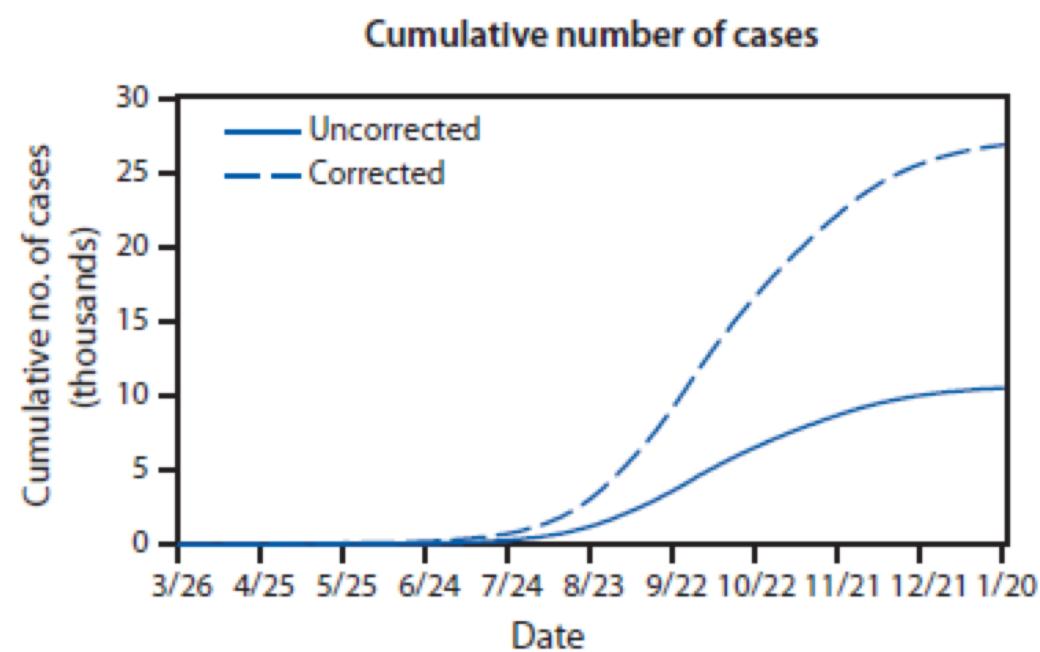


Figure 3. Unbiased and Corrected cumulative cases over time since 1st case.



**TOWARDS EPIDEMIC PREDICTION:
FEDERAL EFFORTS AND OPPORTUNITIES
IN OUTBREAK MODELING**

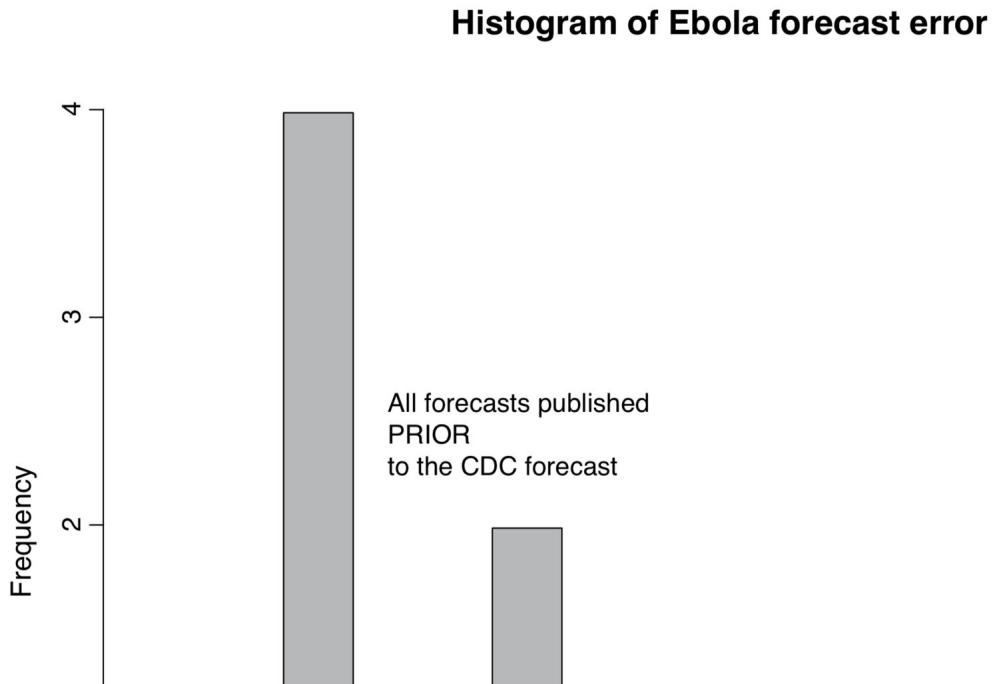
PRODUCT OF THE
Pandemic Prediction and Forecasting
Science and Technology Working Group

"A CDC model [...] was key to increasing the speed and scale of the US and global response.

Frieden, 2015

Key findings:

1. "cases were increasing exponentially, and the response needed was massive and urgent"
2. "the model predicted a severe penalty for delay"
3. "the model identified a tipping point at which the epidemic would [...] decline if enough Ebola patients were isolated effectively and decedents buried safely"
4. "the model predicted that when the tipping point was reached, transmission would decline rapidly"



*Data from Chretien et al. 2015
10.7554/eLife.09186*

Research

Modeling Potential Responses to Smallpox as a Bioterrorist Weapon

Martin I. Meltzer*, Inger K. Damon*, James W. LeDuc*, and J. Donald Millar†

Author affiliations: *Centers for Disease Control and Prevention, Atlanta, Georgia, USA; †Don Millar & Associates, Inc., Atlanta, Georgia, USA

[Main Article](#)

Table 1

Estimates of cumulative total smallpox cases after 365 days without any interventions

Cumulative total no. of smallpox cases, days postrelease^c

No. initially infected ^a	No. infected per infectious person ^b	30 days	90 days	180 days	365 days
10	1.5	31	214	2,190	224 thousand

Uses of real-time forecasts in outbreaks

- Plan the scale of a response or intervention
- Allocate resources (e.g., geographically)
- Plan clinical trials

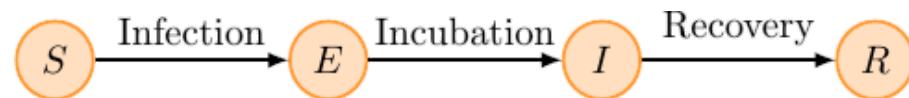
Public health emergencies driven by emerging infectious diseases are at the forefront of global awareness. From HIV in the 1980s to Zika virus's (ZIKV's) recent invasion of the Americas, models that mathematically capture disease processes have played a role in assessing the risk and framing the response to emerging pathogens. The most prominent, and perhaps most fraught, role of such models is to forecast the course of epidemics (1, 2). Yet, expli-

A semi-mechanistic model for real-
time forecasting

The unknown

- Community/hospital/funeral transmission
- Spatial dynamics
- Changes in behaviour
- Changes in reporting
- Interventions
- Seasonality
- etc

The known



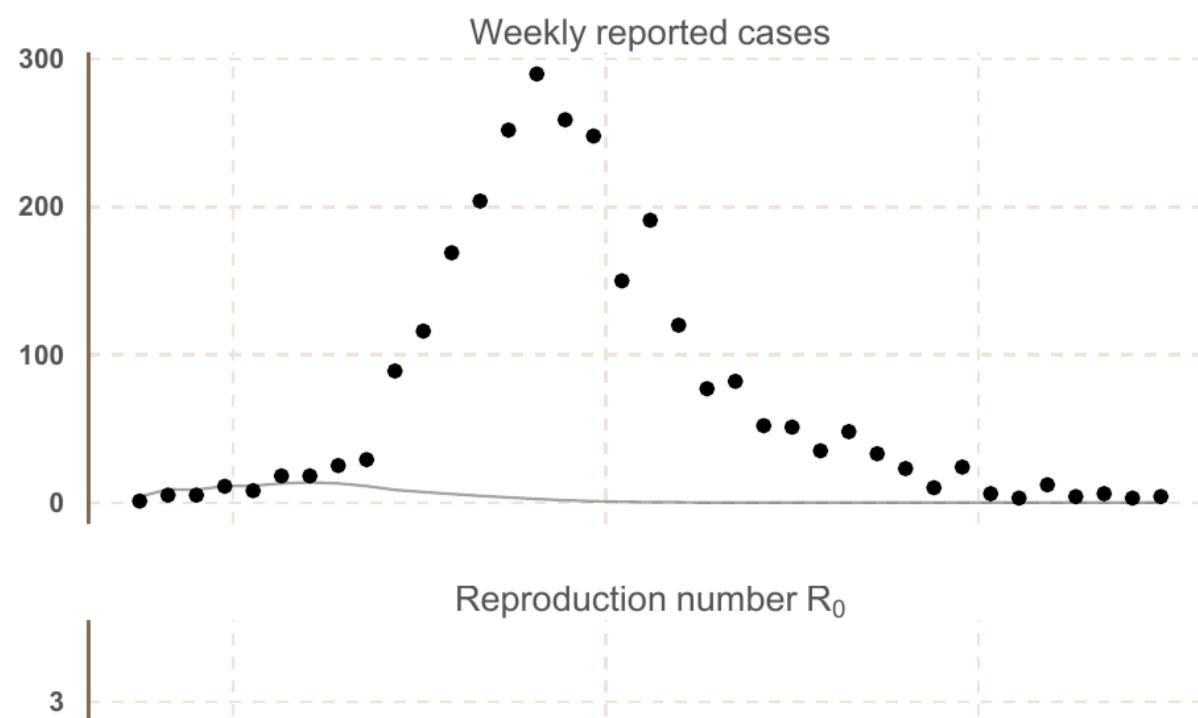
- Average incubation period (~9 days)
- Average infectious period (~11 days)
- Case-fatality rate (~70%)

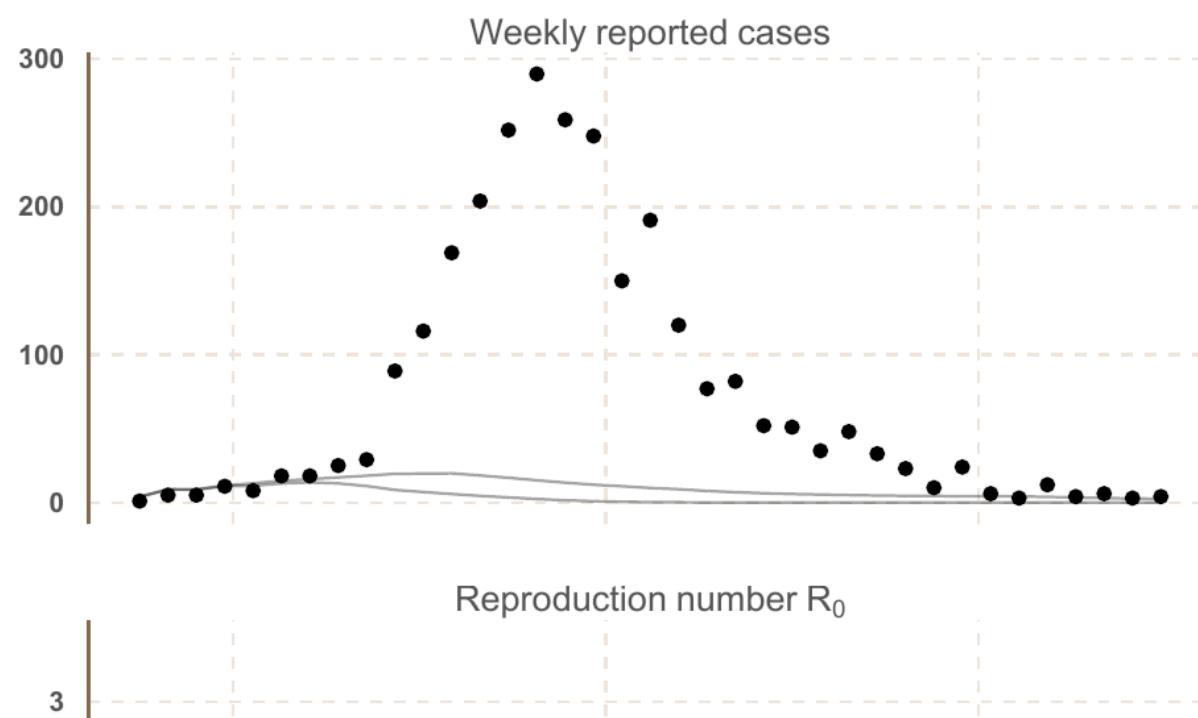
WHO Ebola response team (2014)

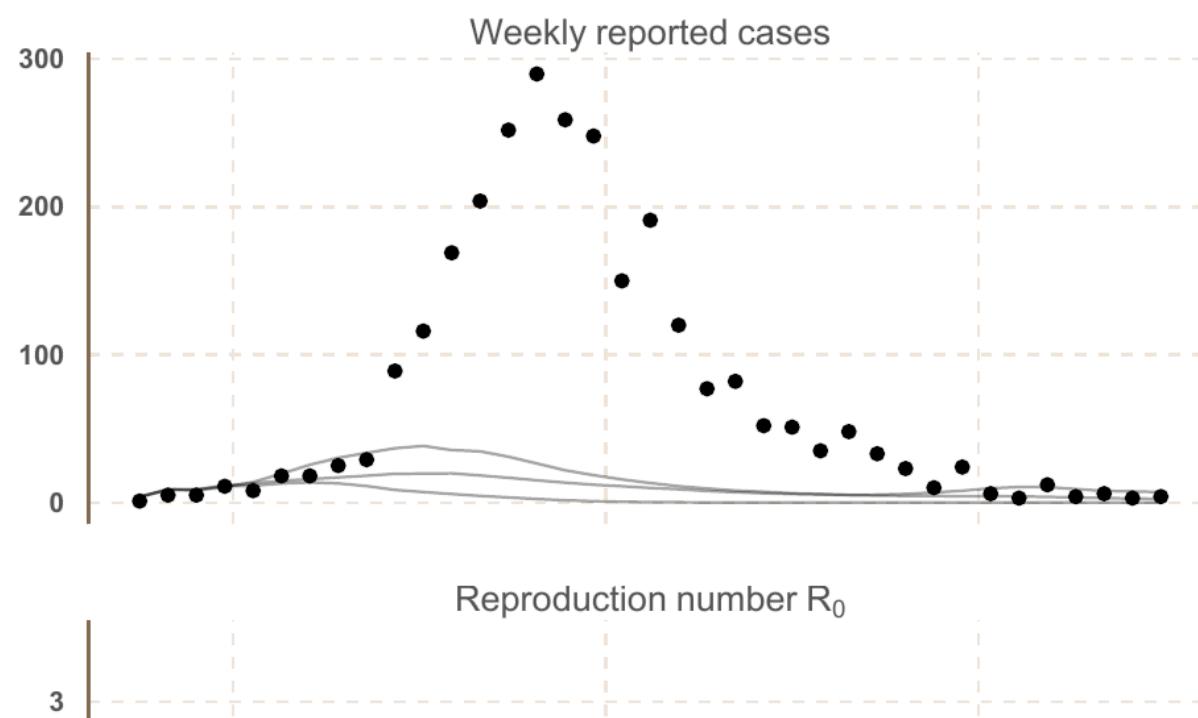
Transmission intensity as a stochastic process

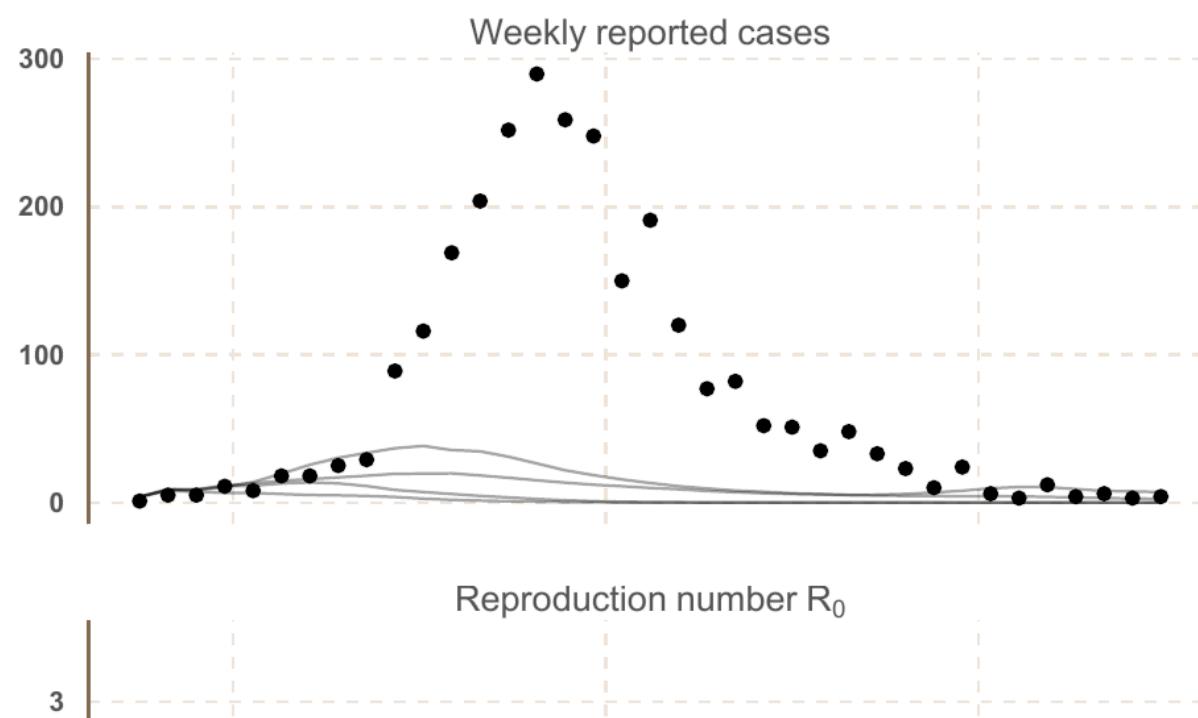
$$d \log(R_0(t)) = \sigma dW_t$$

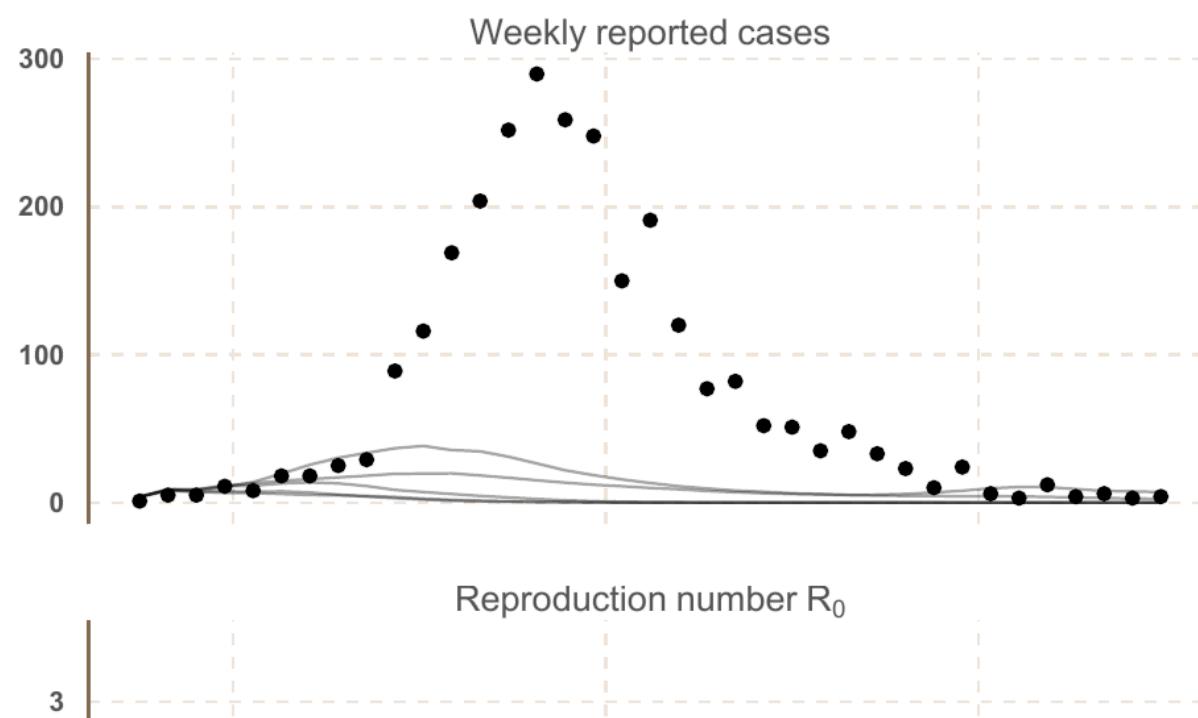
Dureau (2013)



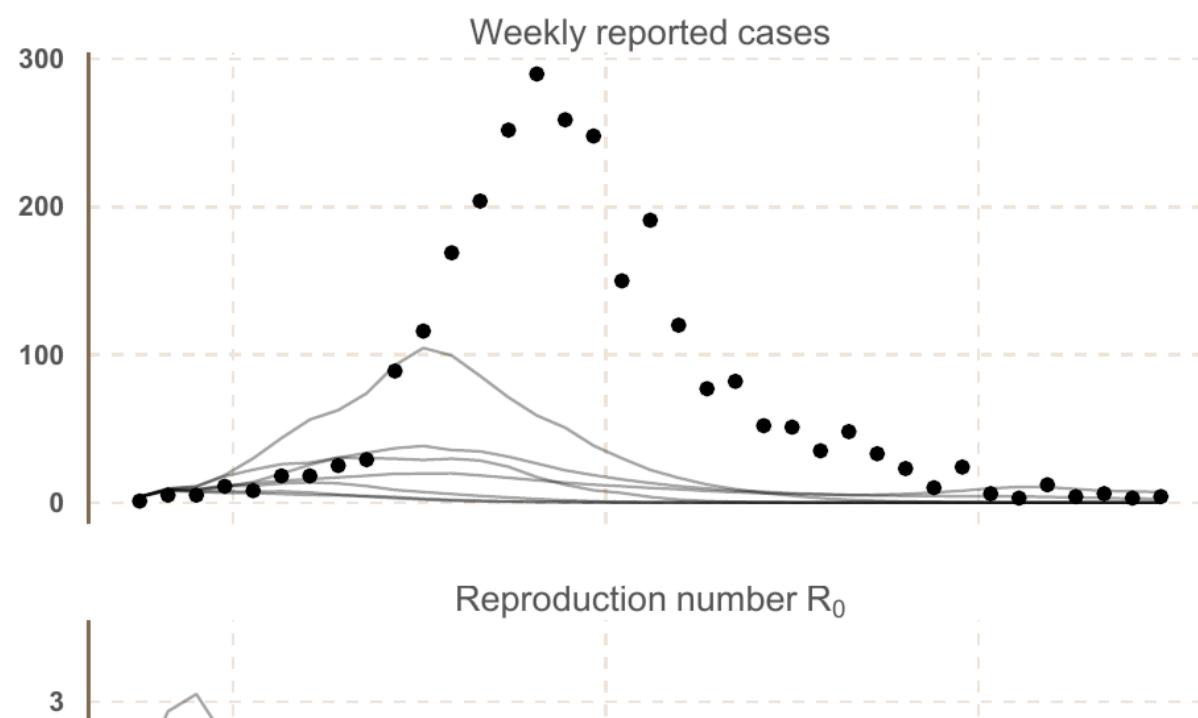






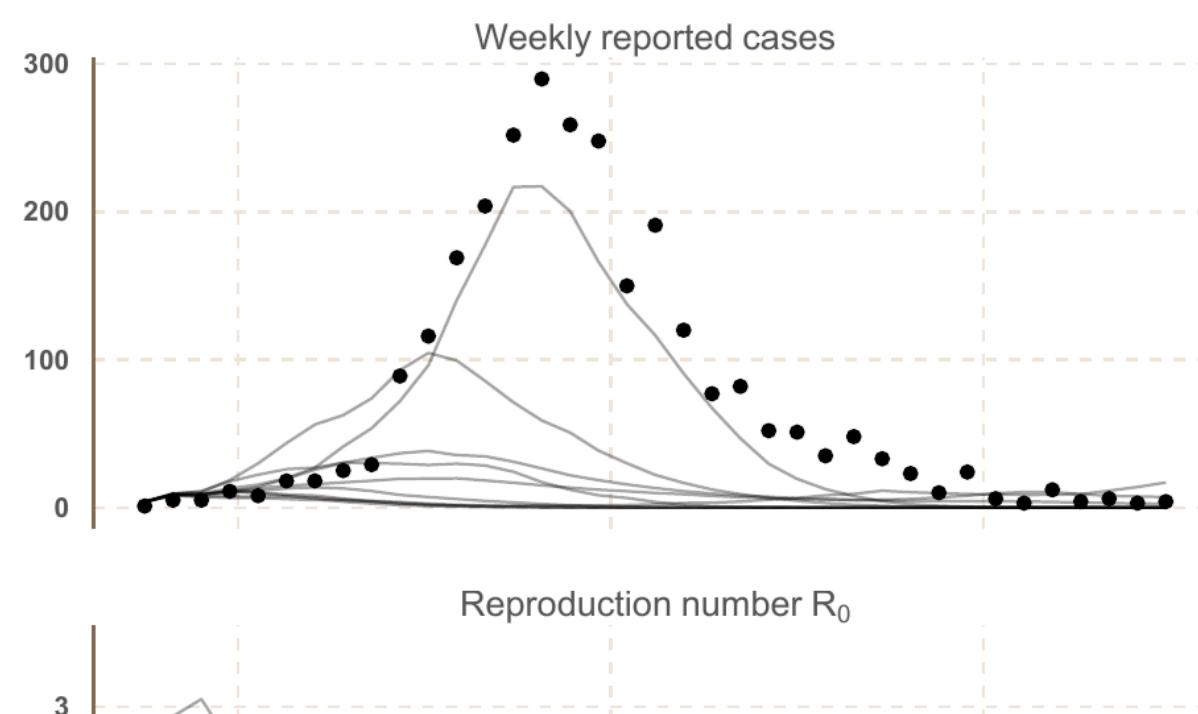




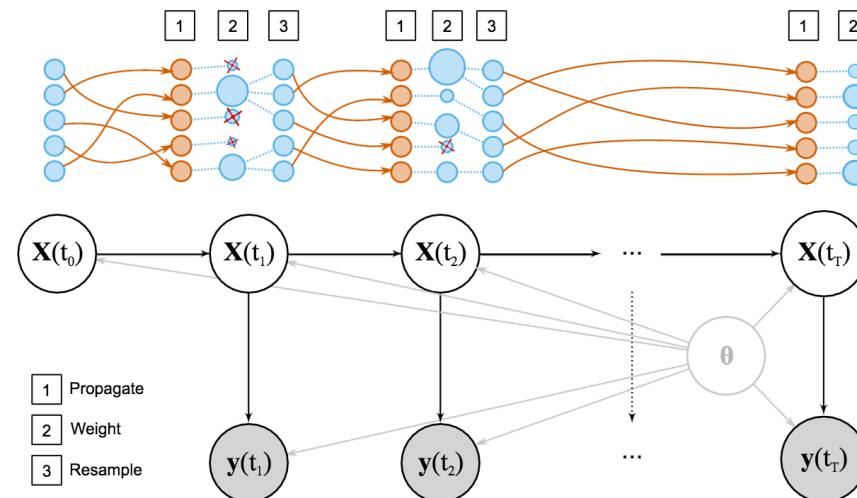








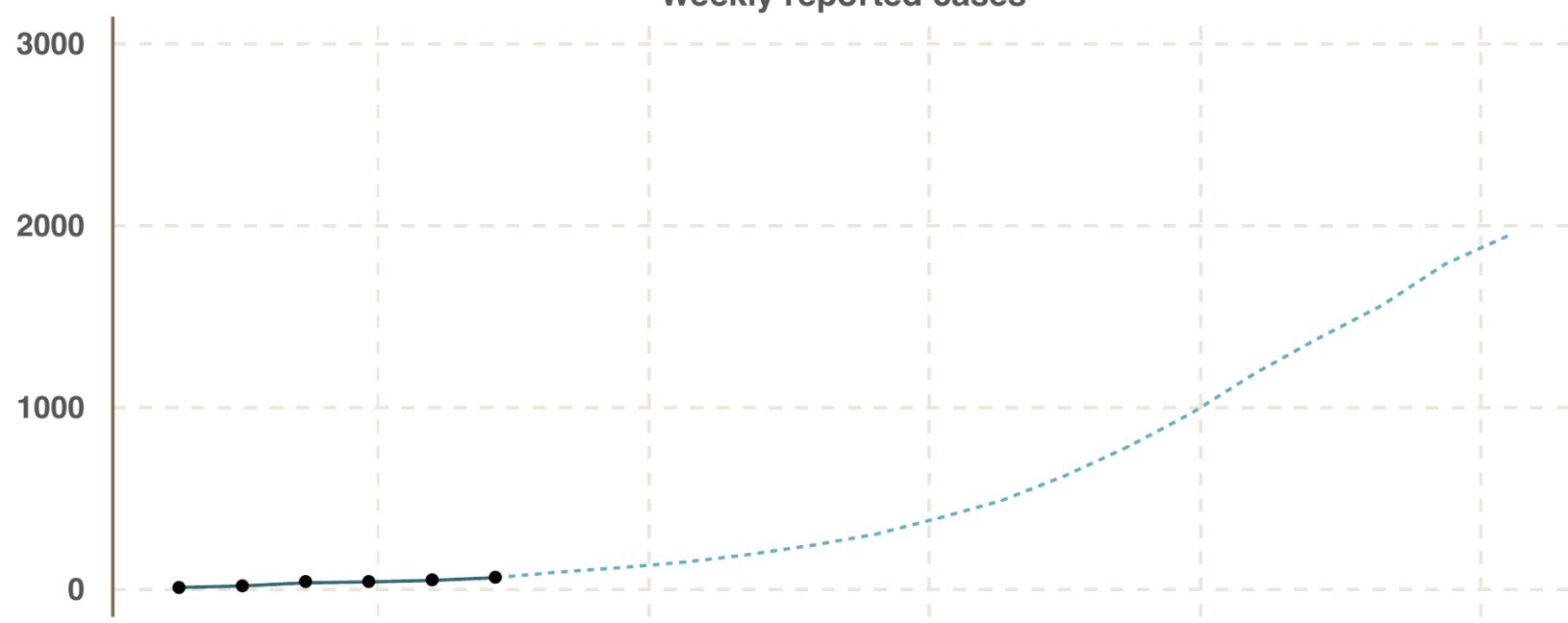
Particle MCMC

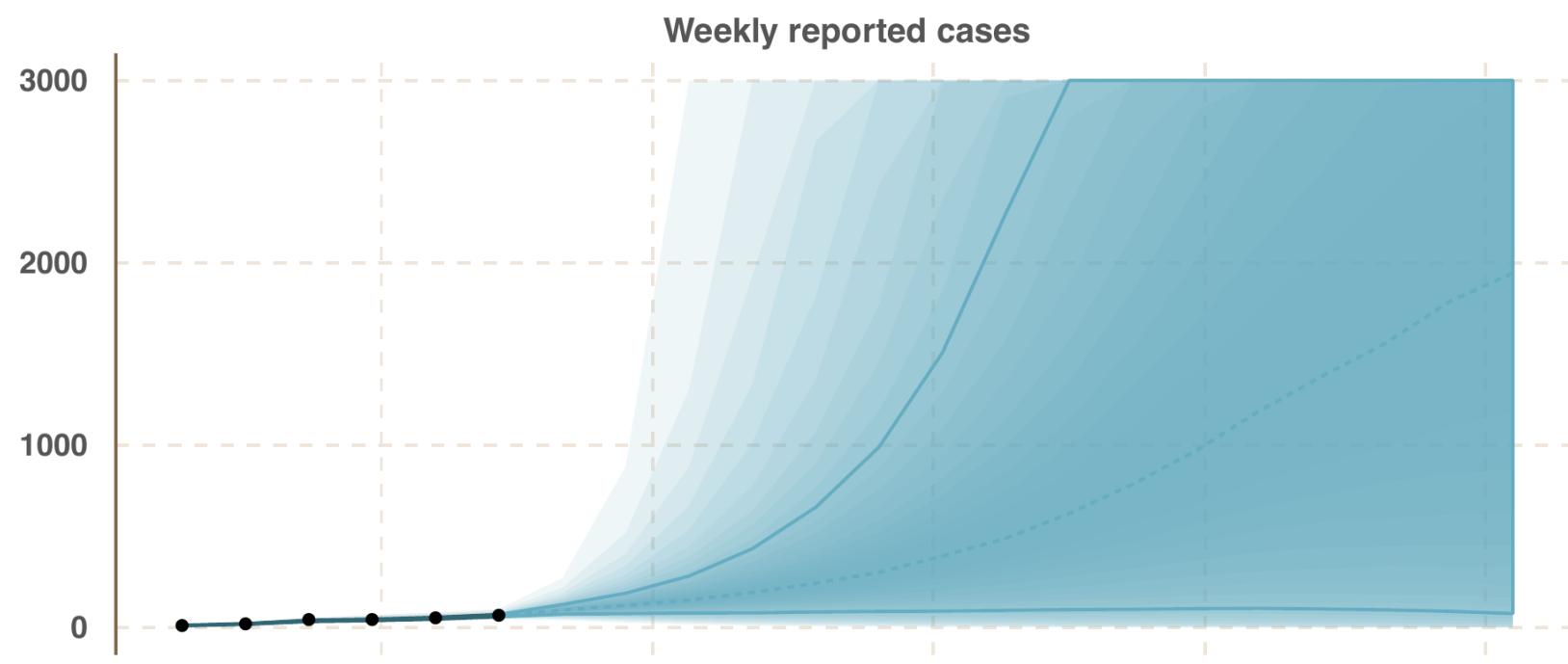


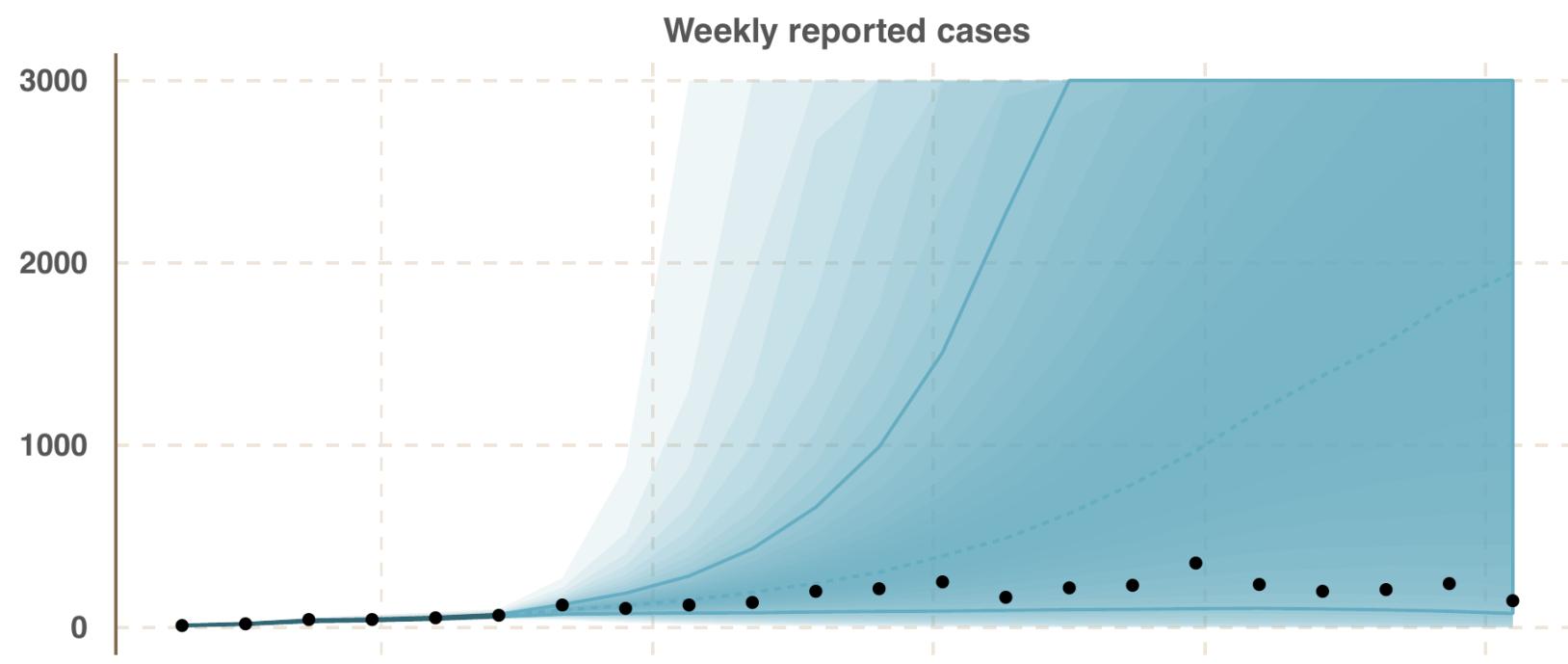
- Method for **filtering** trajectories consistent with data
- Highly parallelisable

Forecasting the Ebola epidemic

Weekly reported cases





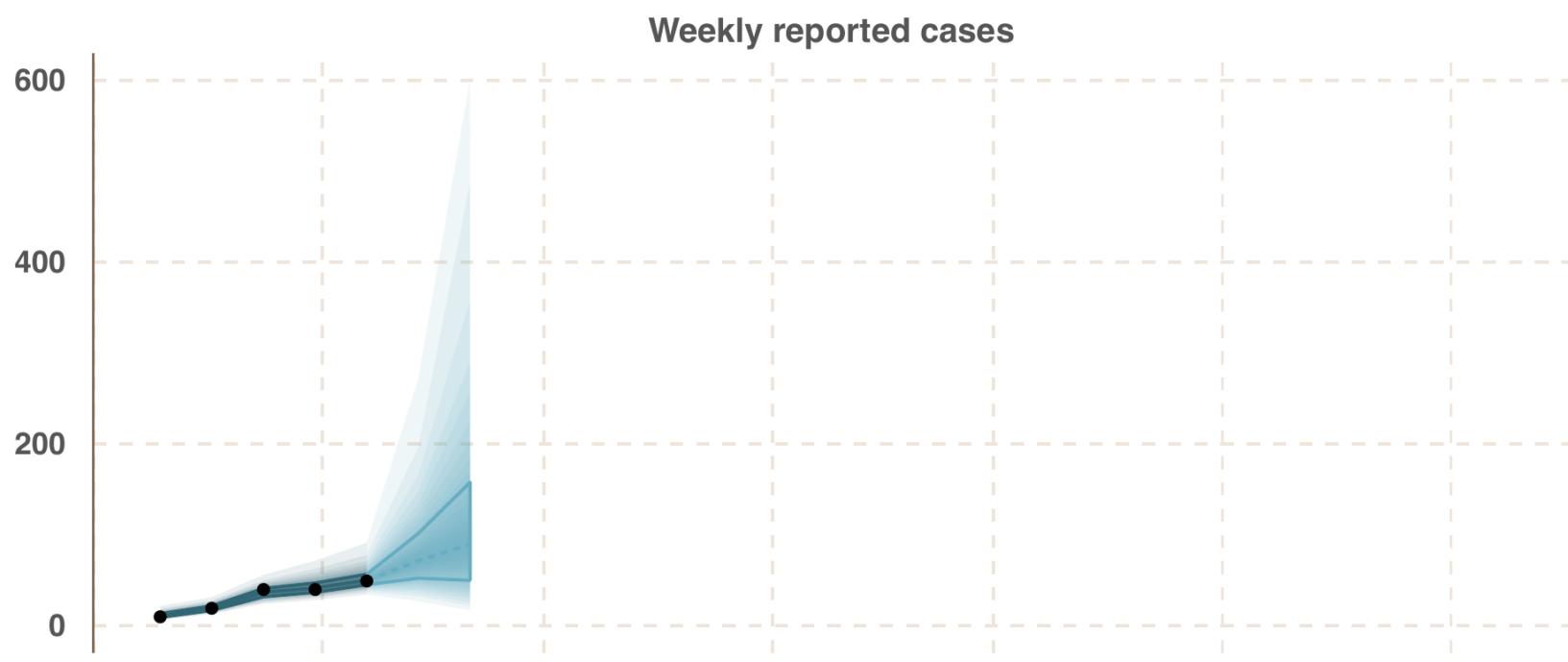


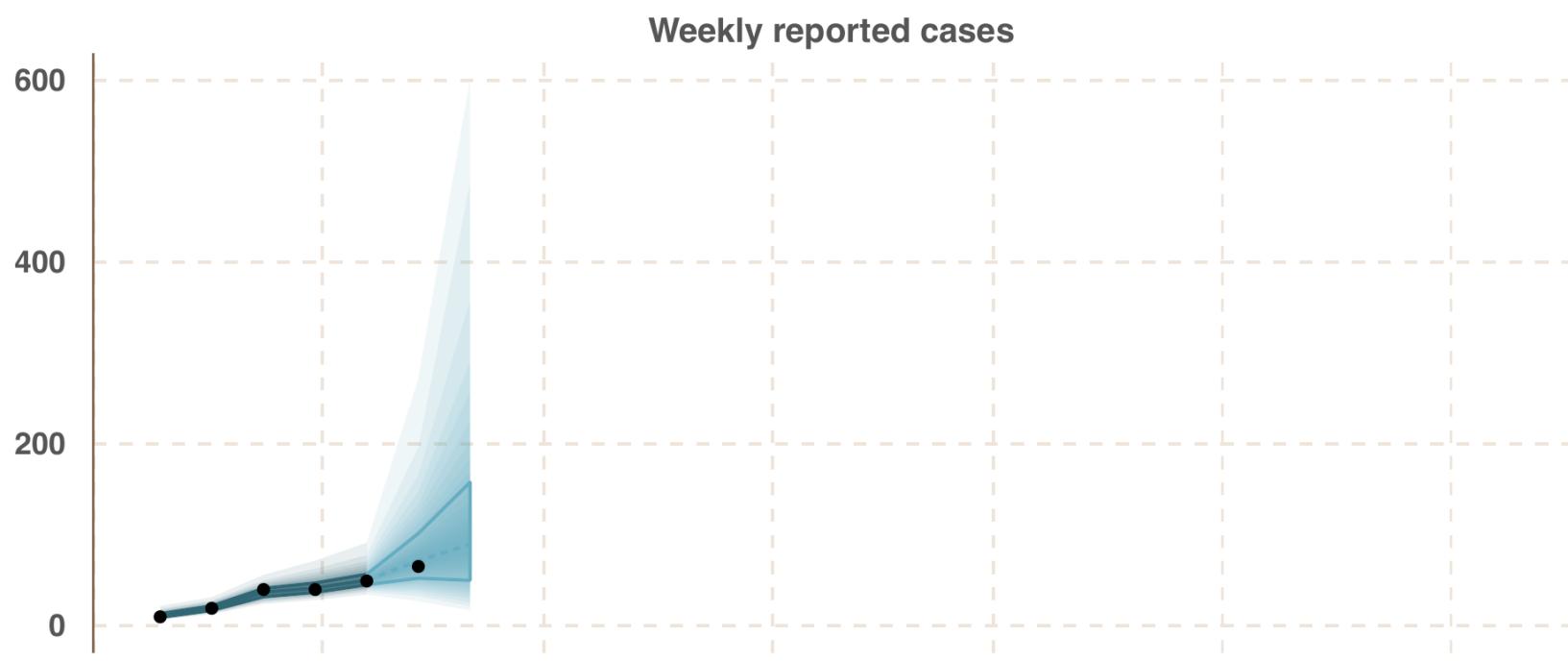


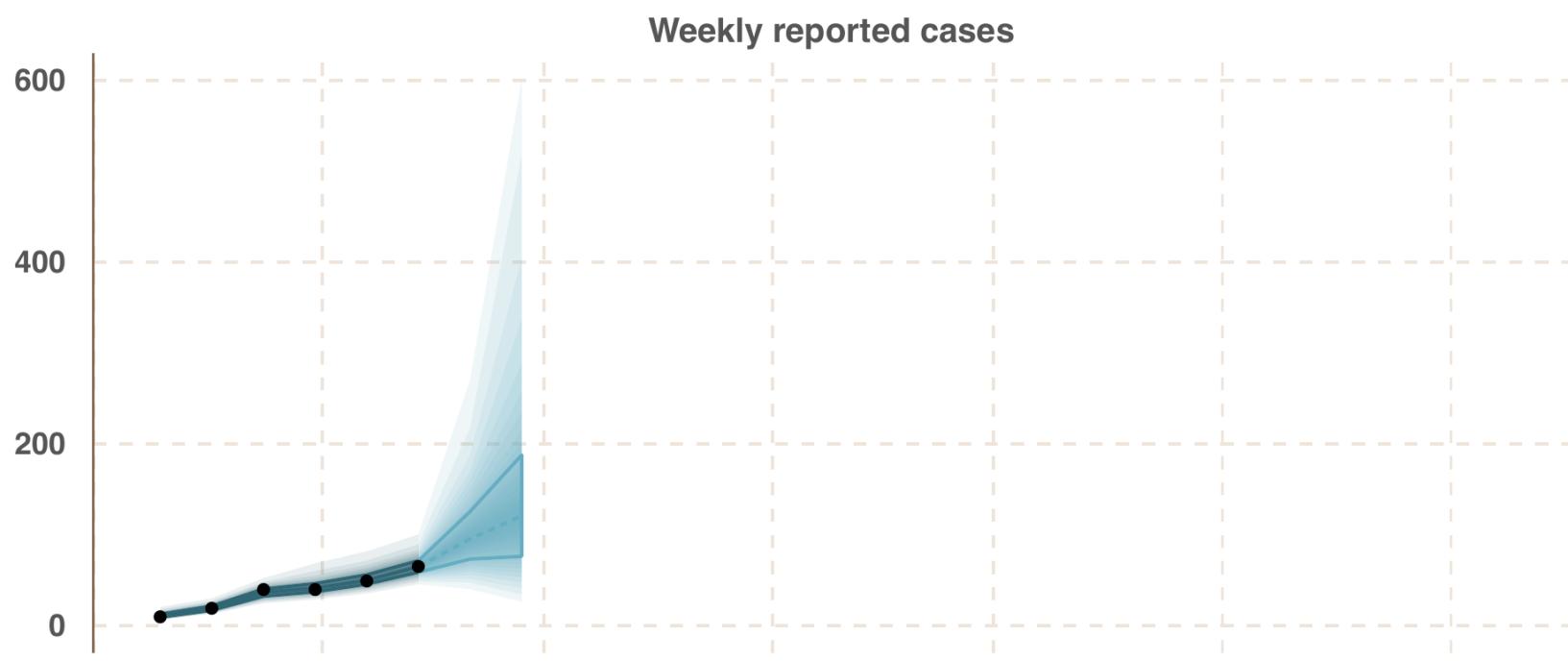


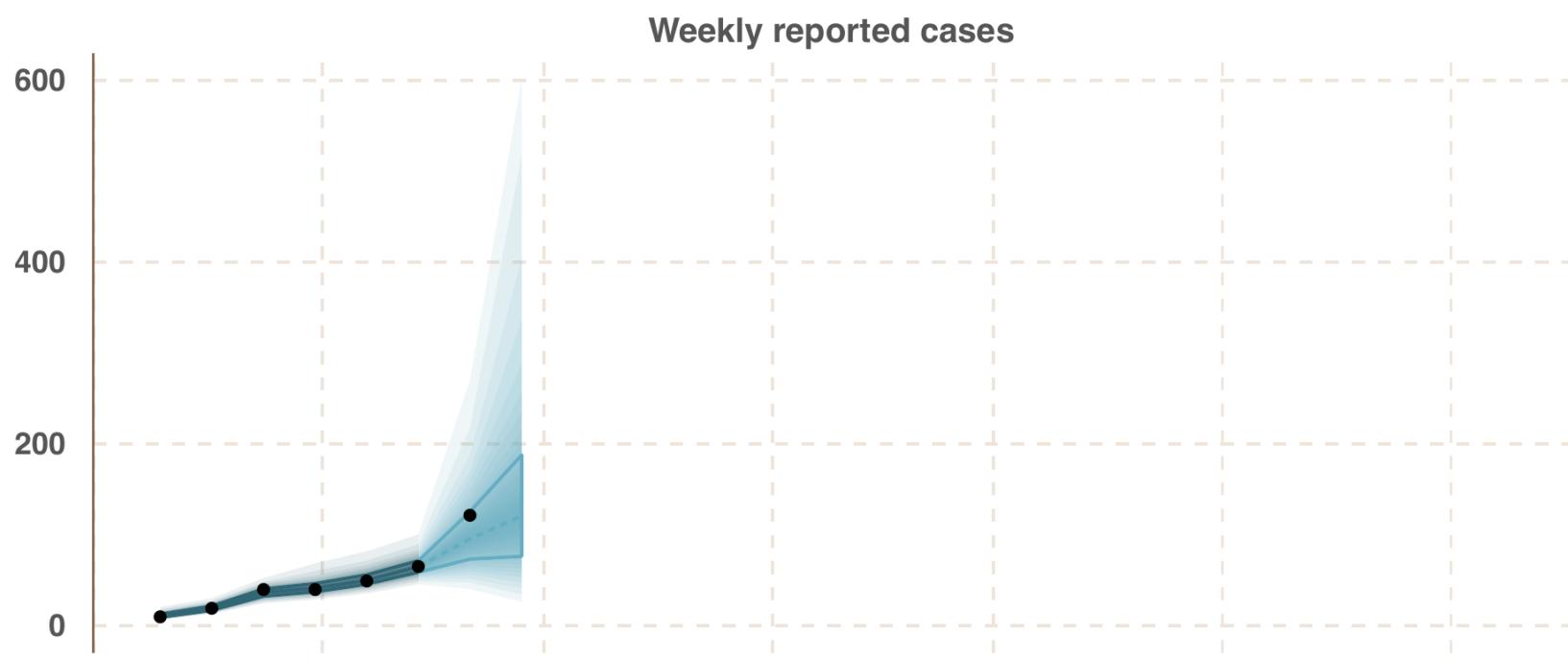


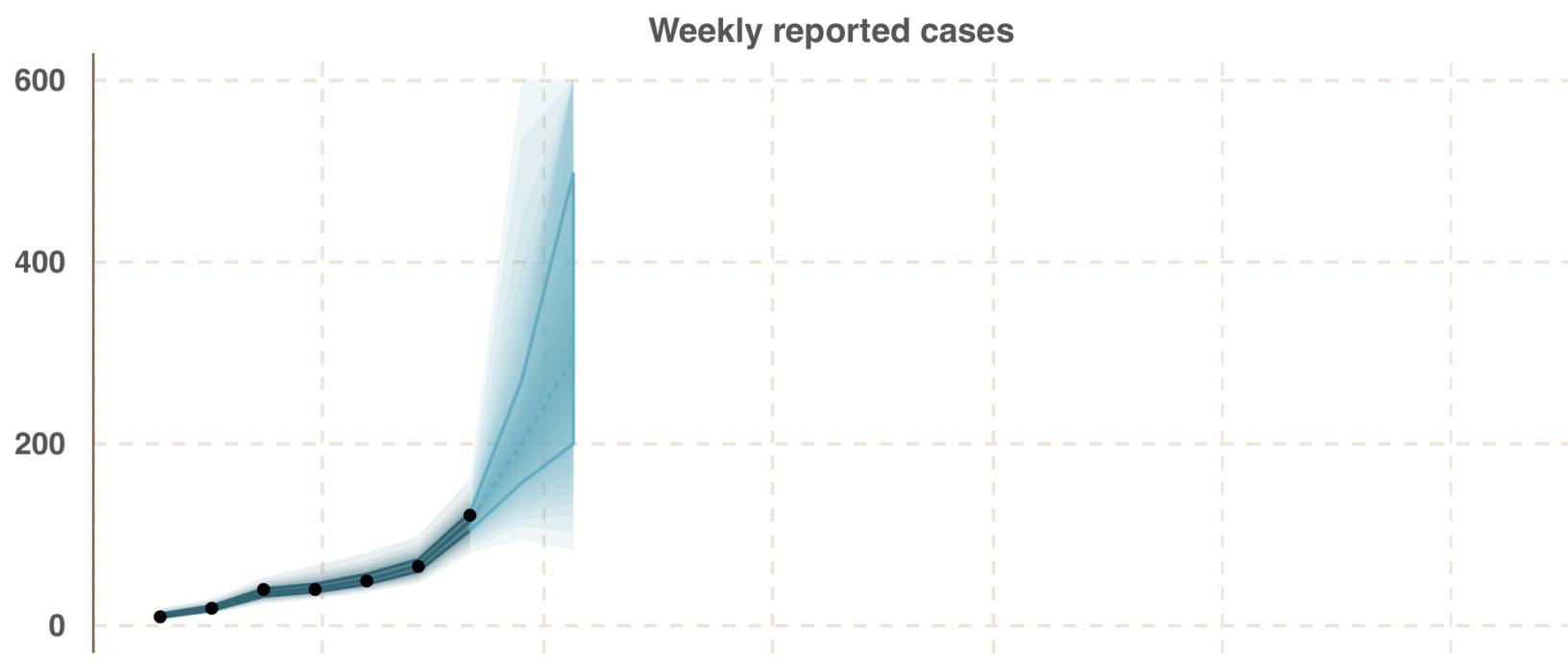


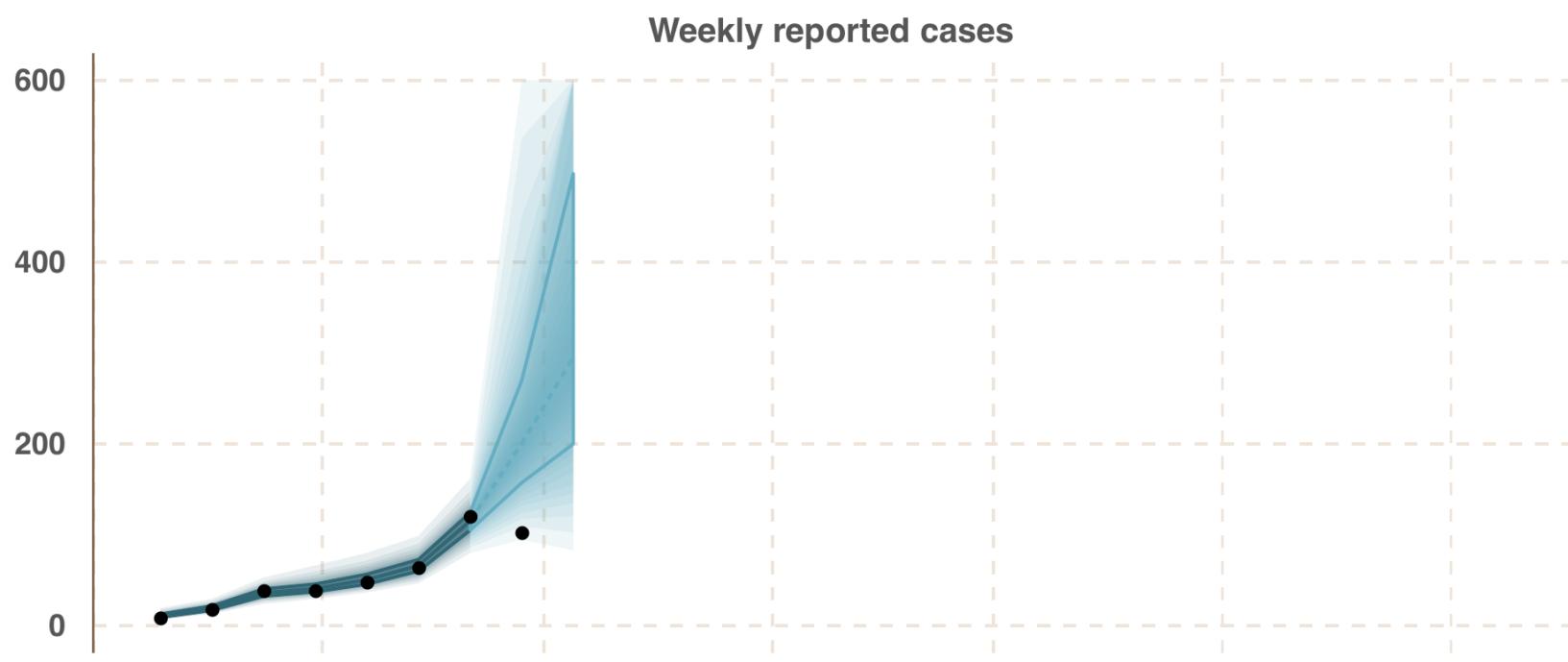


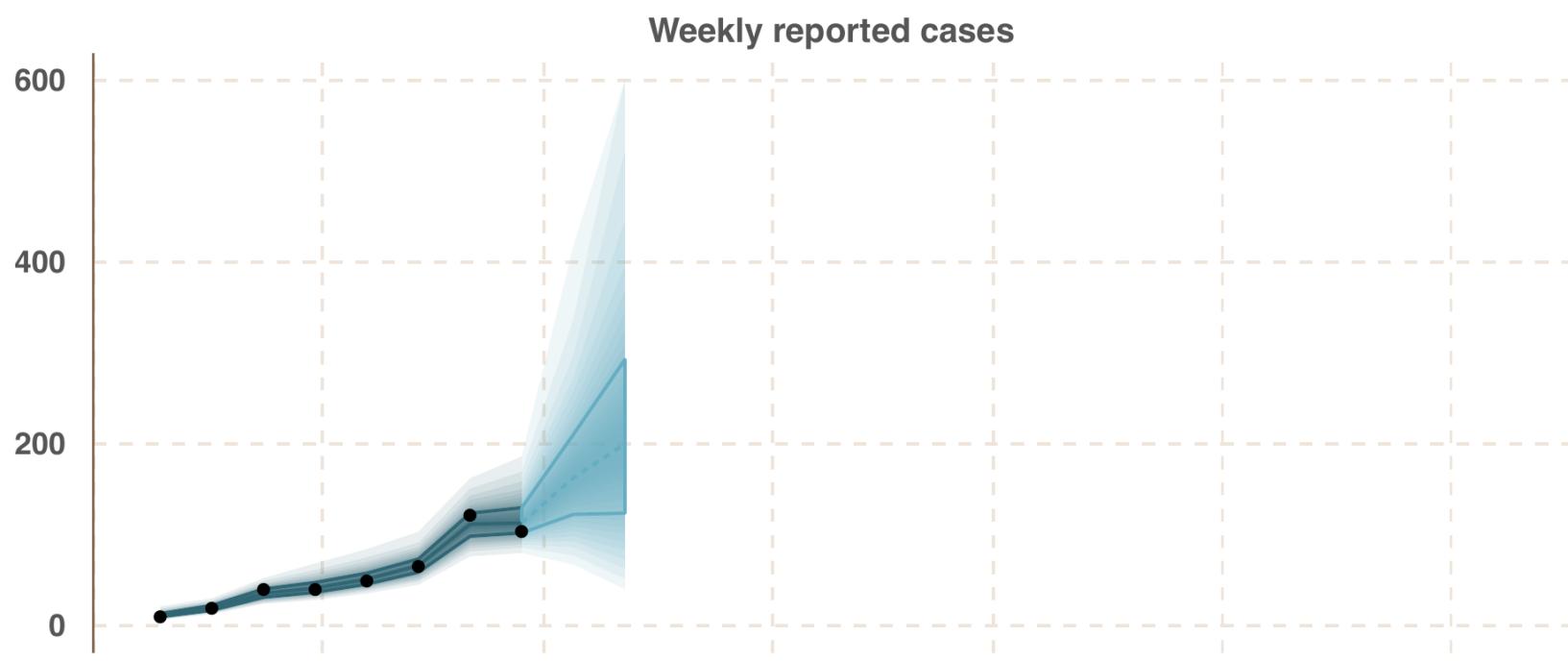


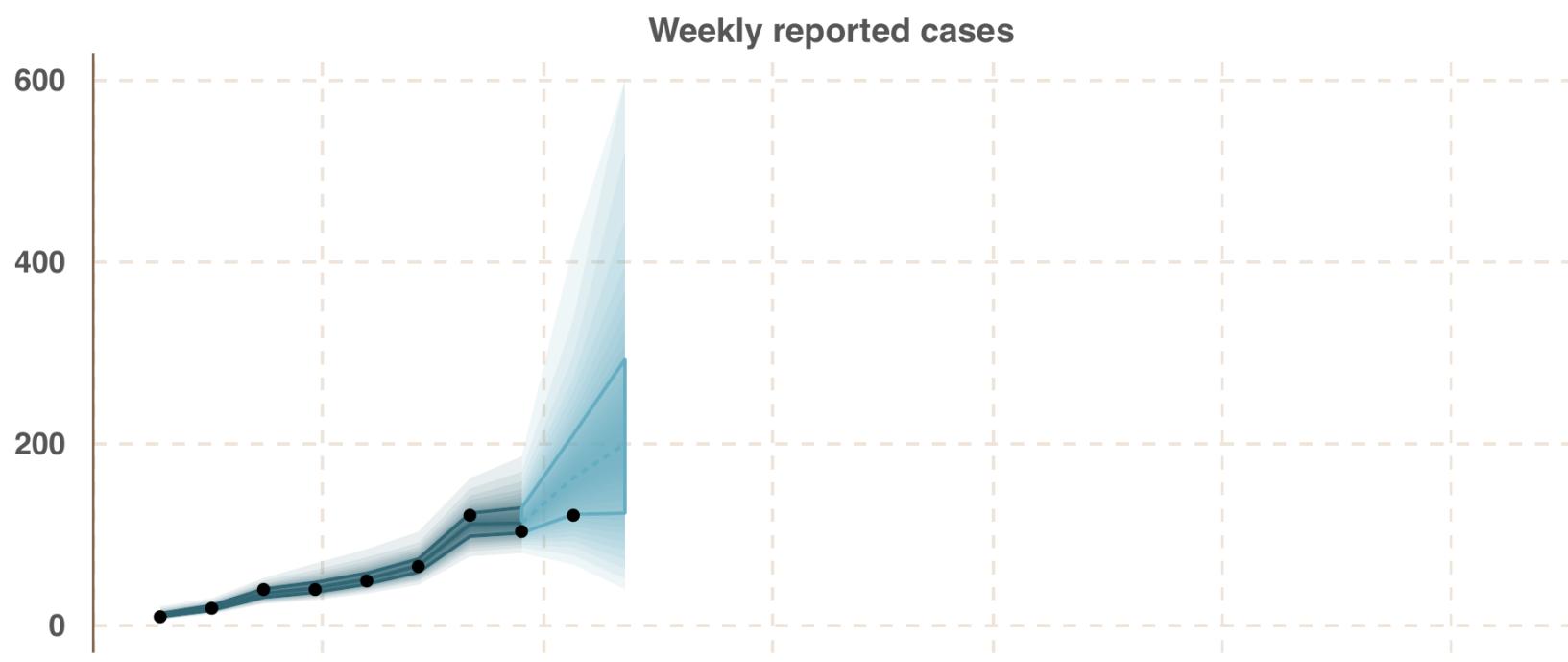






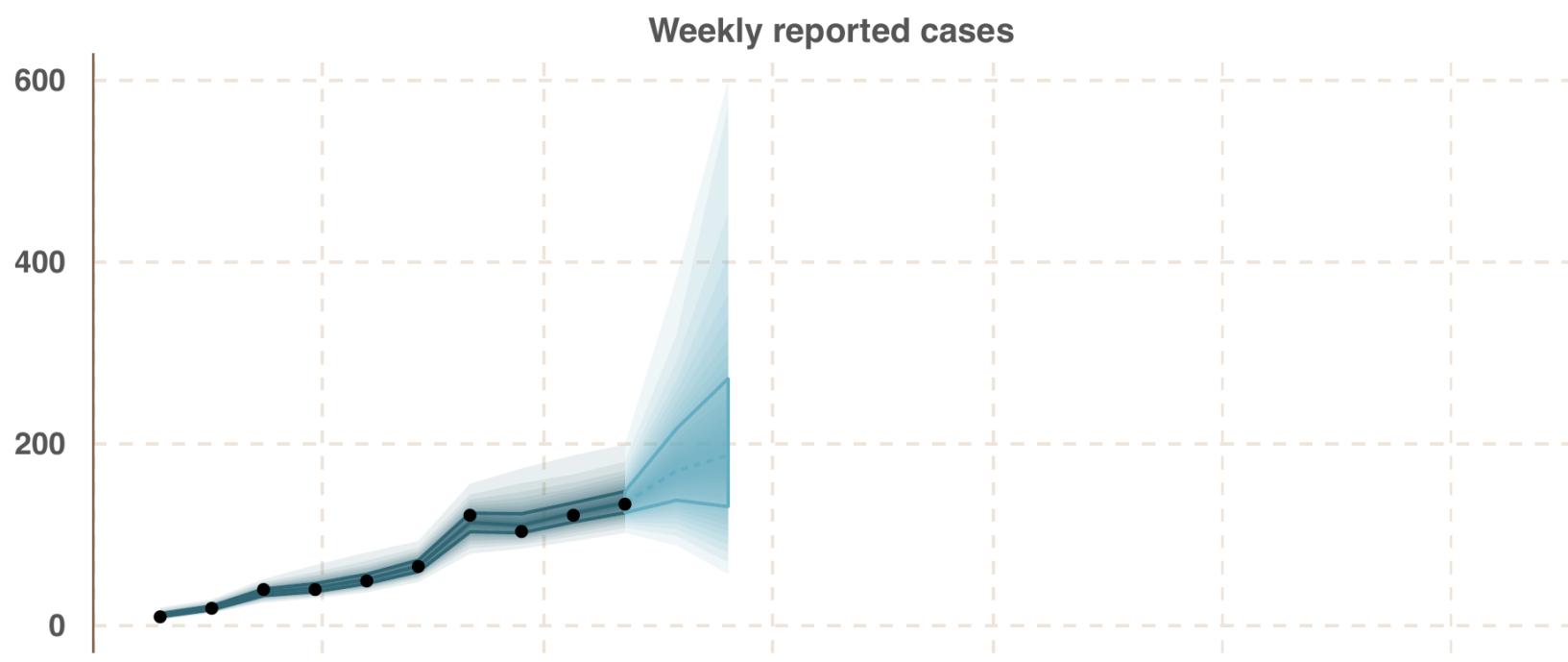


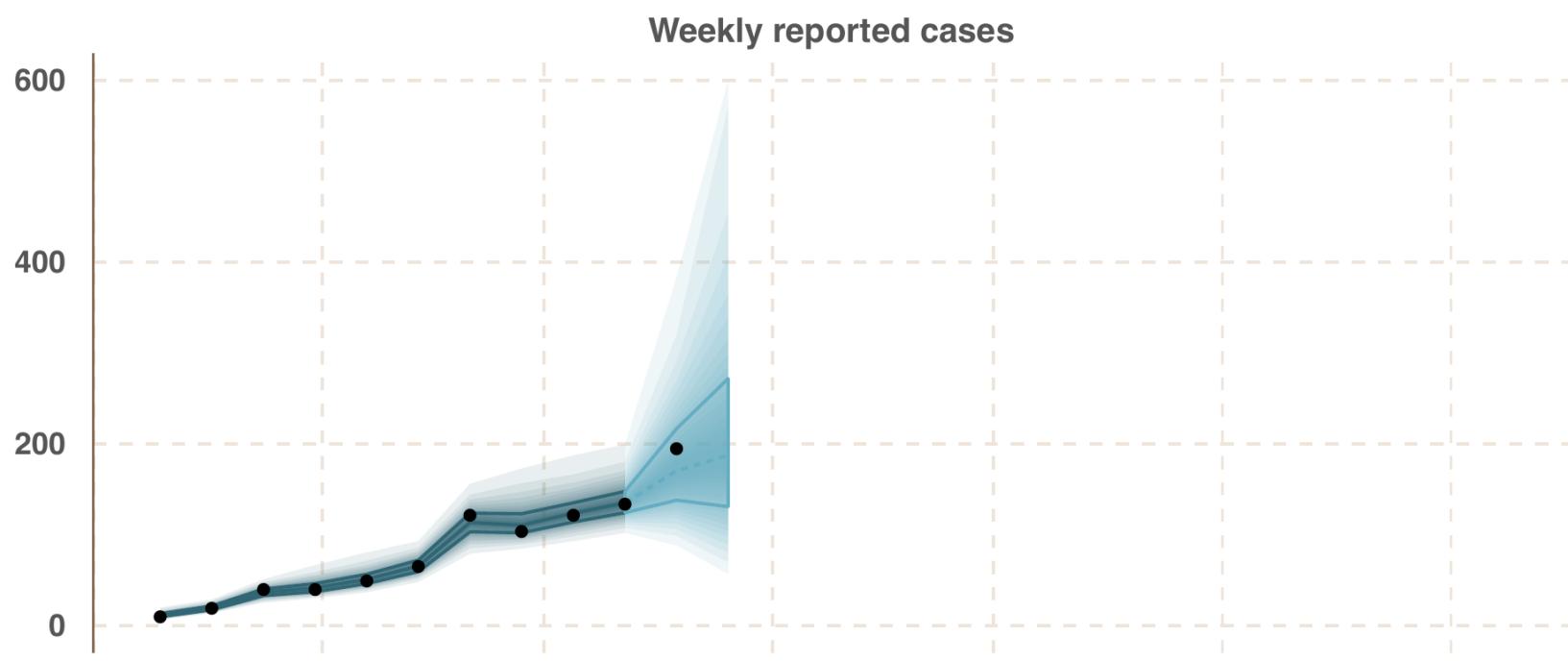


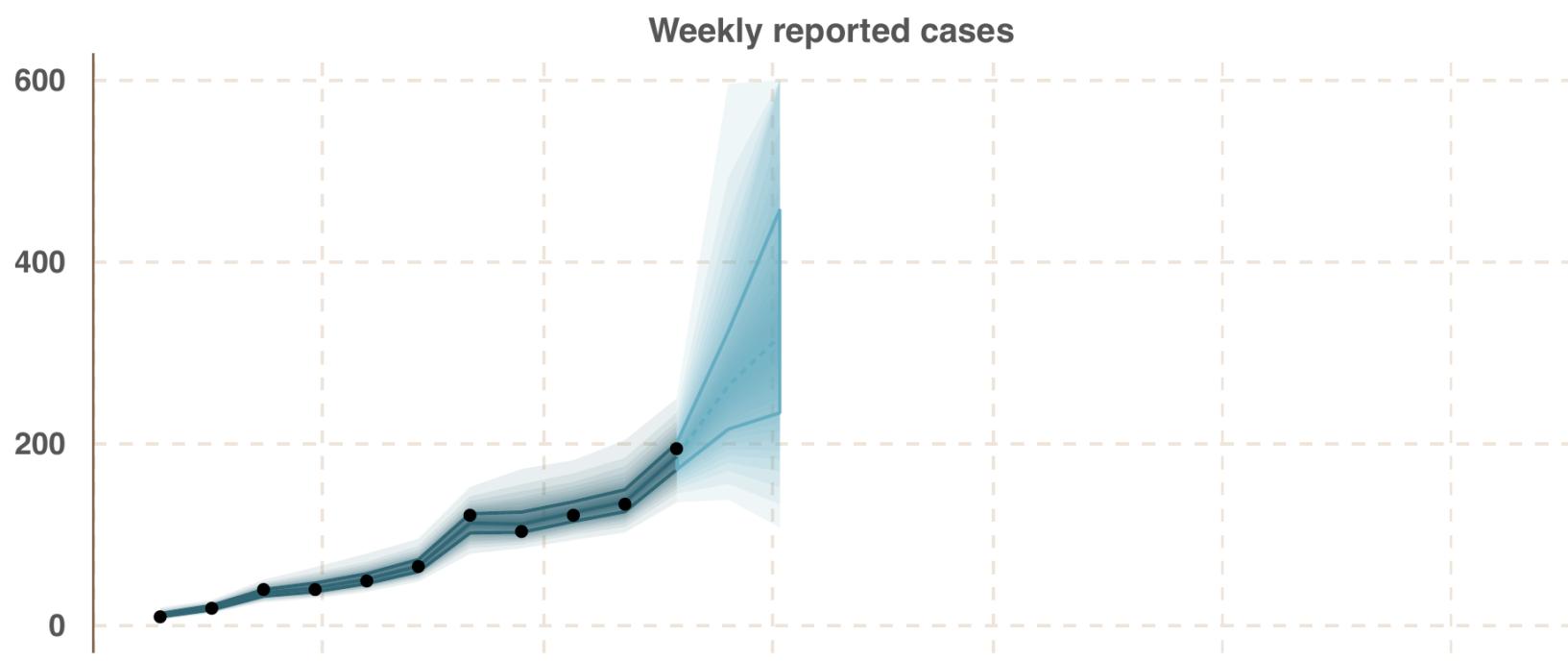


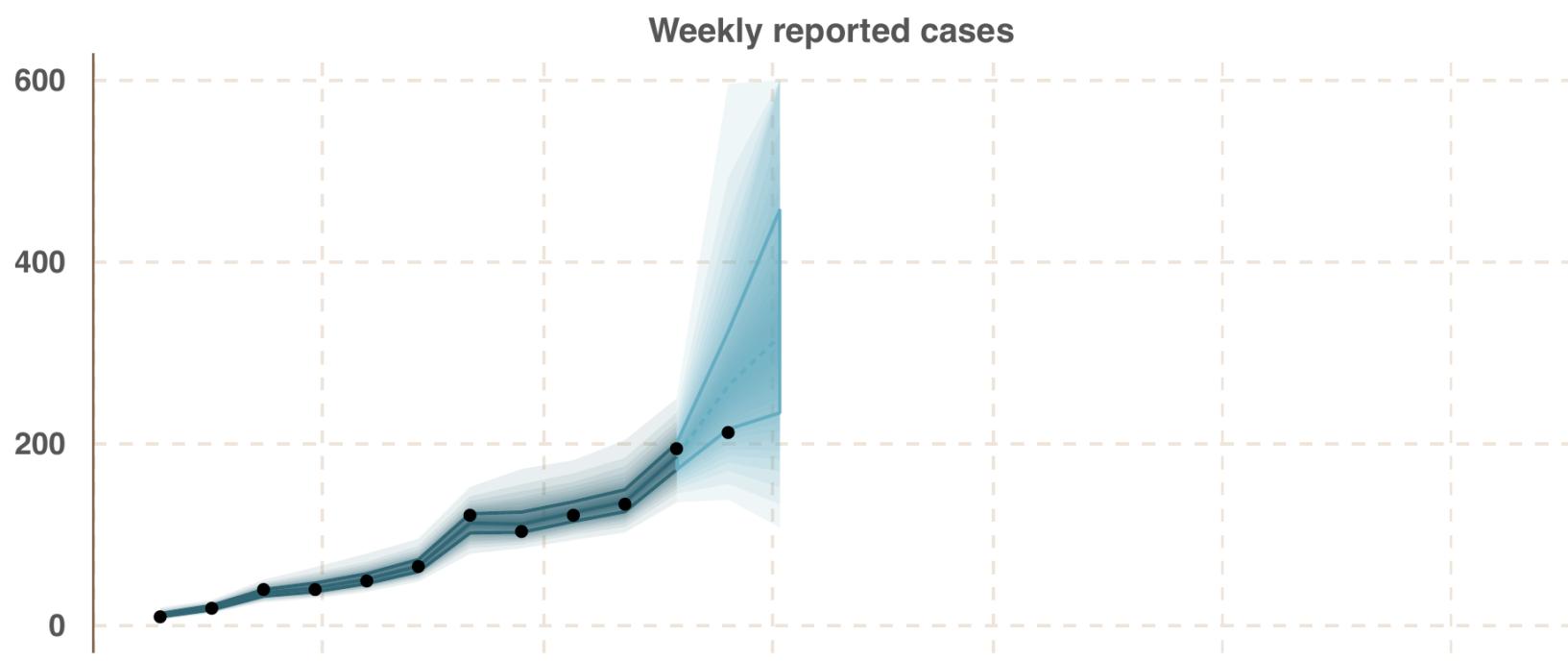


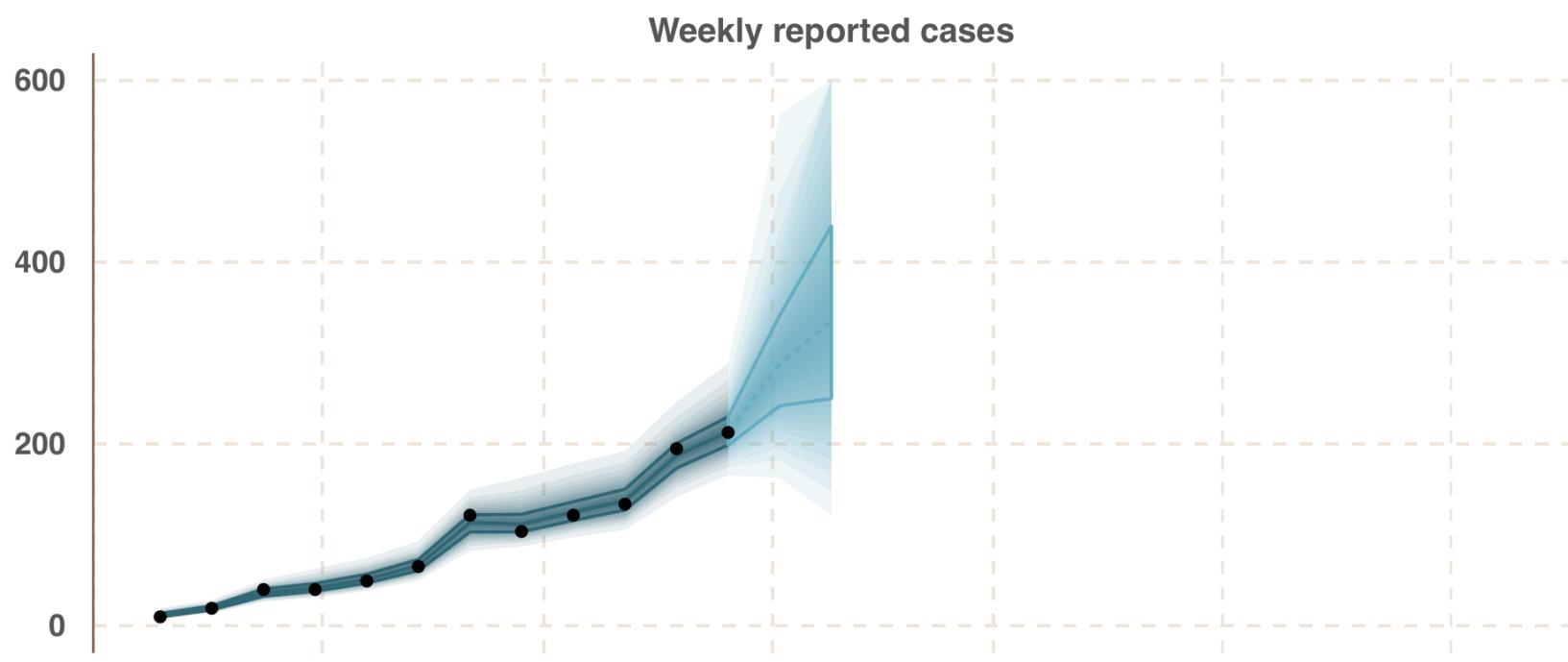






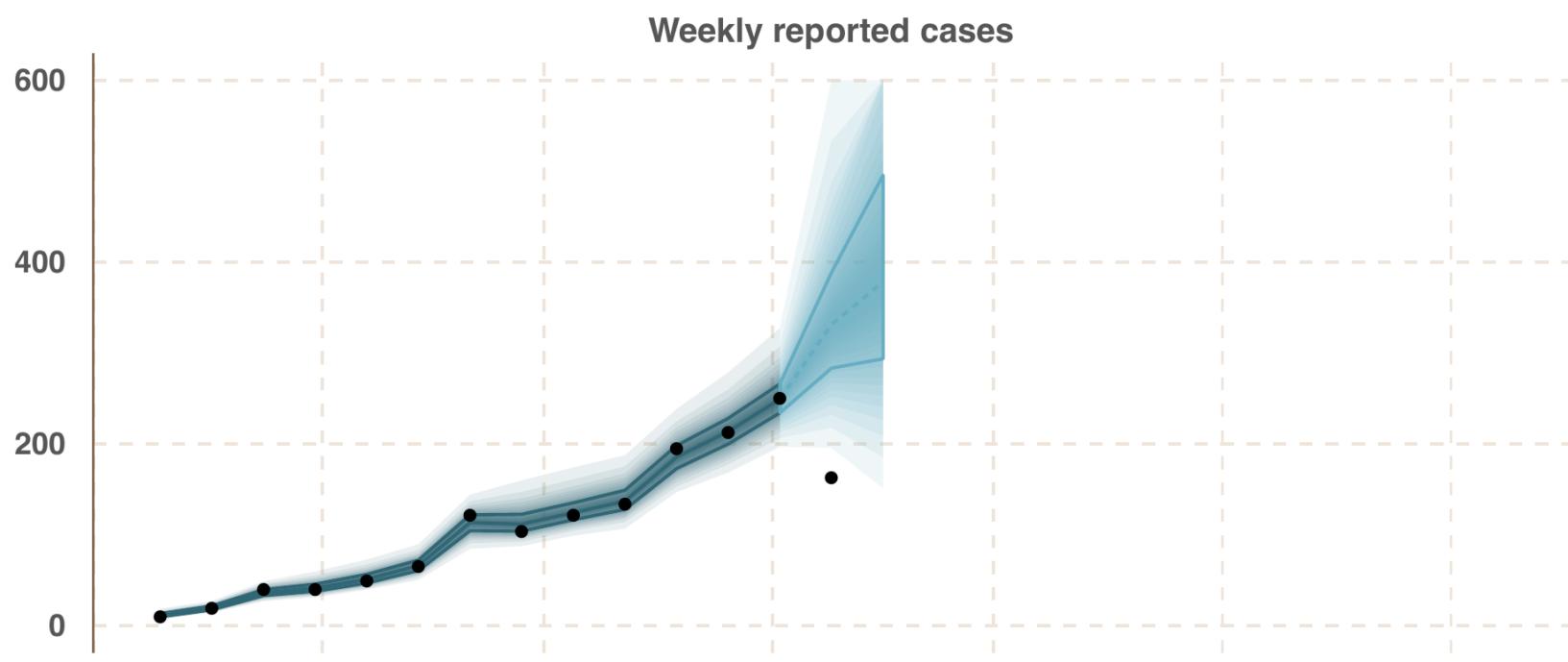




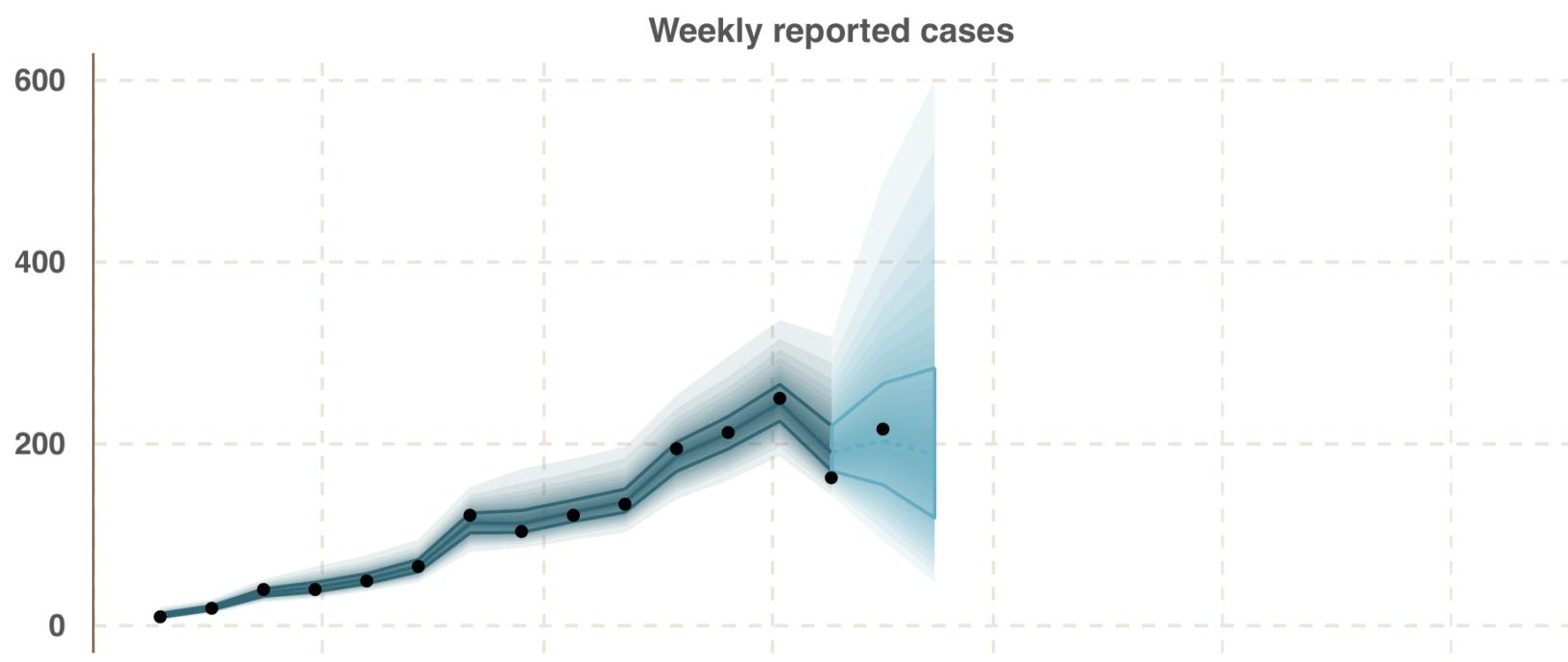


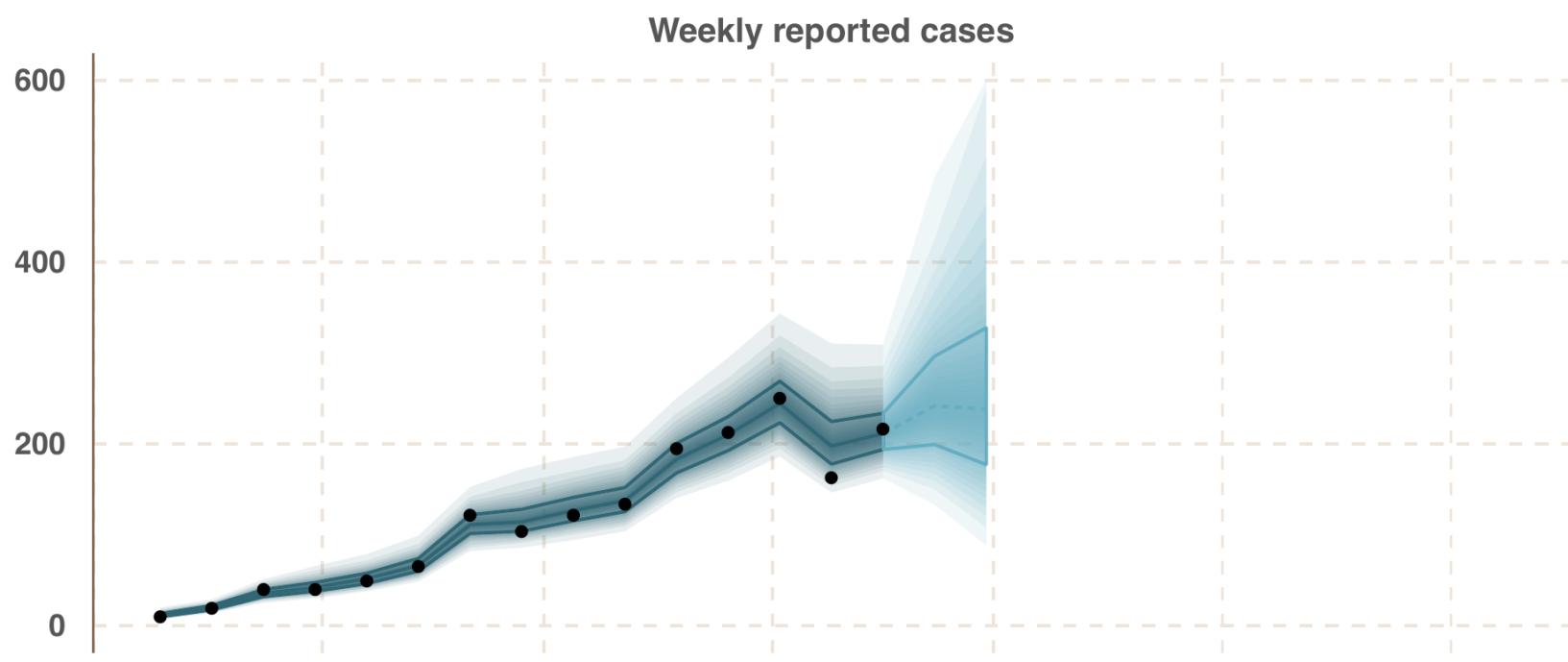


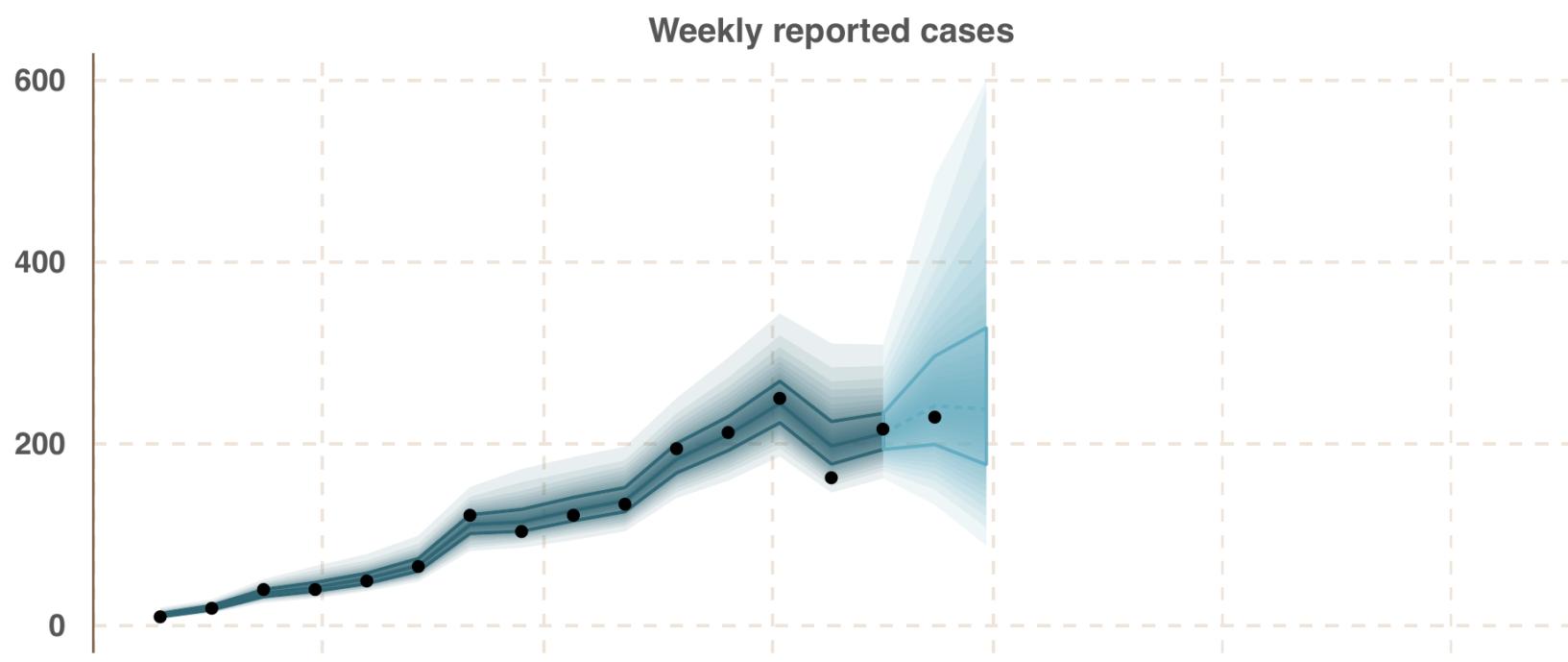


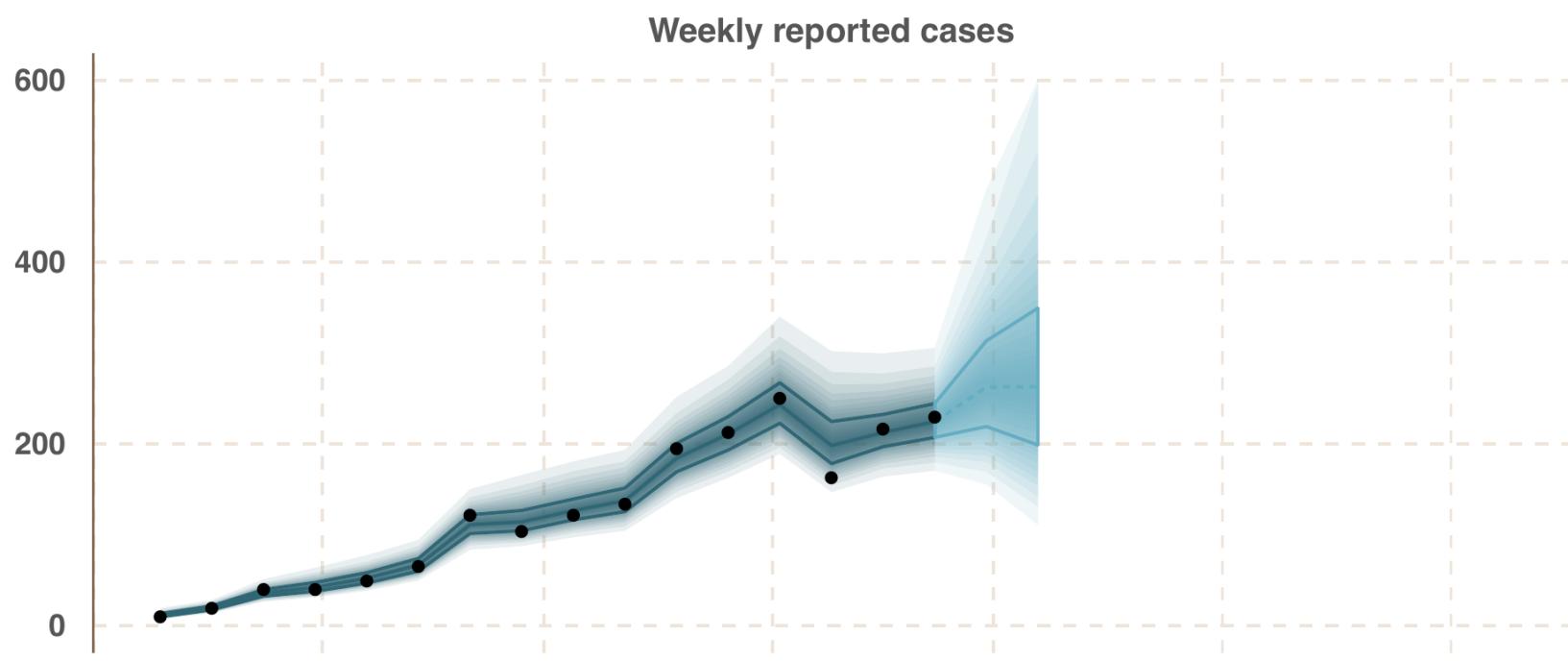


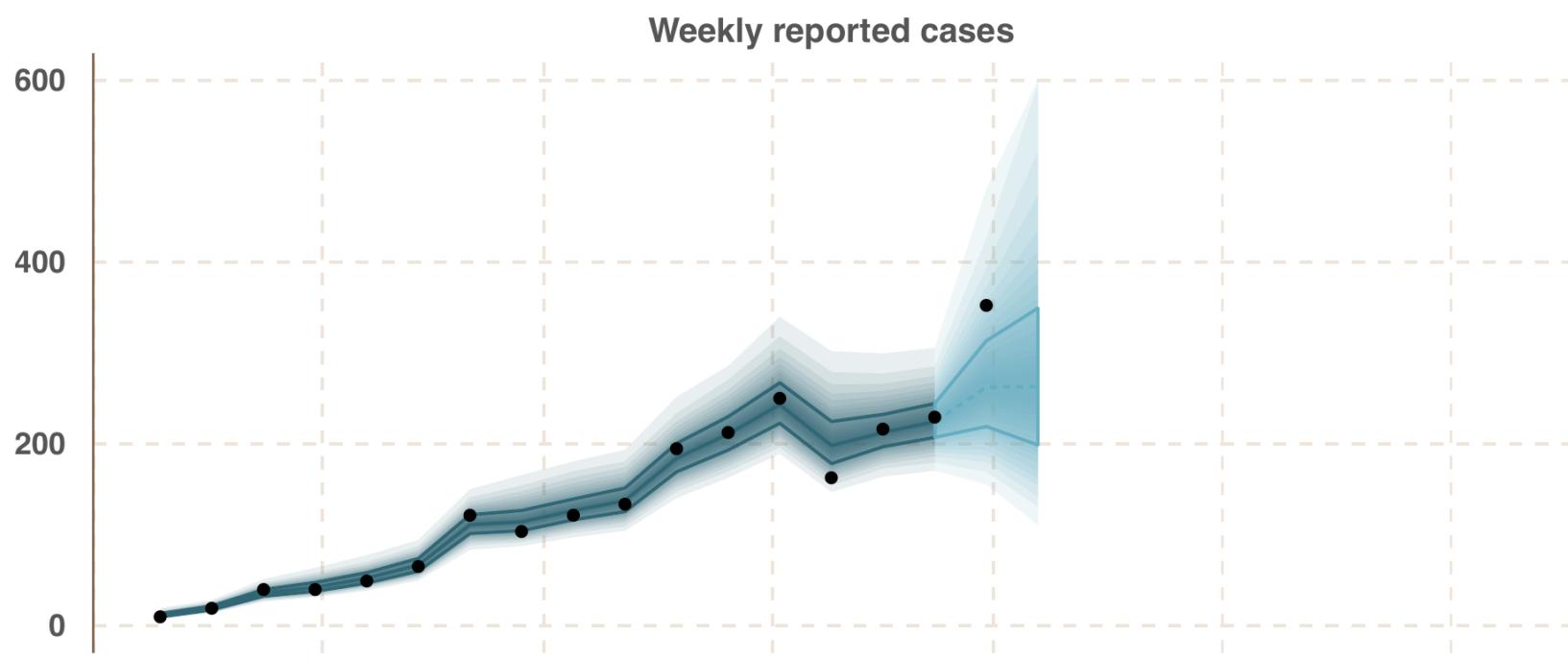




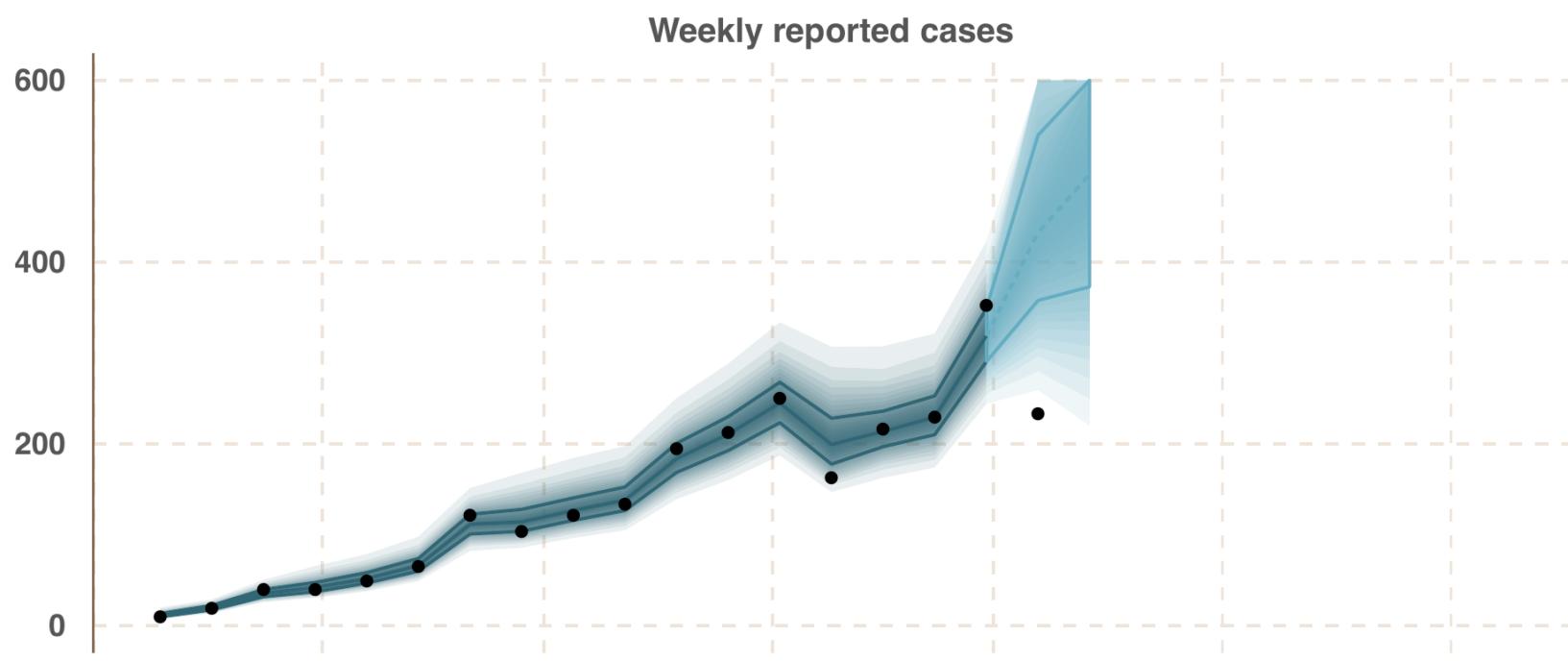


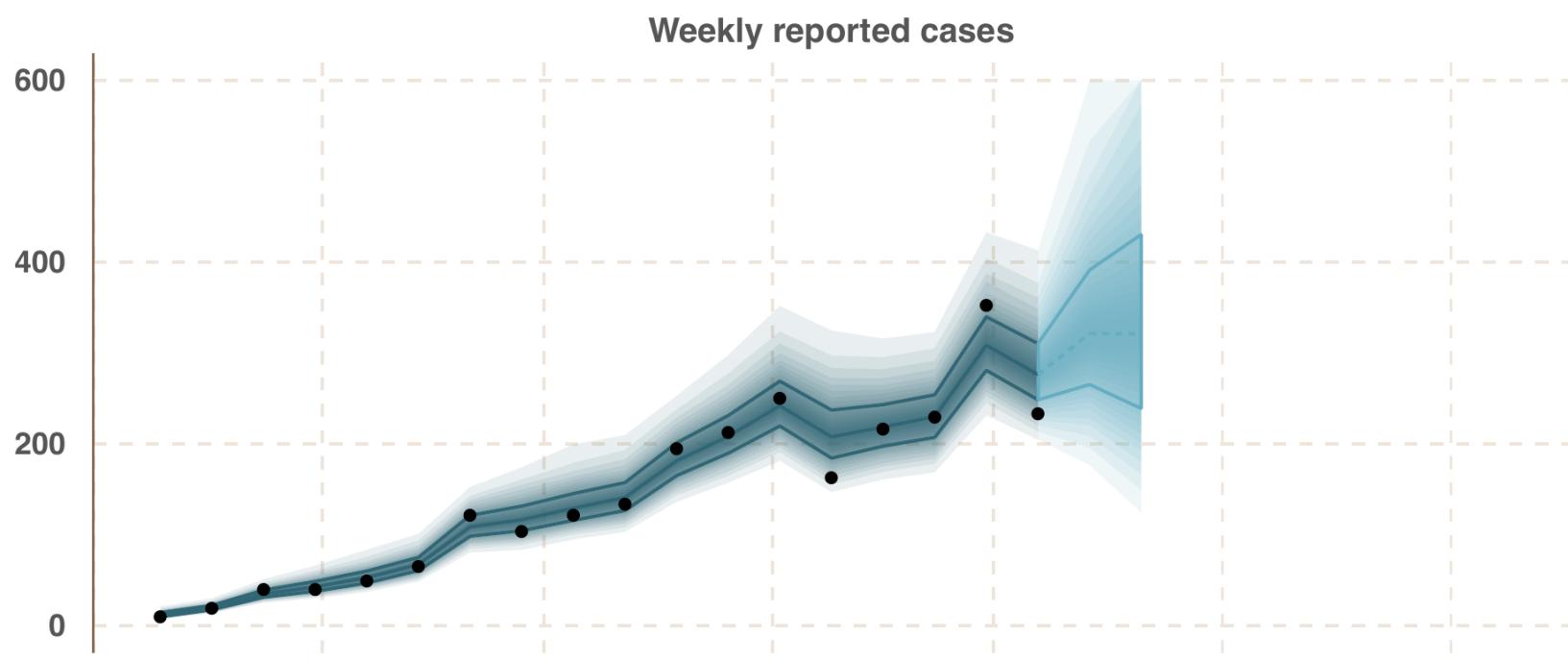


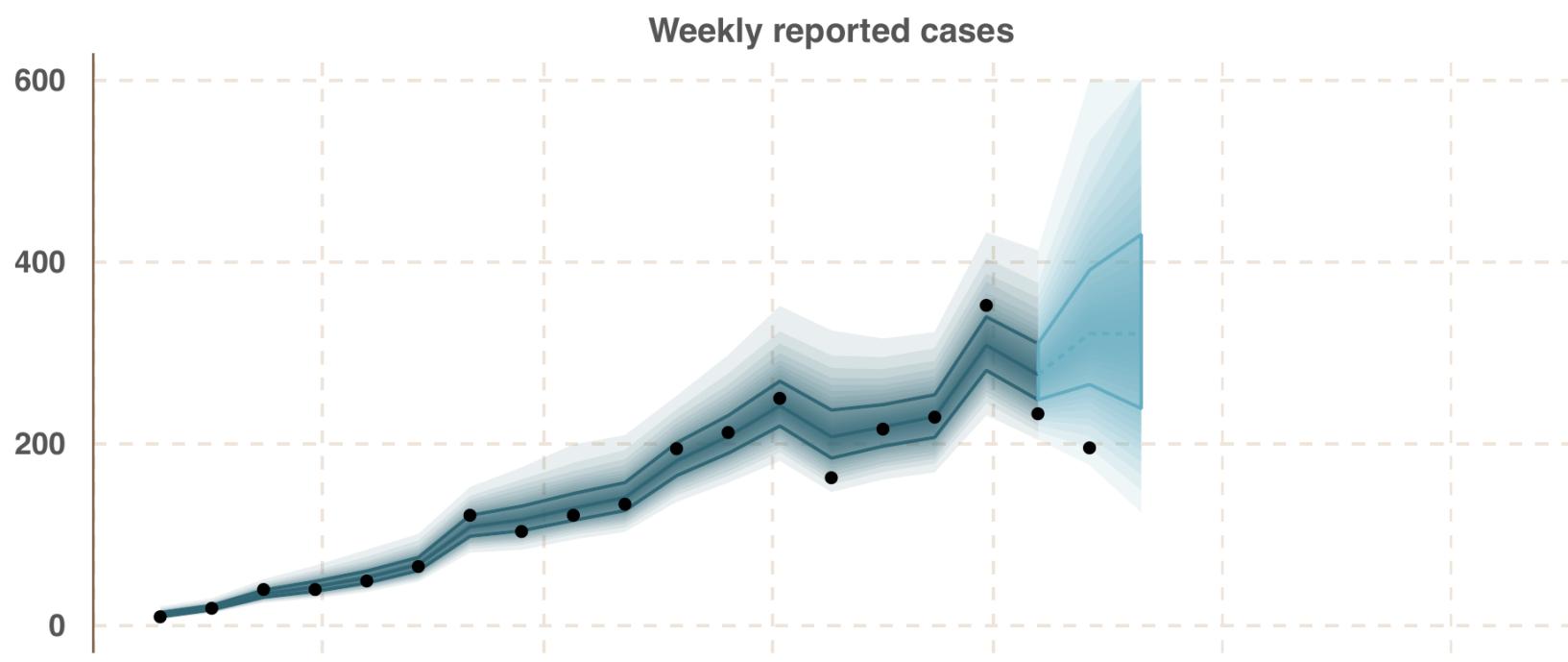


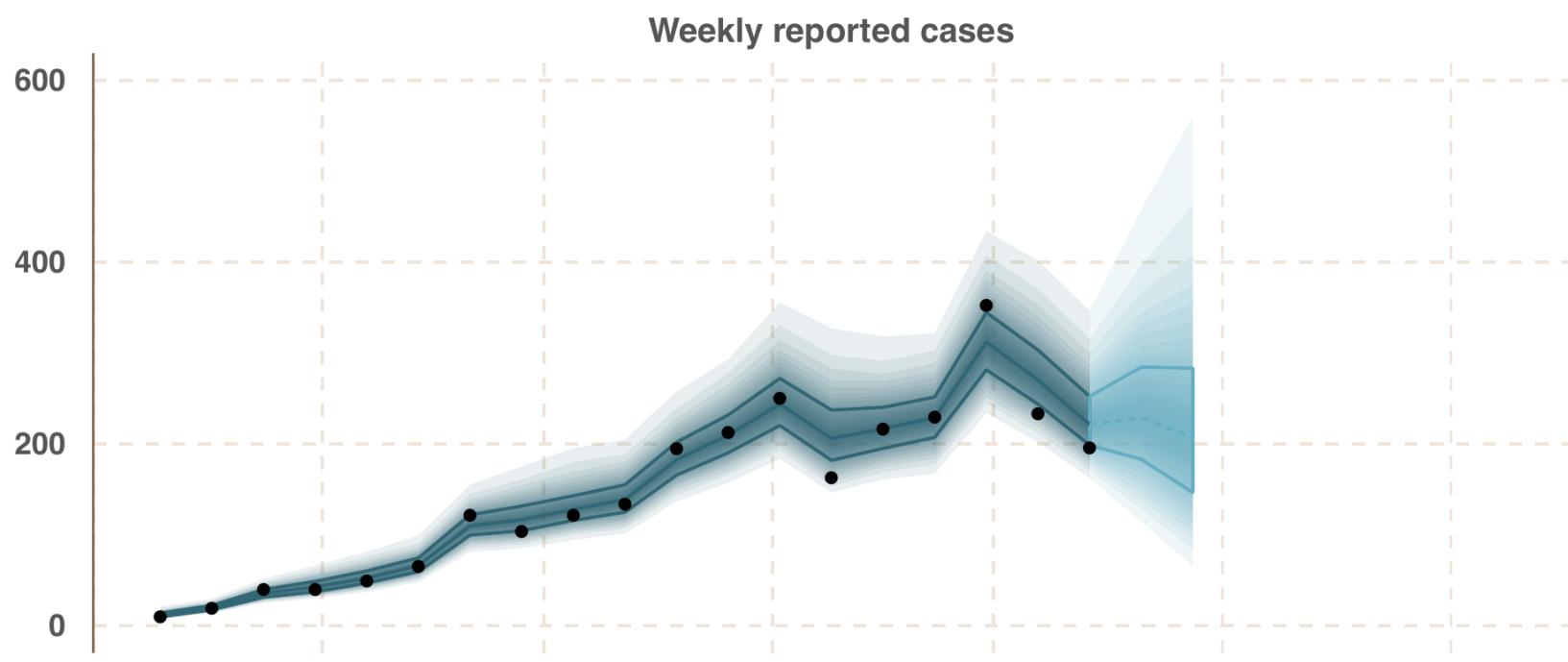


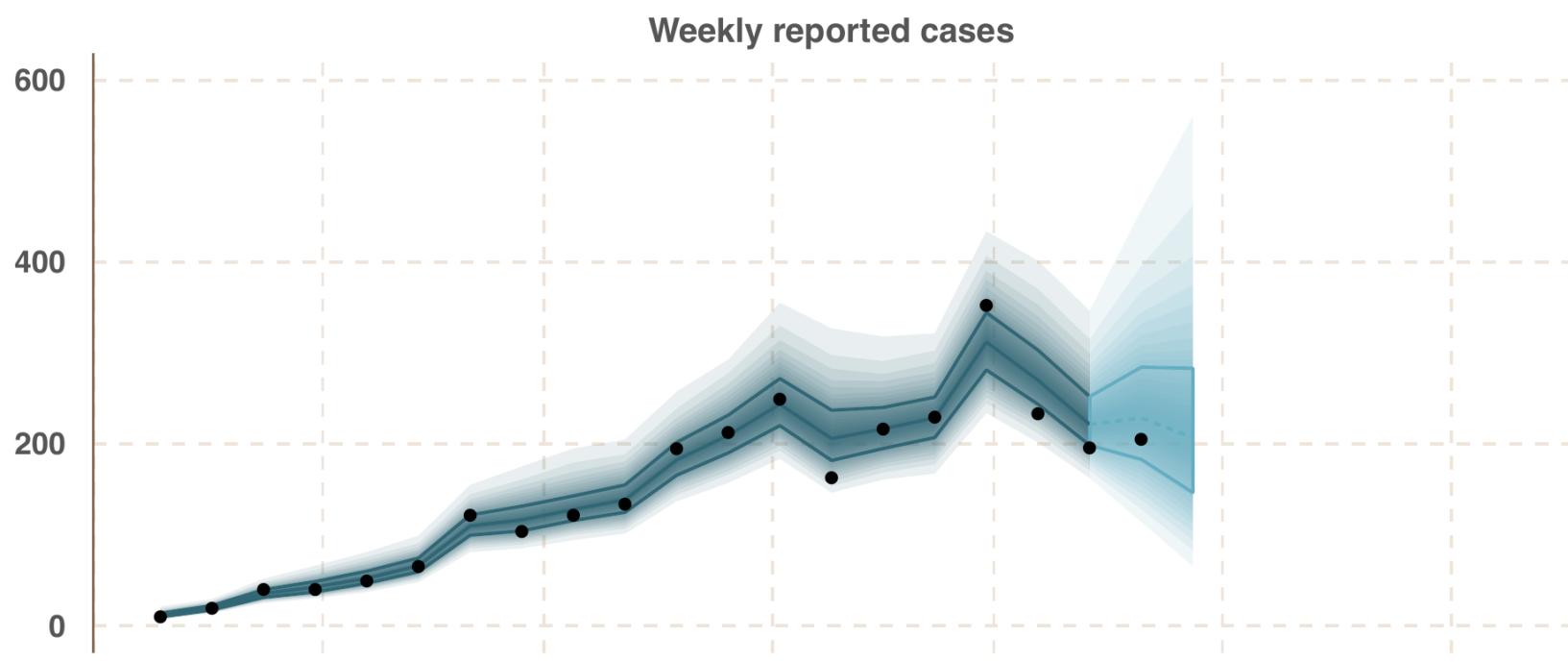


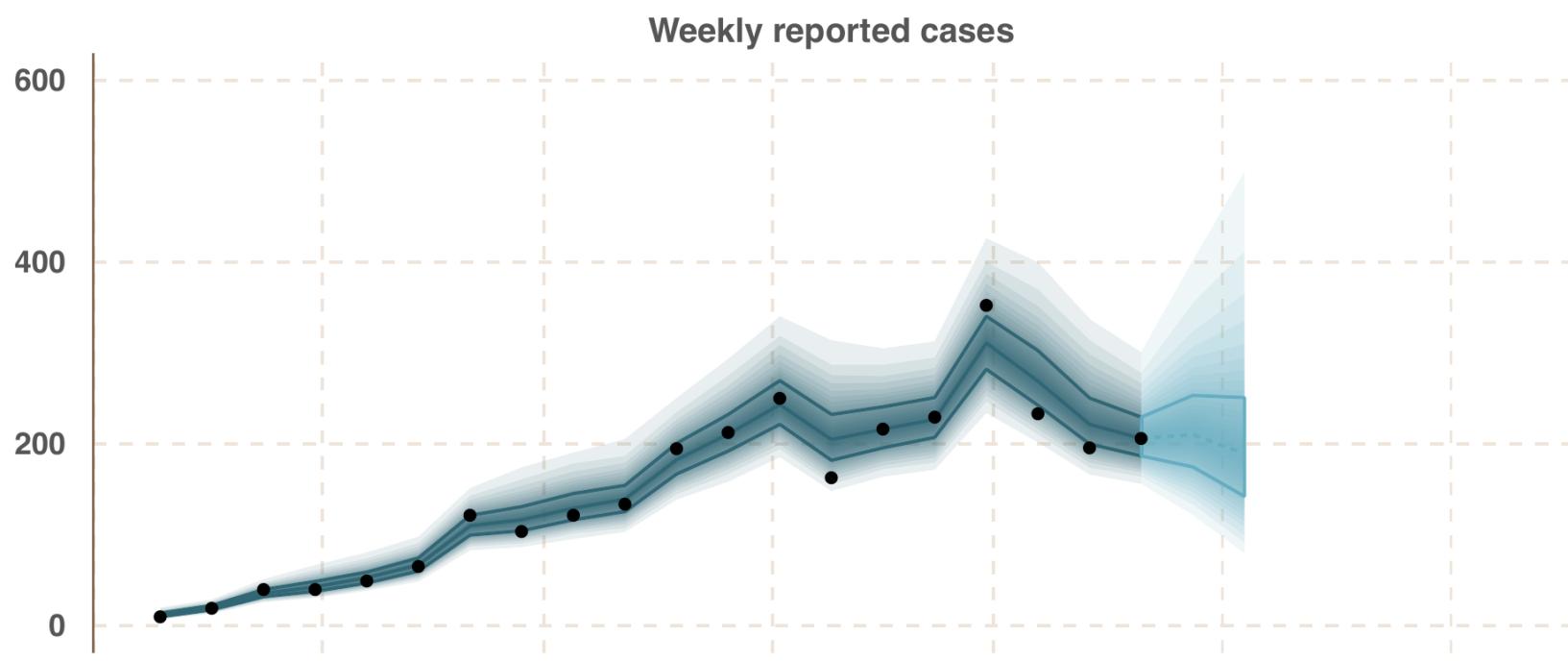


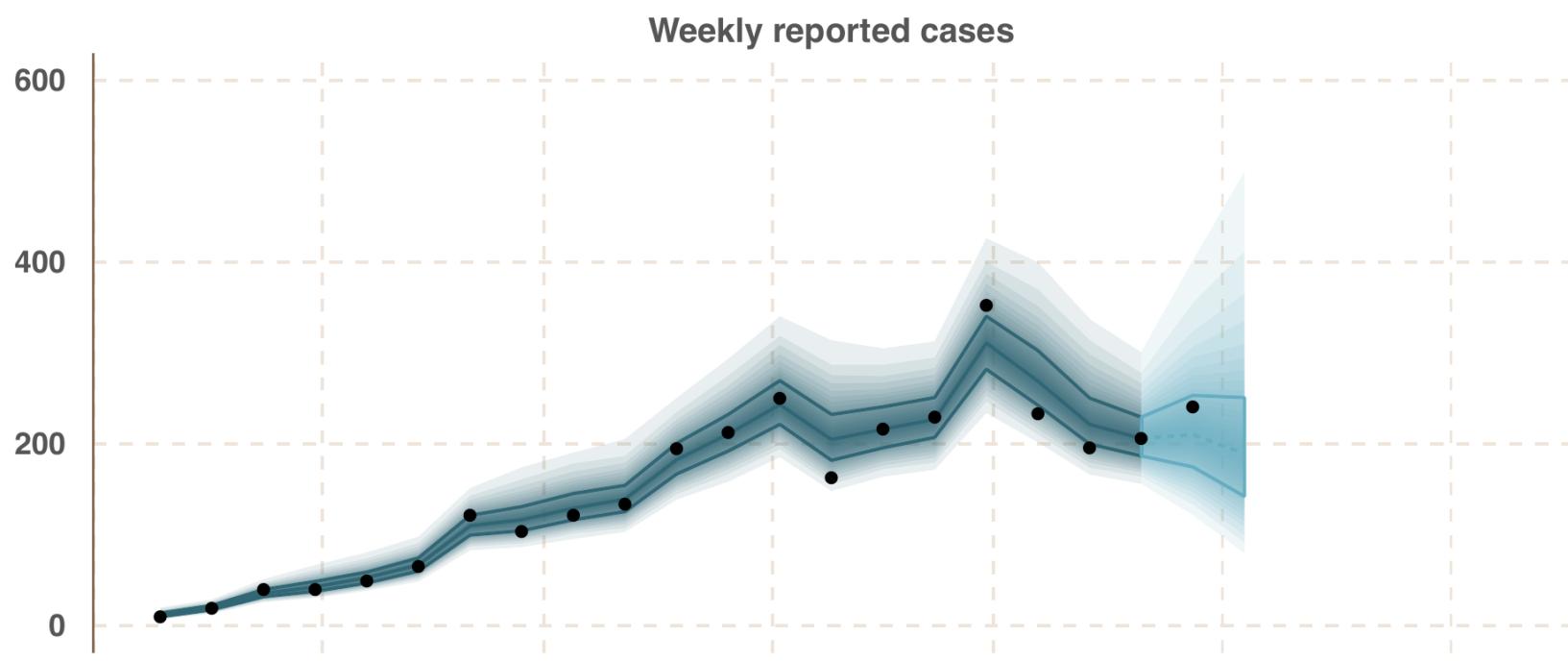


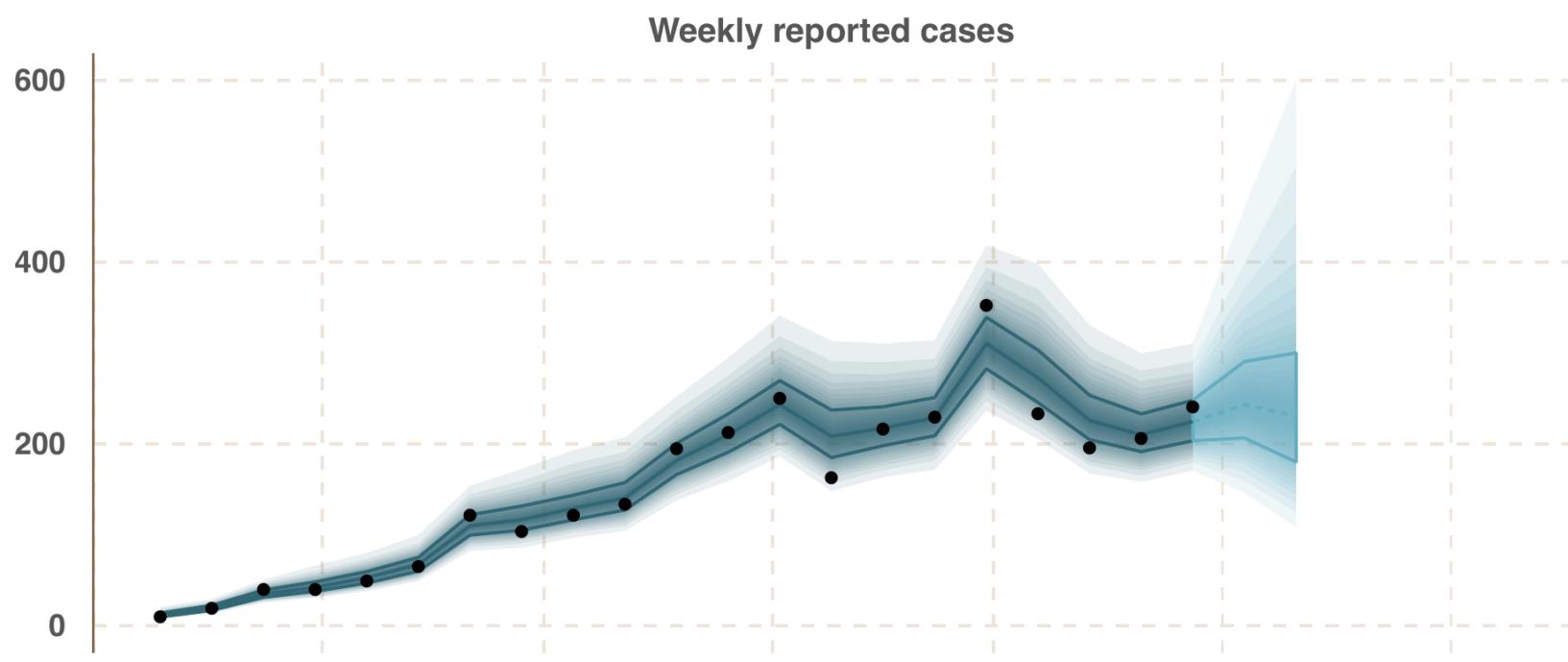


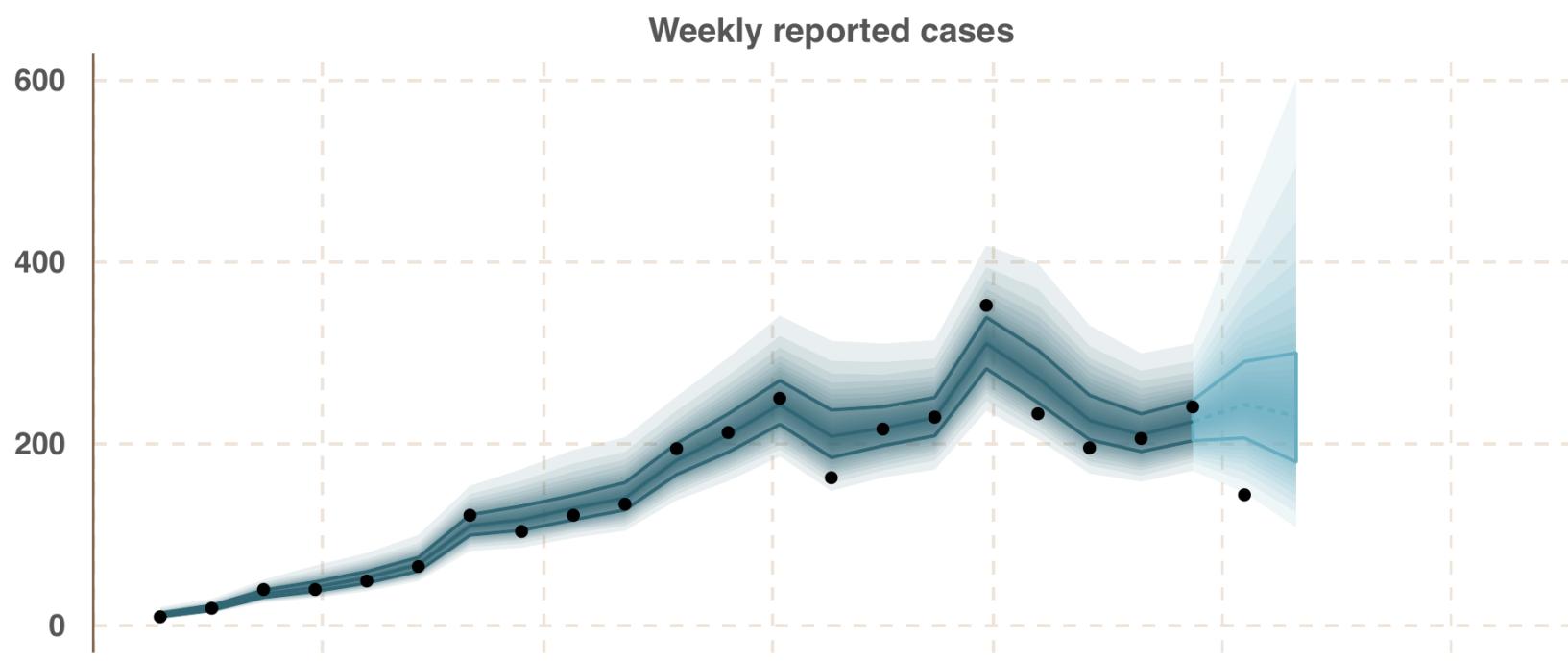


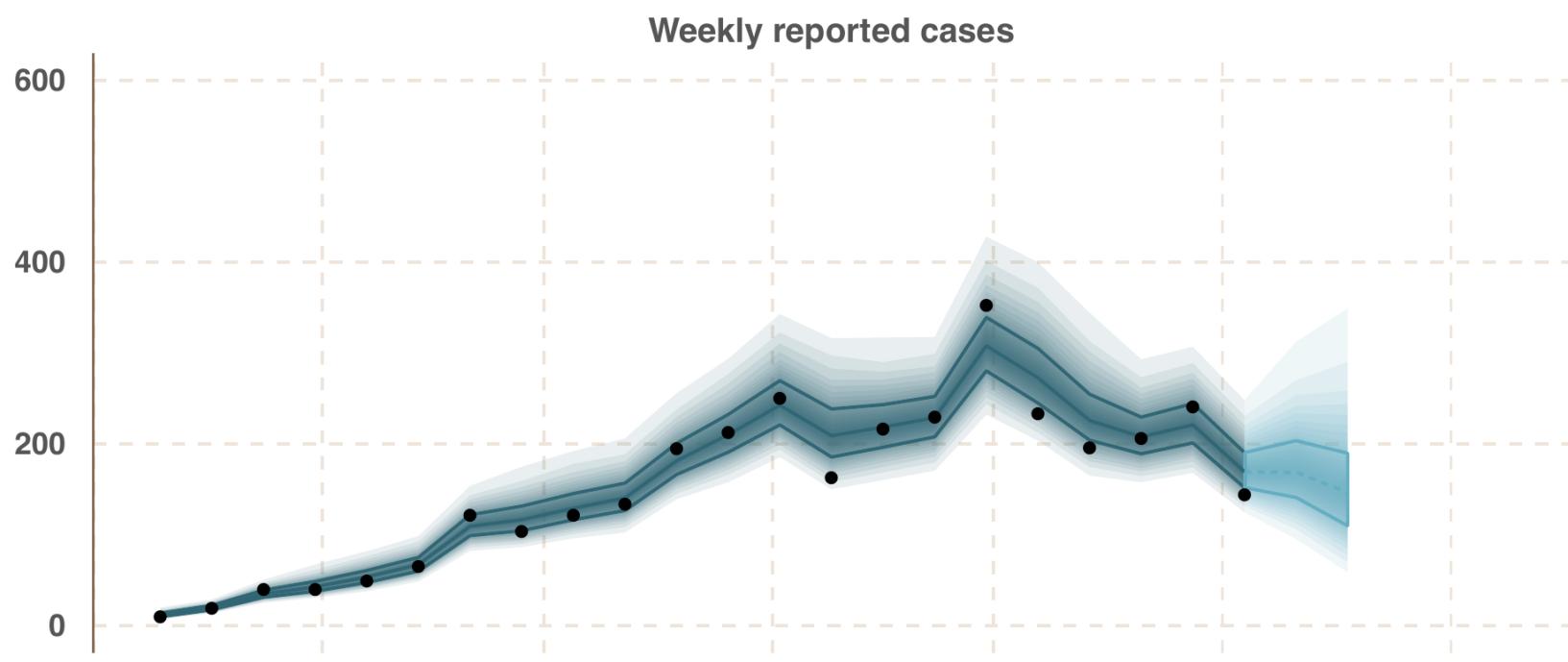


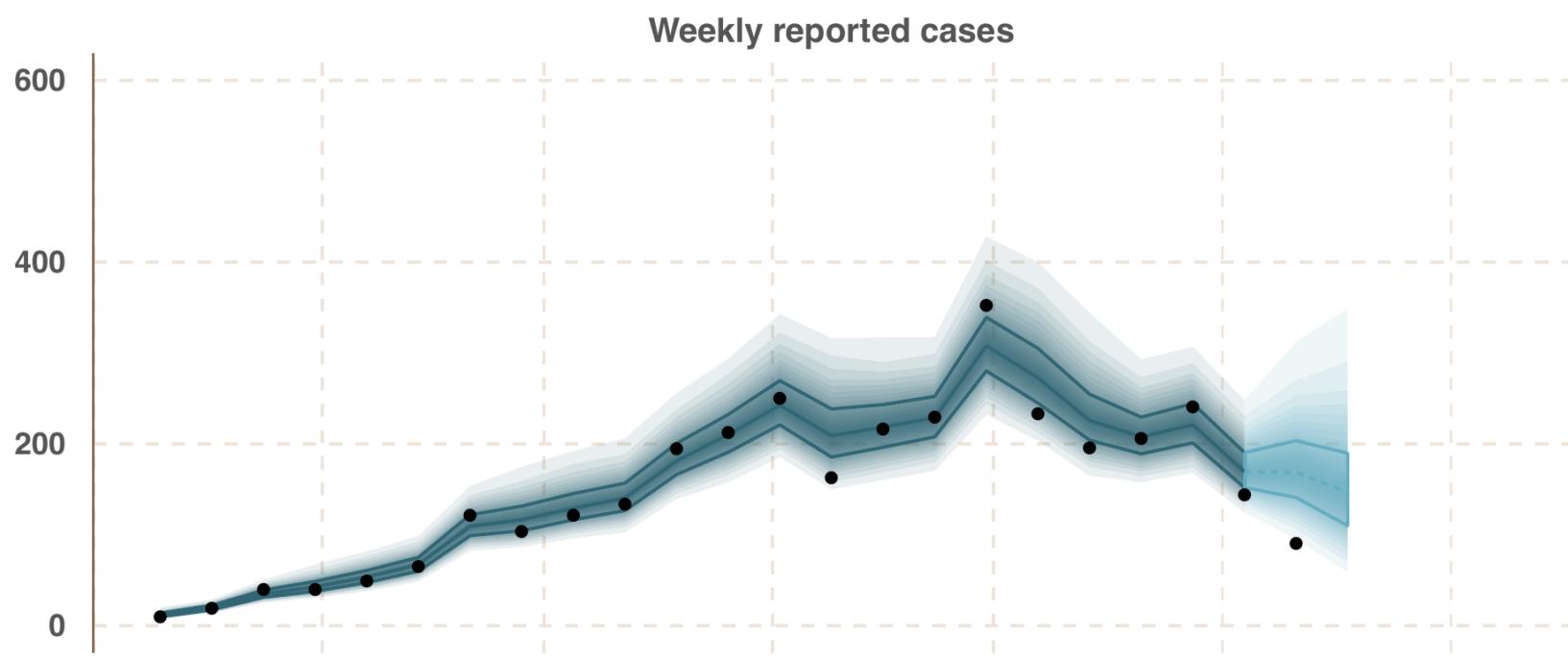


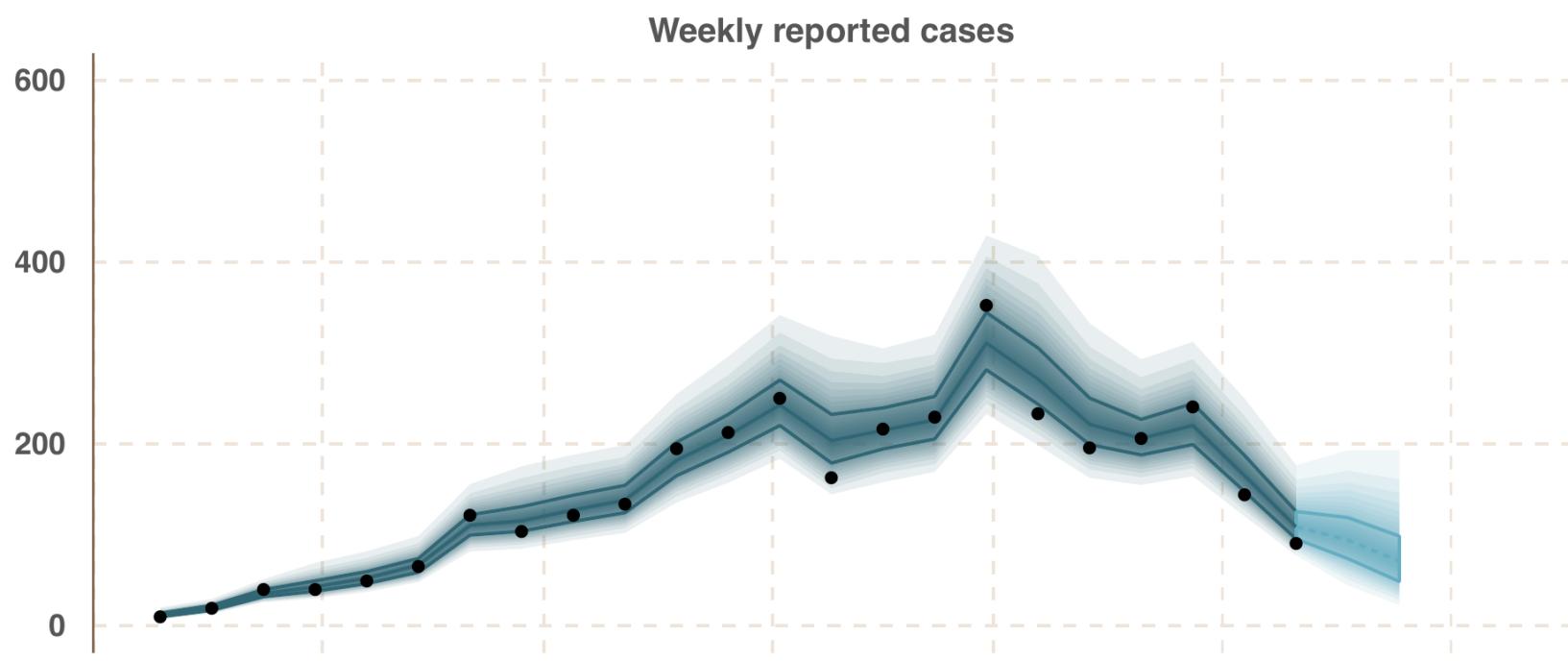


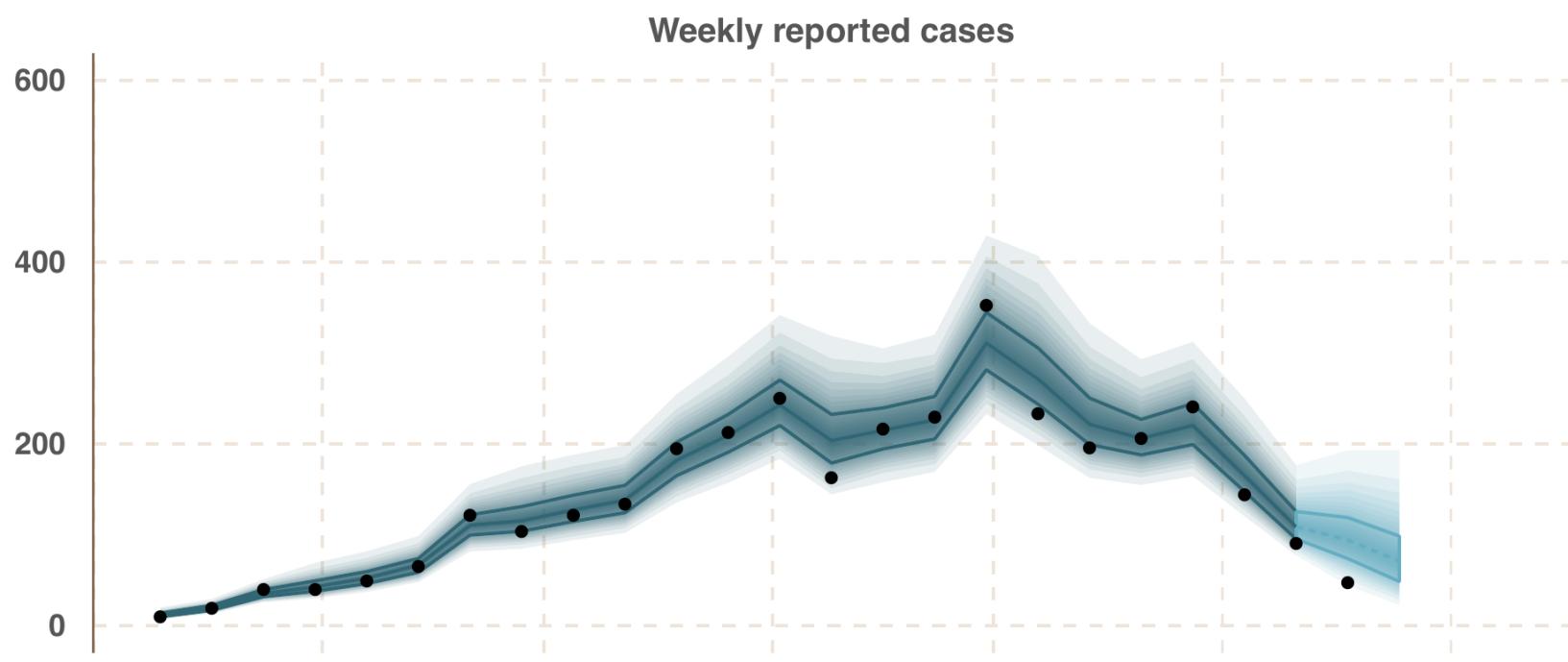


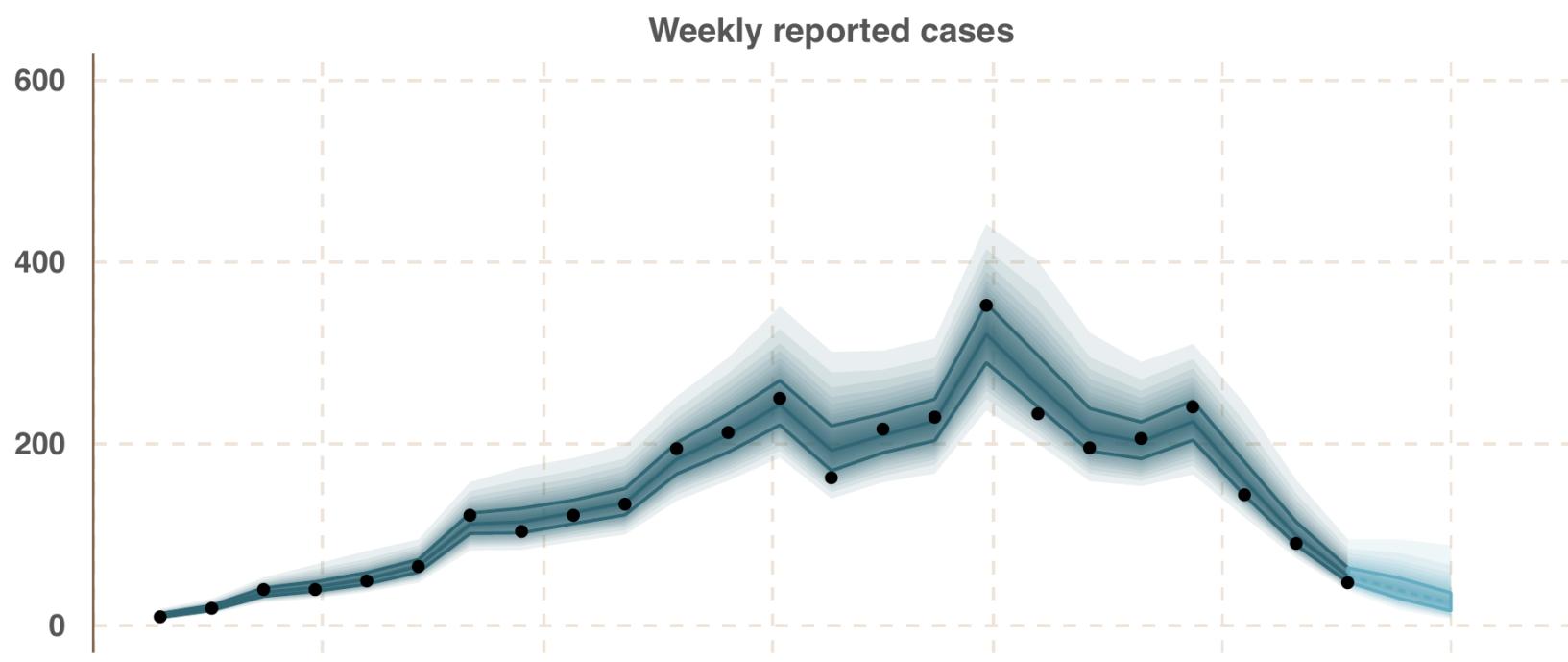


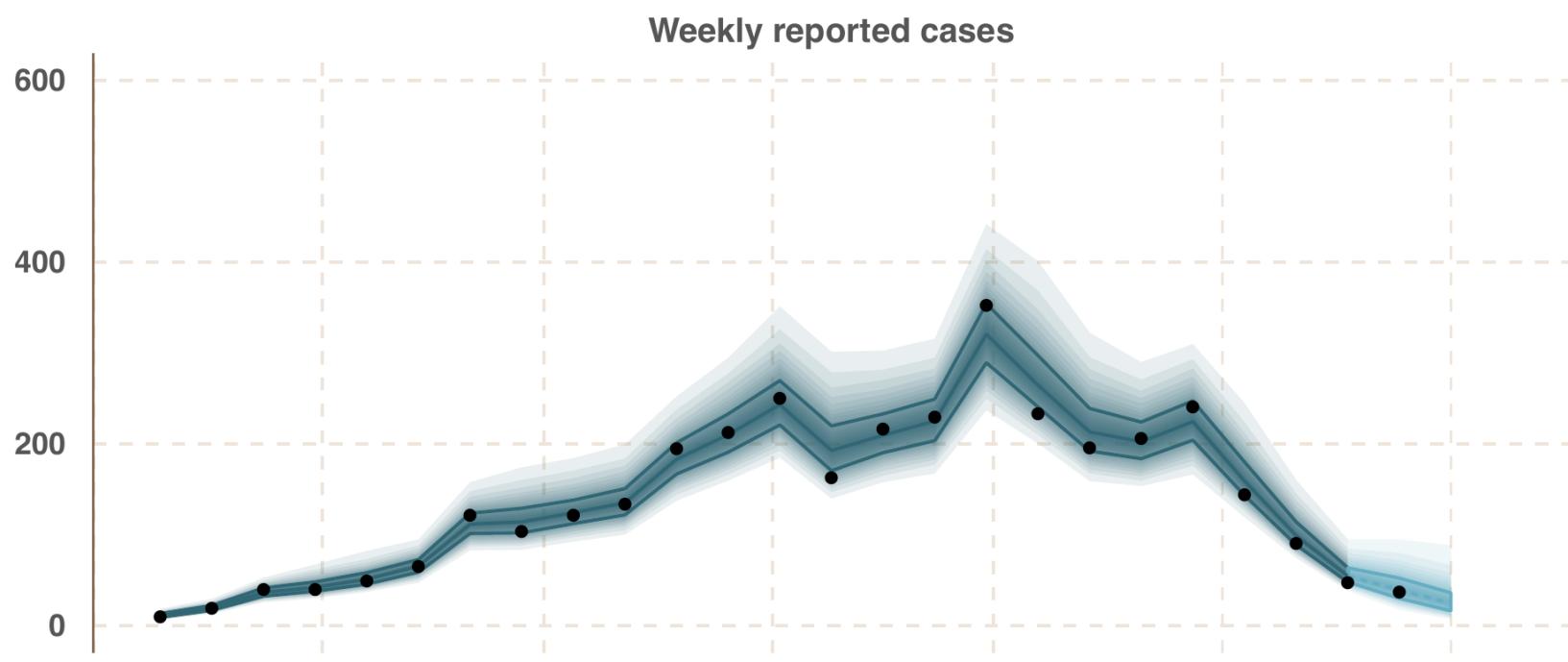


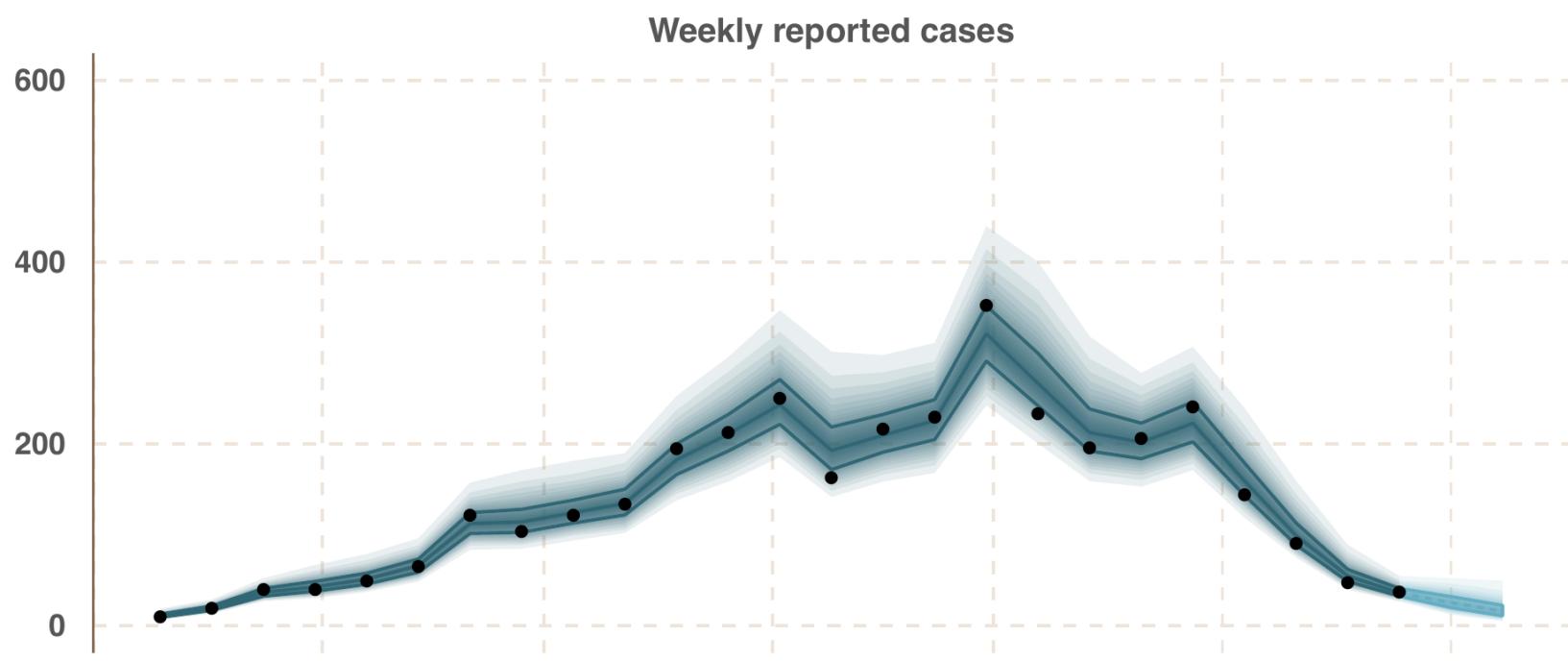


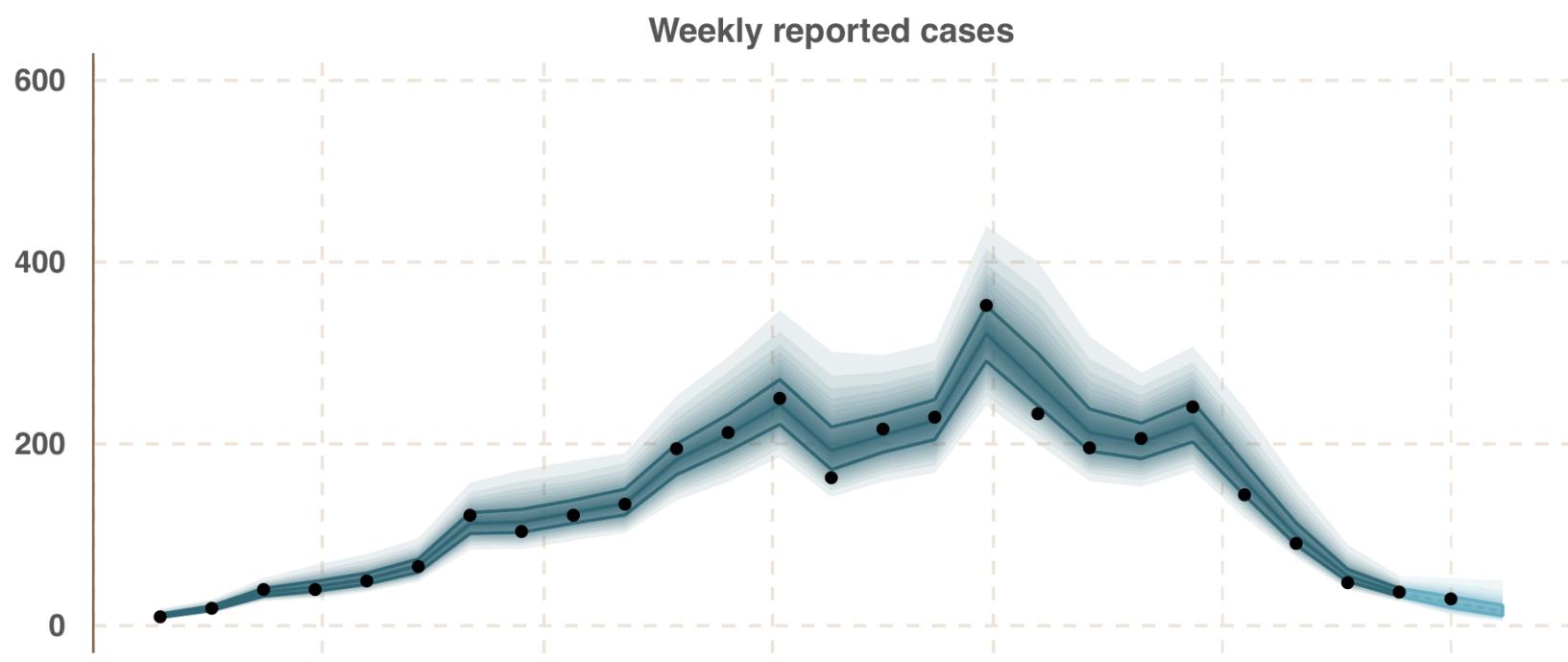


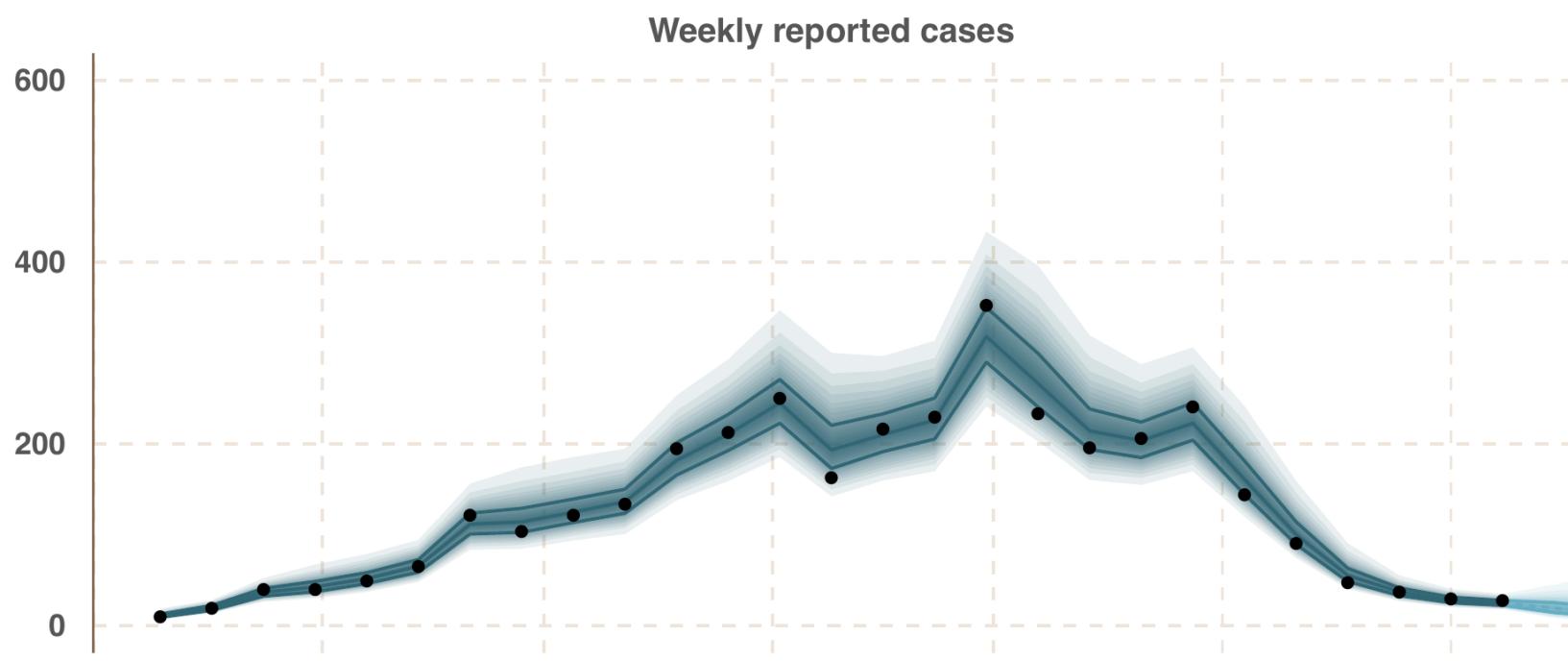


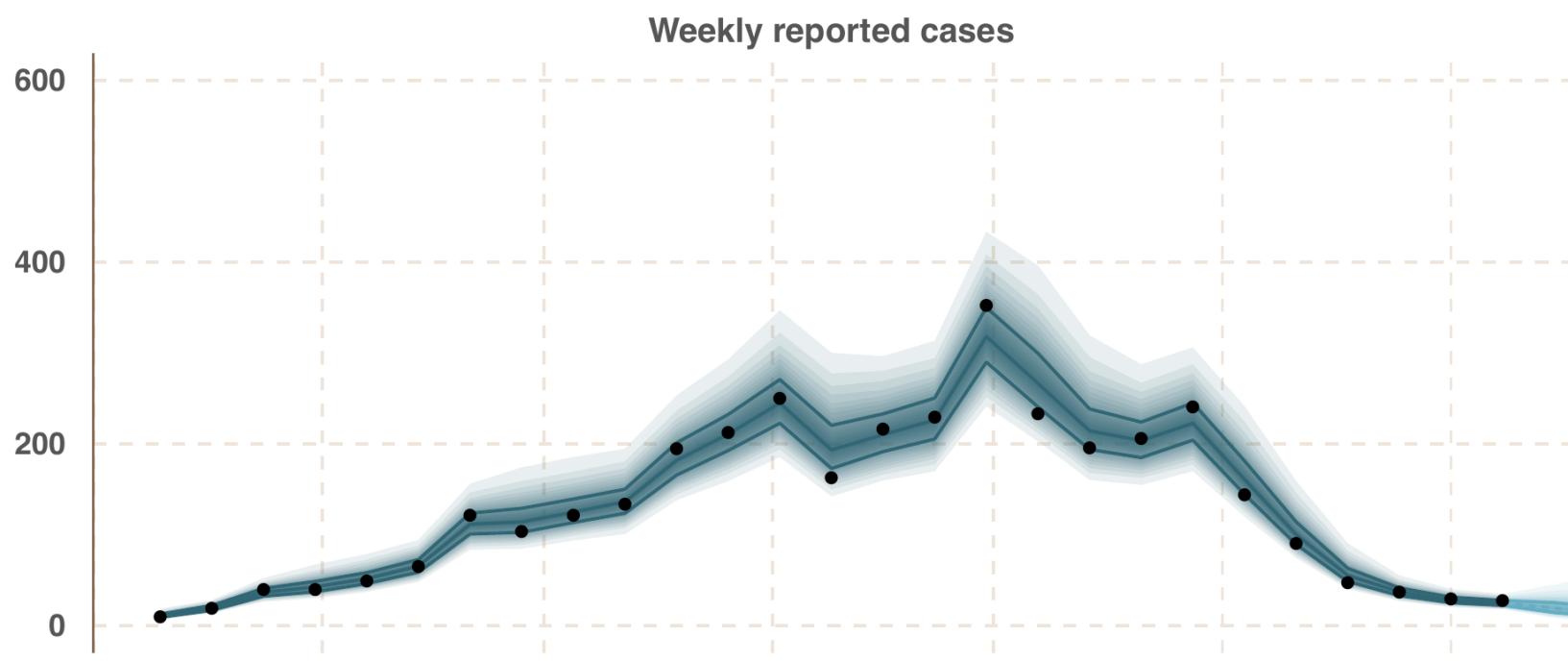












ntncmch.github.io

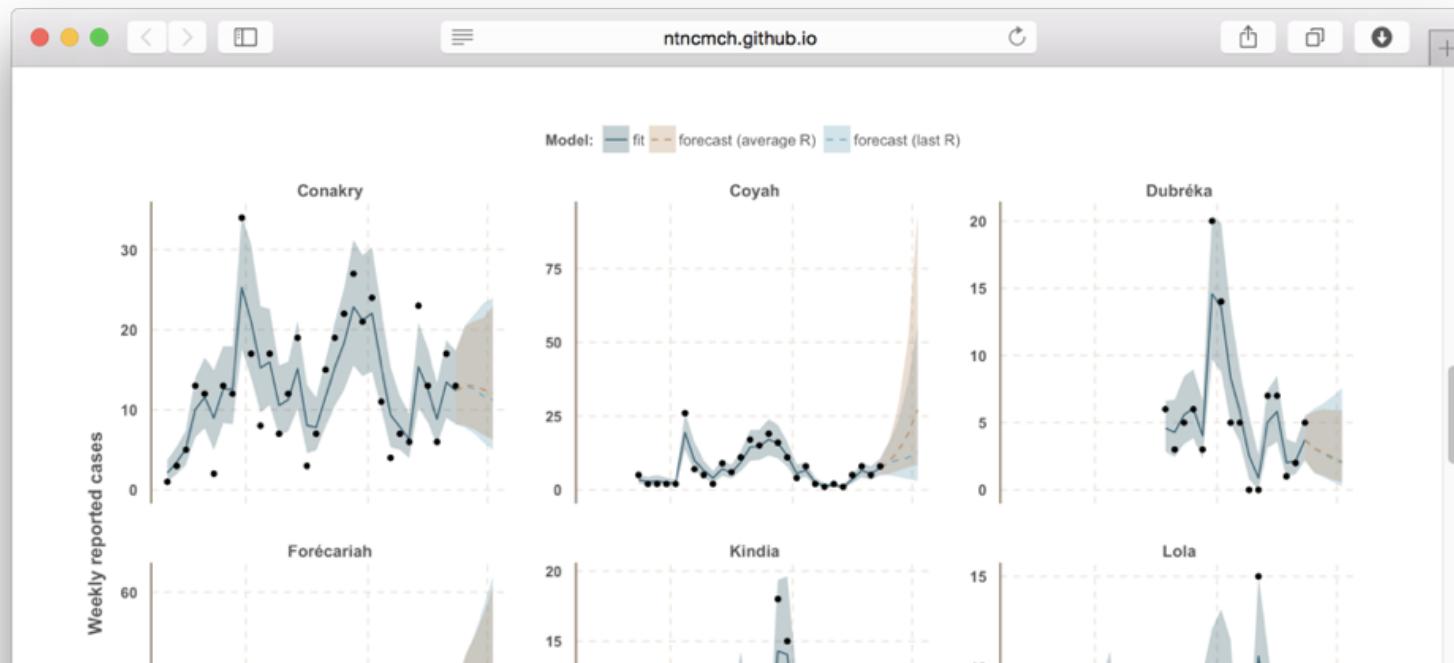
Visualisation and projections of the Ebola outbreak in West Africa

by the Centre for the Mathematical Modelling of Infectious Diseases
London School of Hygiene & Tropical Medicine

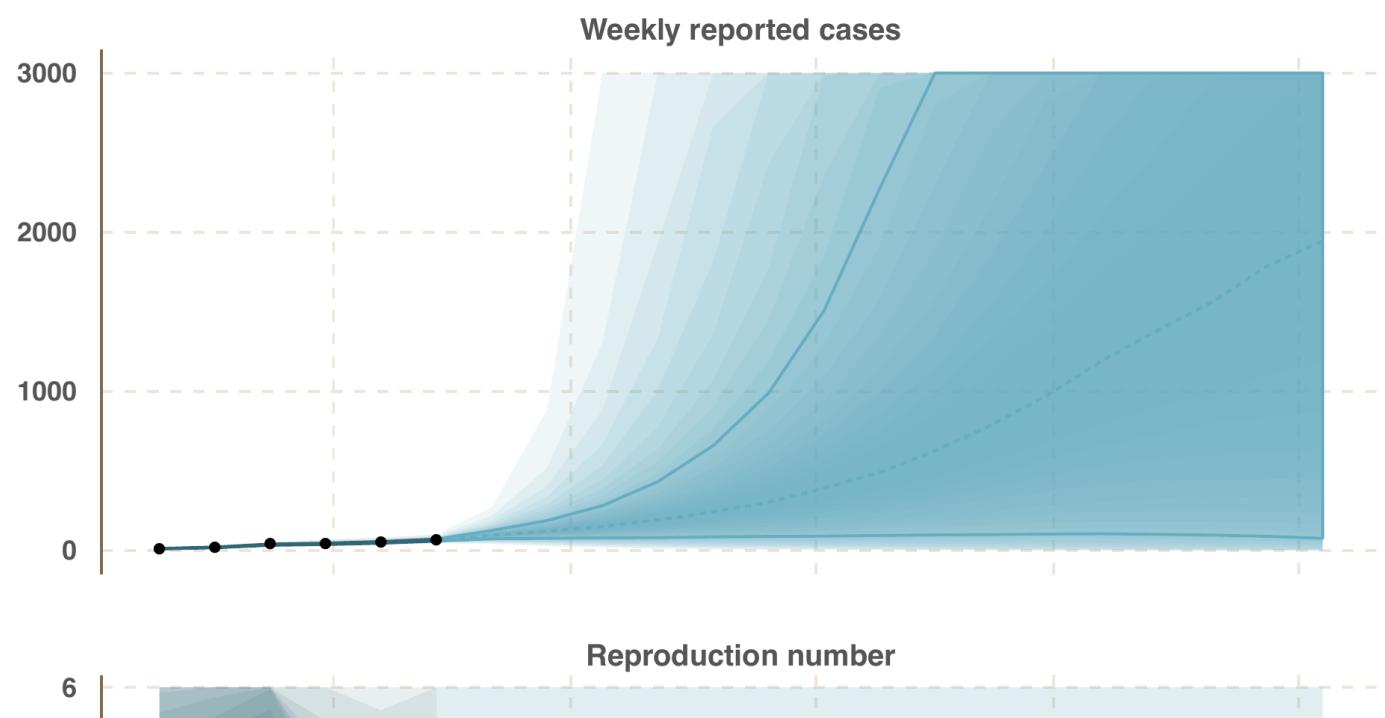
- [Latest weekly reports](#)
- [Modelling and projections](#)
- [Interactive maps](#)
- [Motivation](#)
- [Funding](#)

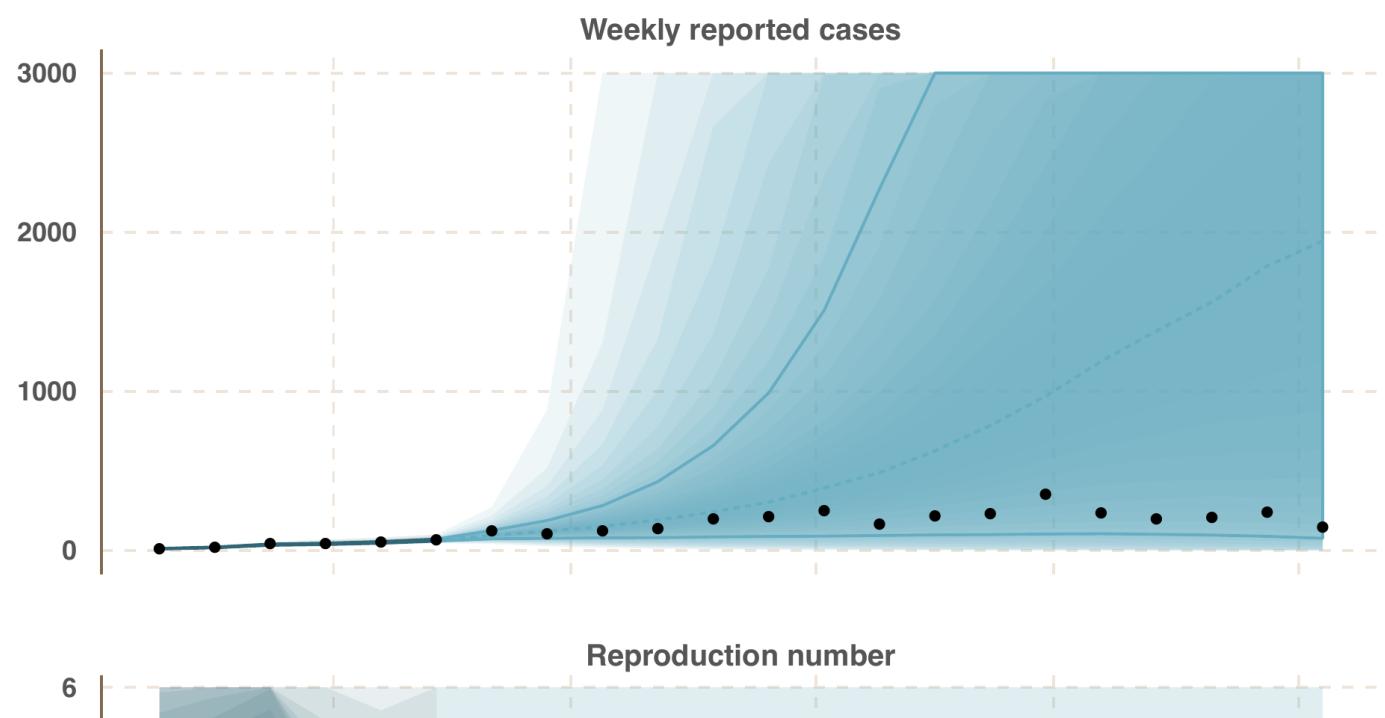
Latest weekly reports

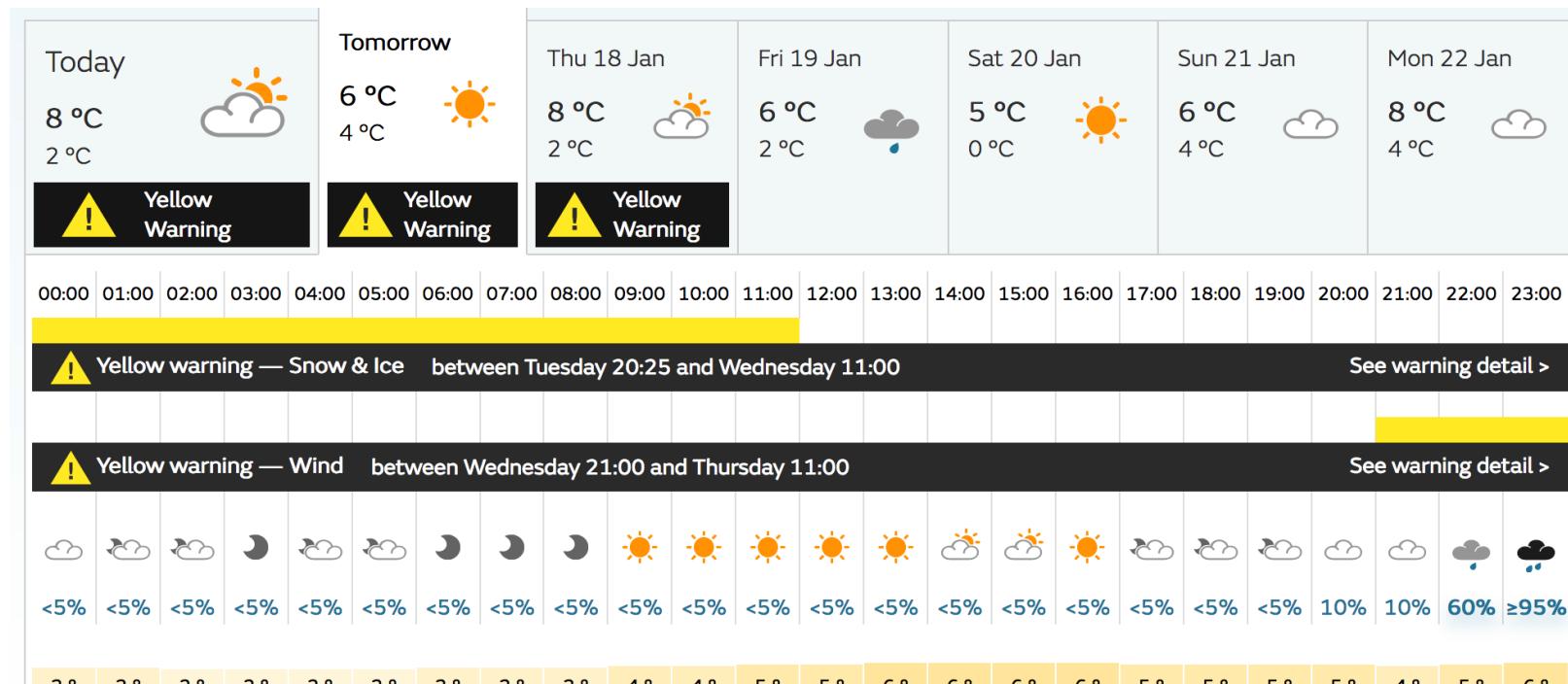
- Liberia (up to 15 March 2015): view [online version](#) or download [pdf slides](#)
- Sierra Leone (up to 15 March 2015): view [online version](#) or download [pdf slides](#)
- Guinea (up to 15 March 2015): view [online version \(French version\)](#) or download [pdf slides \(French version\)](#)

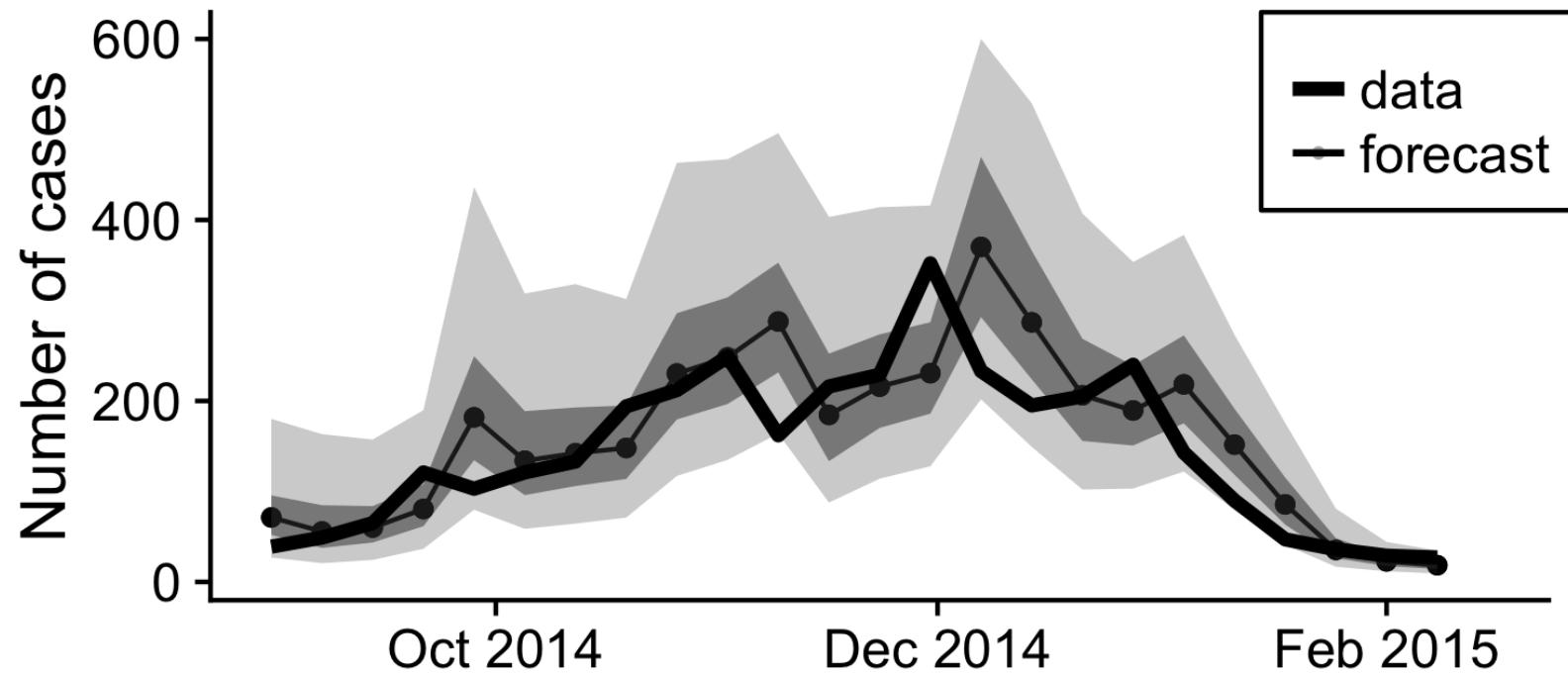


Assessing forecasts

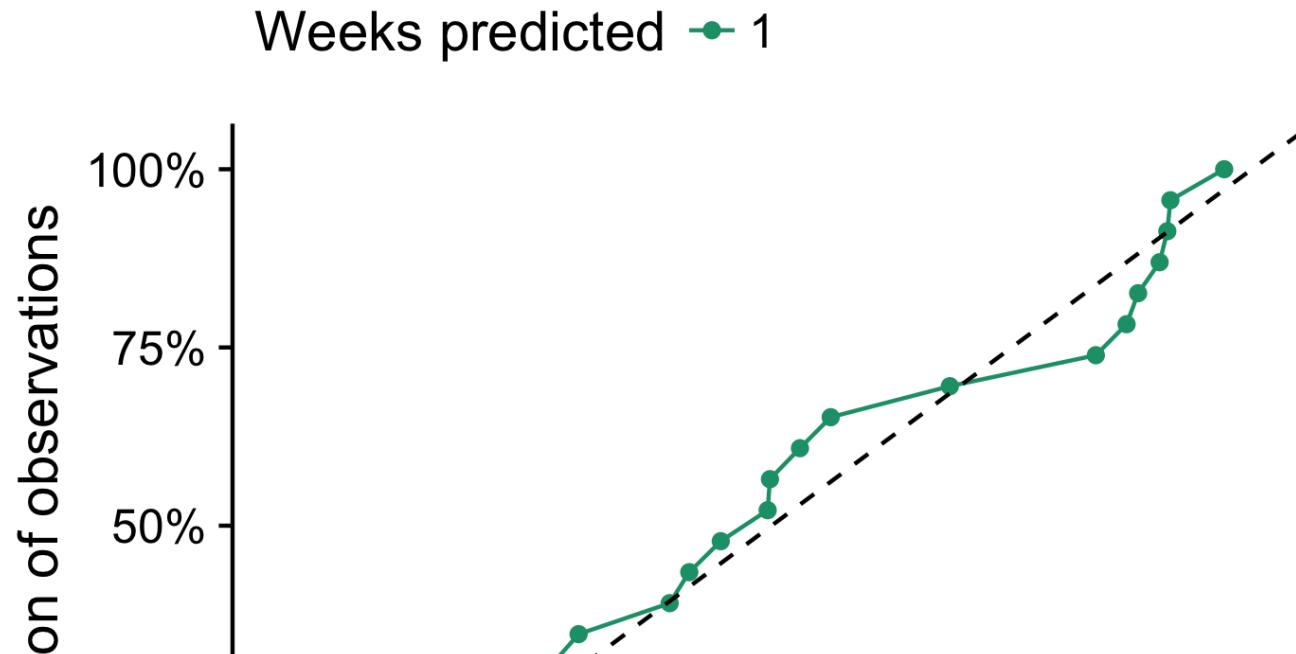




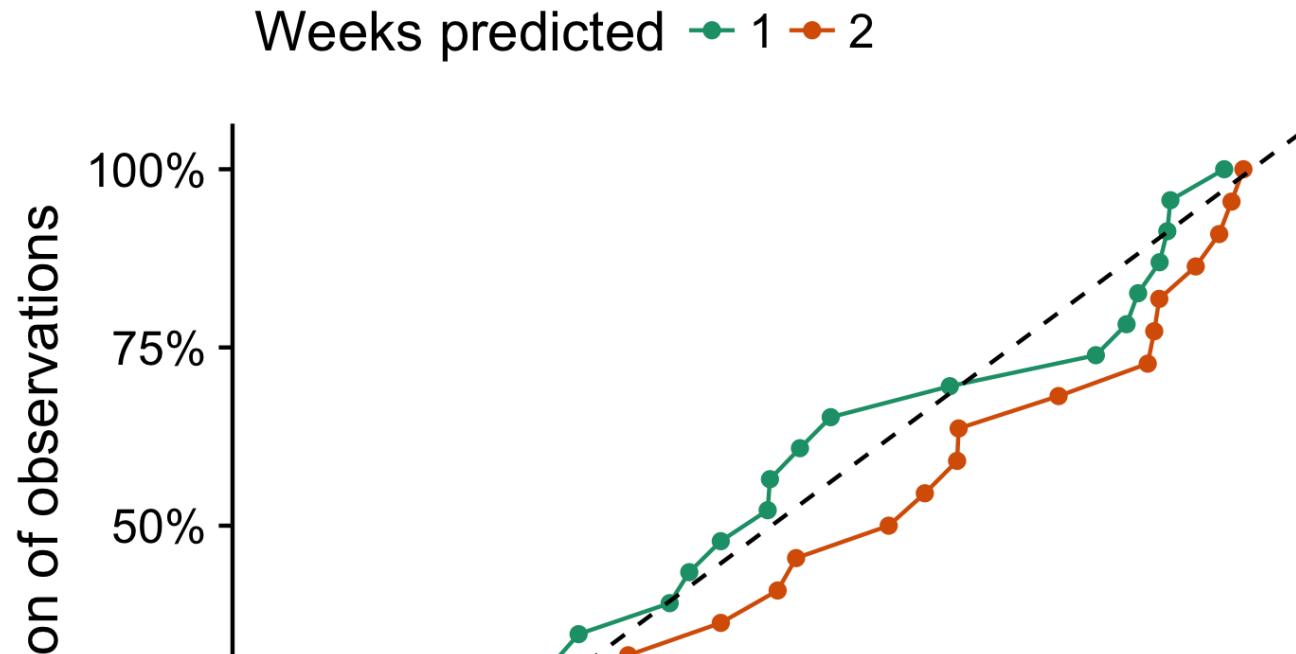




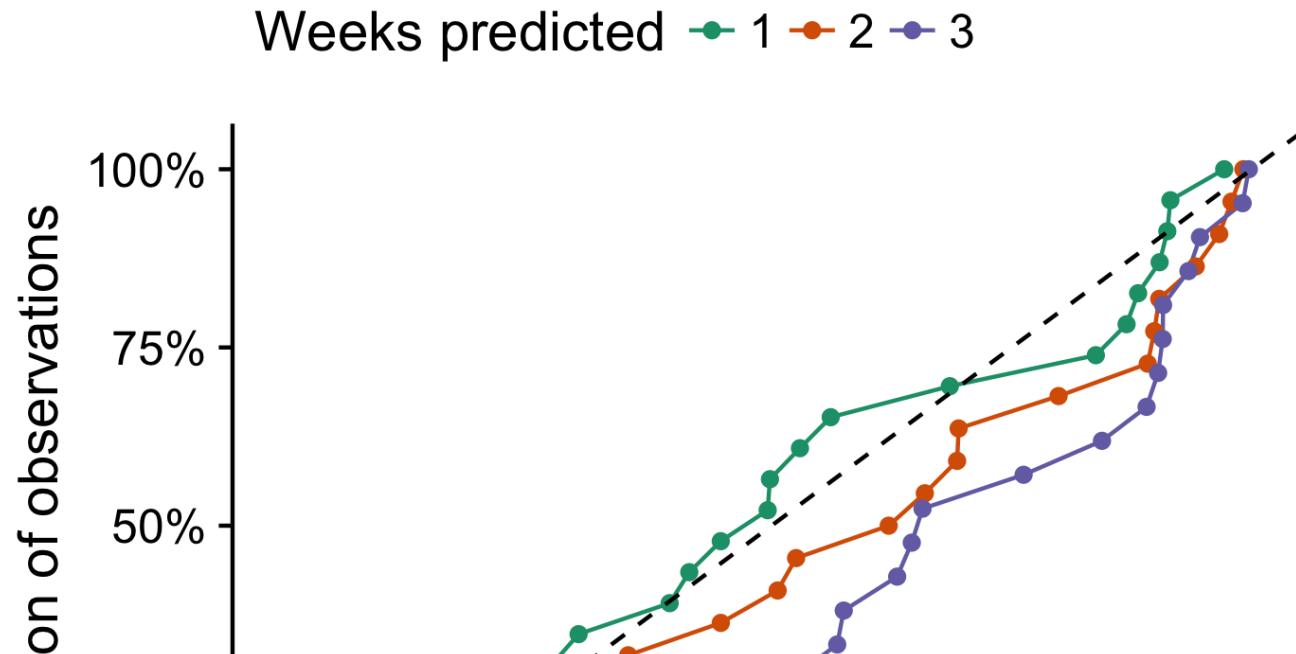
Reliability plot



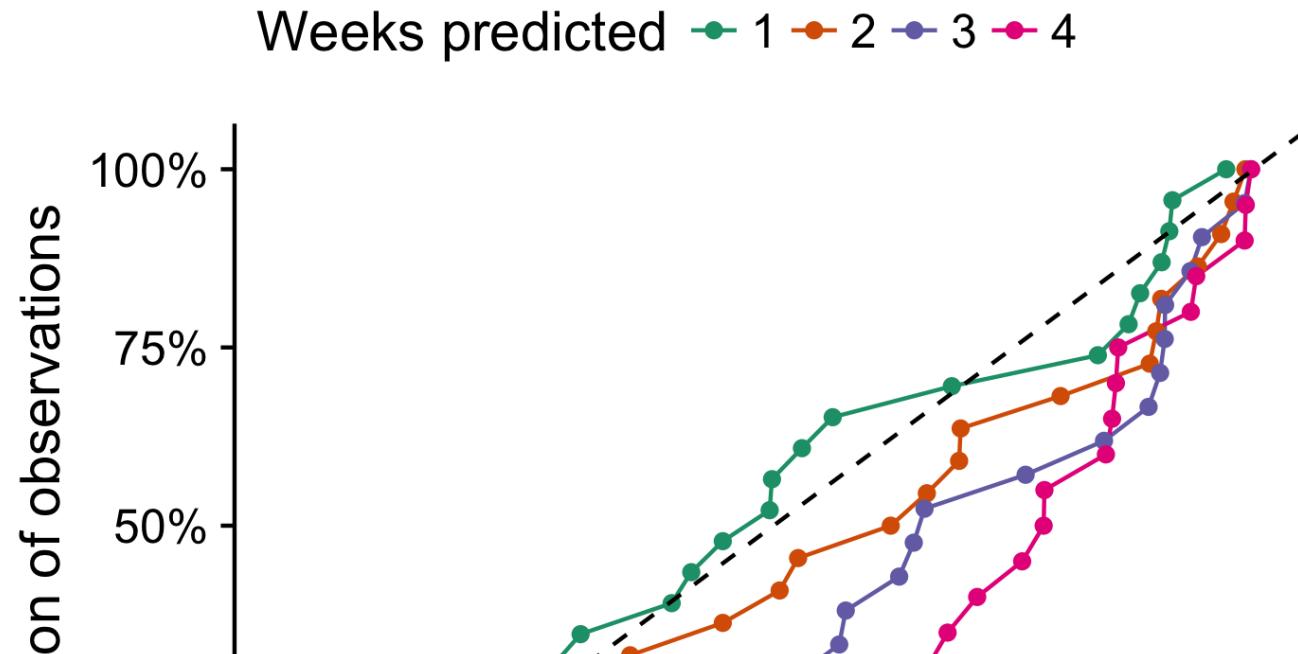
Reliability plot



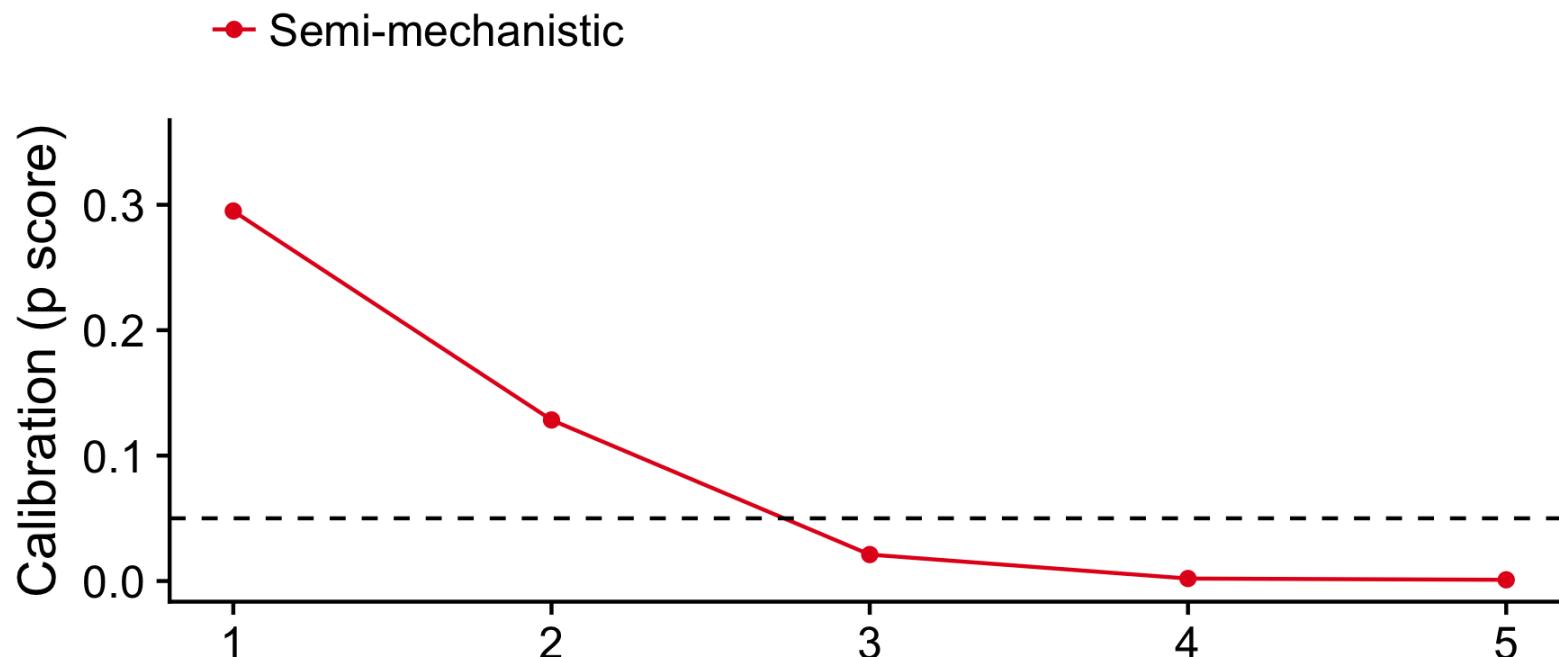
Reliability plot



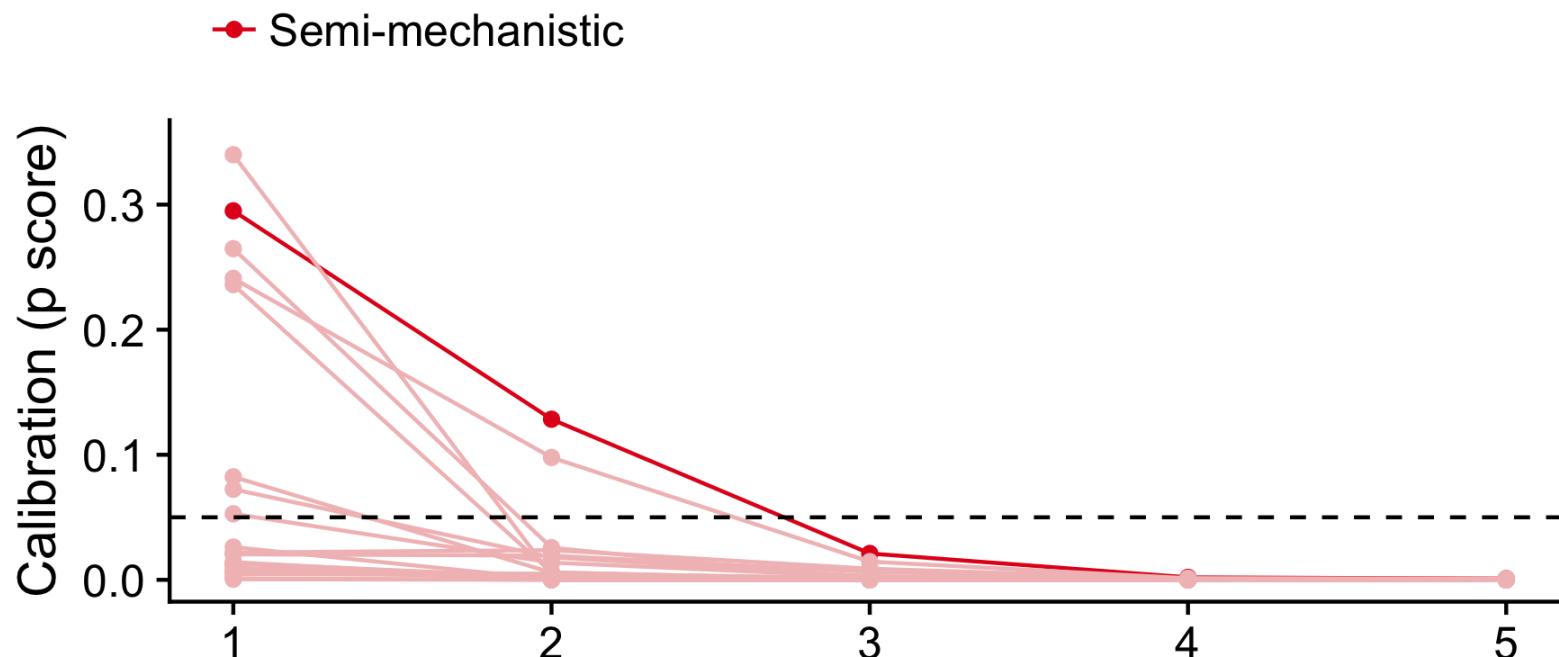
Reliability plot



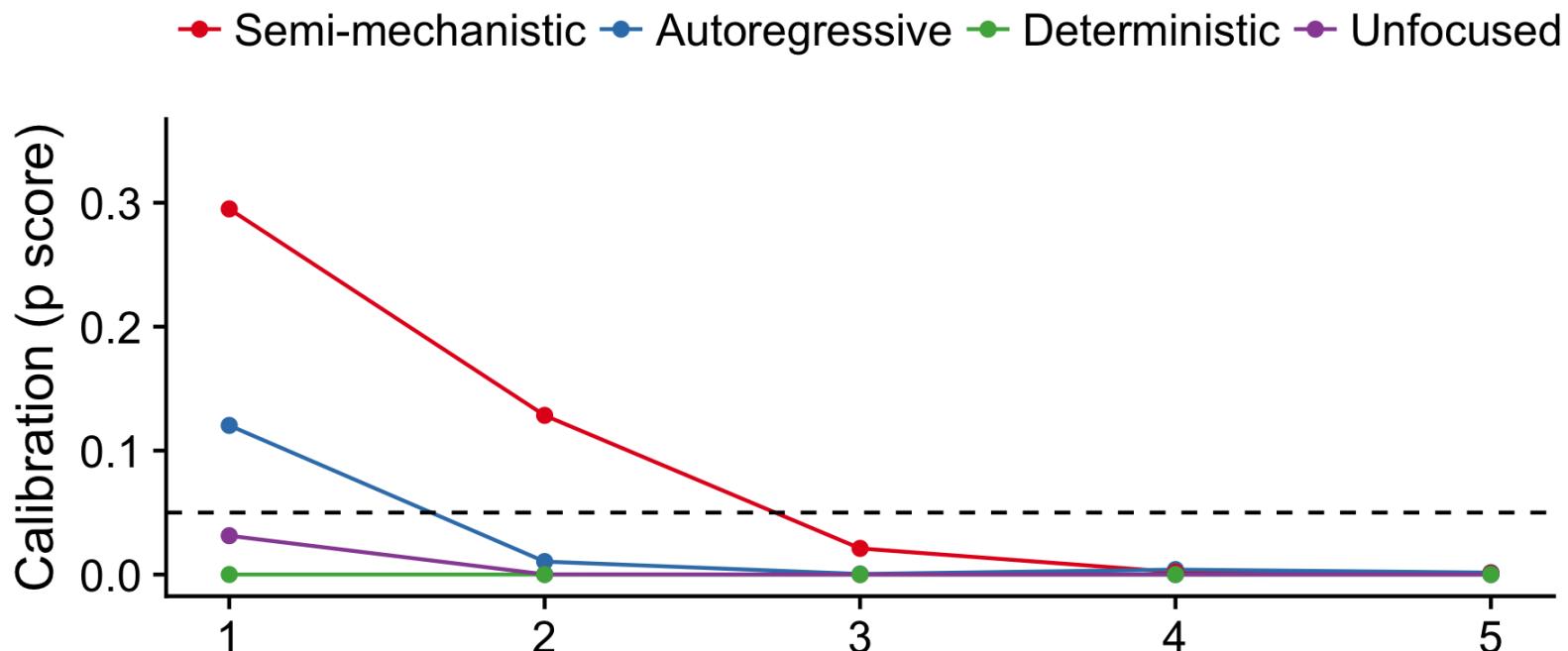
Calibration: Compatibility of forecasts and observations.



Calibration: Compatibility of forecasts and observations.



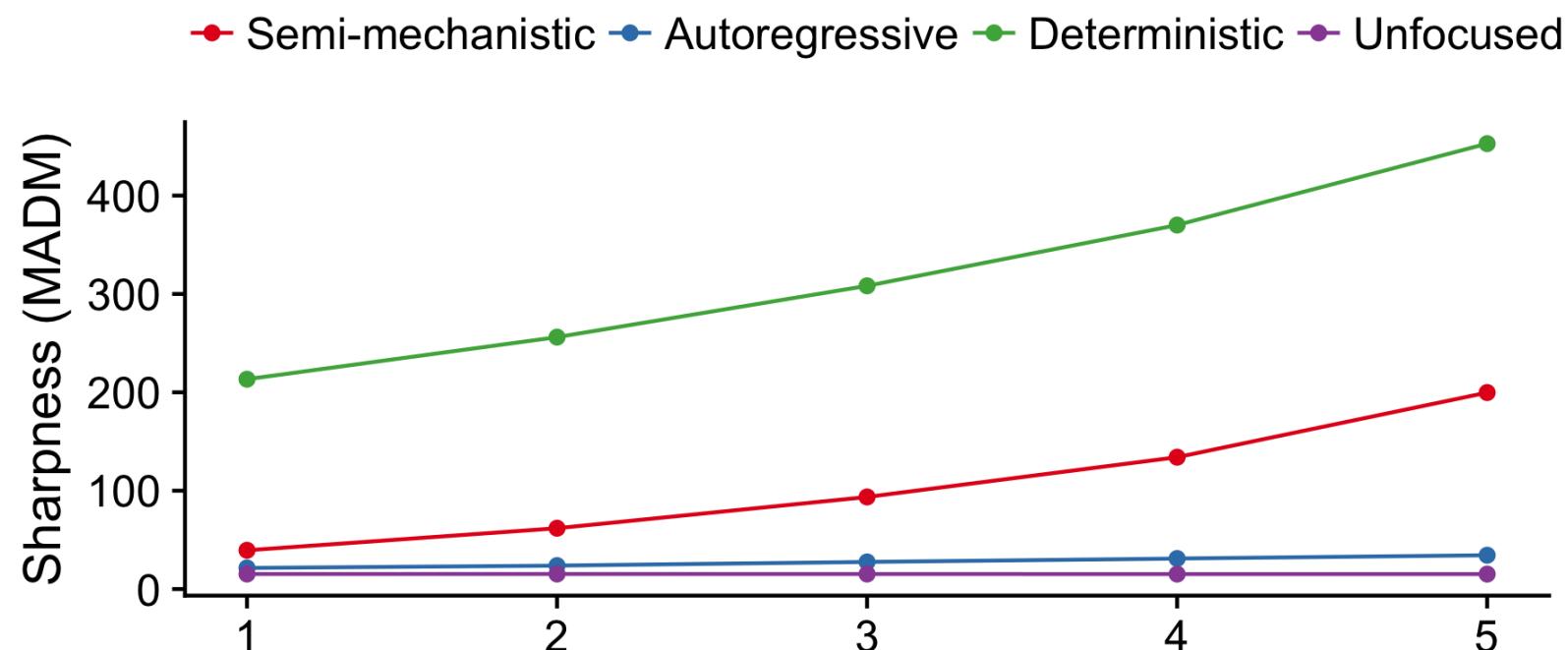
Calibration: Compatibility of forecasts and observations.



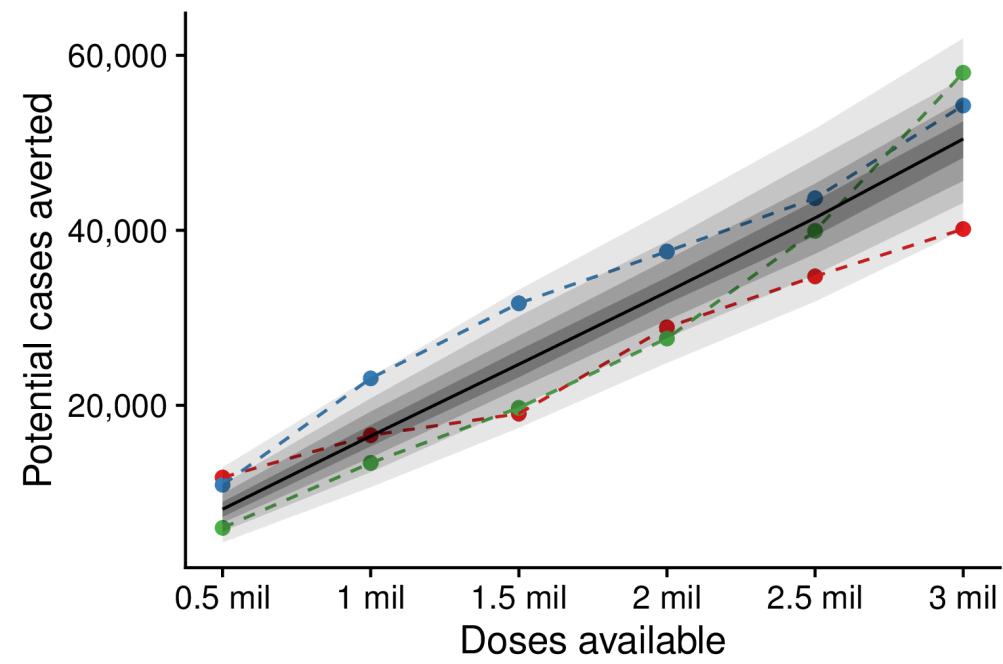
"Evaluate predictive performance on the basis of
maximising the sharpness of the predictive distribution
subject to calibration"

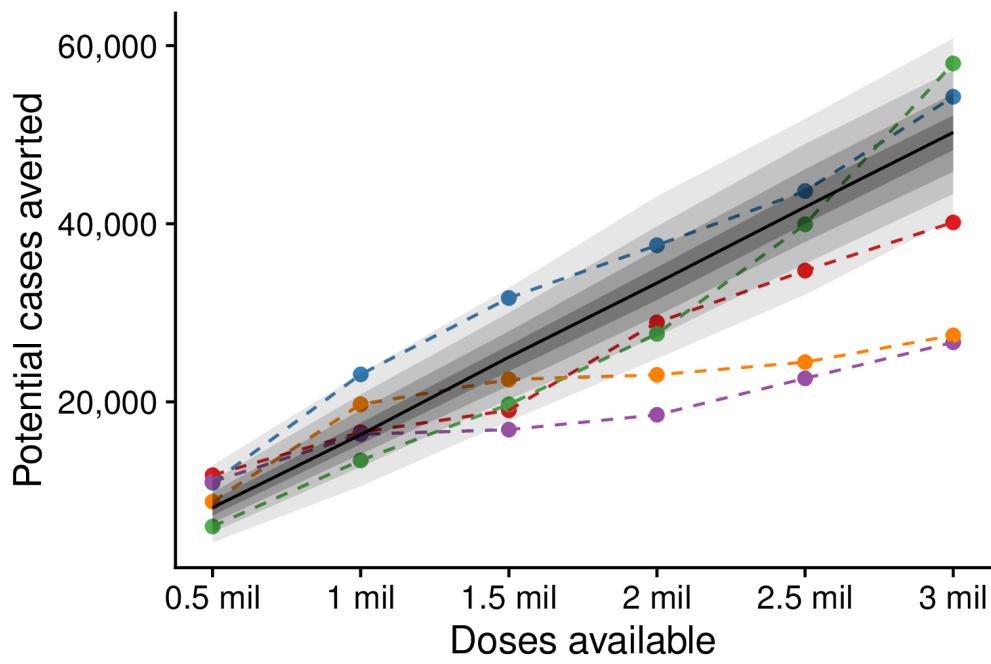
Gneiting et al., *J R Stat Soc B* (2007)

Sharpness



Quality of forecasts vs quality of decisions





Outlook

Forecasts are becoming part of outbreak response

TOWARDS EPIDEMIC PREDICTION:
FEDERAL EFFORTS AND OPPORTUNITIES
IN OUTBREAK MODELING

Forecasting challenges

EBOLA CHALLENGE

Welcome to the RAPIDD Ebola challenge

Comparison of disease forecasting models



DARPA Forecasting Chikungunya Challenge

Epidemic Prediction Initiative **BETA**

LOGIN CREATE AN AC

FluSight 2016-17

Home

National Forecasts

FluSight: Seasonal Influenza Forecasting

Influenza (flu) is a respiratory virus that can result in illness ranging from mild to severe. Each year, millions of people get sick with influenza, thousands are hospitalized and thousands of people die from flu.



DENGUE FORECASTING

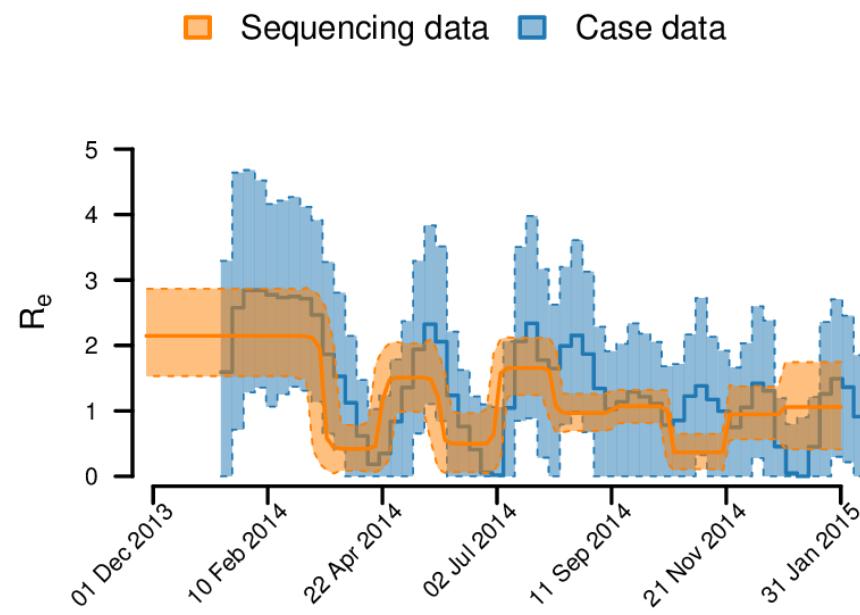
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

HOME NEWS ABOUT SEARCH

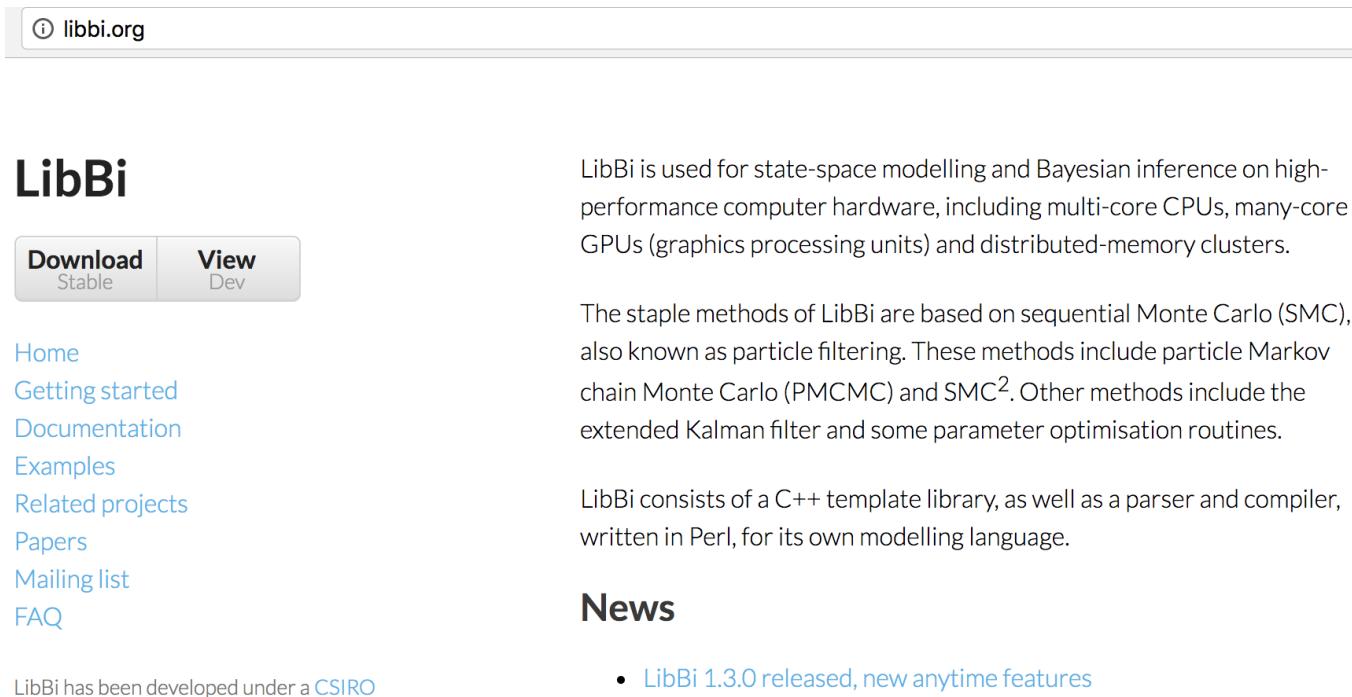
Welcome to the Dengue Forecasting project website. This site is designed specifically for the data, rules and background about the effort.

Forecasting methodology is underdeveloped

Need methods to **select the best model** and
combine all available **data streams**
(individual/spatial/genetic/media)



New tools



The screenshot shows the LibBi project page on libbi.org. At the top, there's a navigation bar with a logo and links for "Home", "Getting started", "Documentation", "Examples", "Related projects", "Papers", "Mailing list", and "FAQ". Below the navigation is a search bar with placeholder text "Search LibBi". The main content area features a large image of a computer monitor displaying a terminal window with the text "libbi> ./libbi -h". To the right of the image, there's a section titled "What is LibBi?" with a brief description and a "Read more" link. Further down, there's a "Download" section with "Stable" and "Dev" tabs, and a "View" section with "Stable" and "Dev" tabs. A "News" section lists recent updates, and a "Contact" section provides links for GitHub, Stack Overflow, and the mailing list.

libbi.org

LibBi

[Download Stable](#) [View Dev](#)

[Home](#) [Getting started](#) [Documentation](#) [Examples](#) [Related projects](#) [Papers](#) [Mailing list](#) [FAQ](#)

What is LibBi?

LibBi is used for state-space modelling and Bayesian inference on high-performance computer hardware, including multi-core CPUs, many-core GPUs (graphics processing units) and distributed-memory clusters.

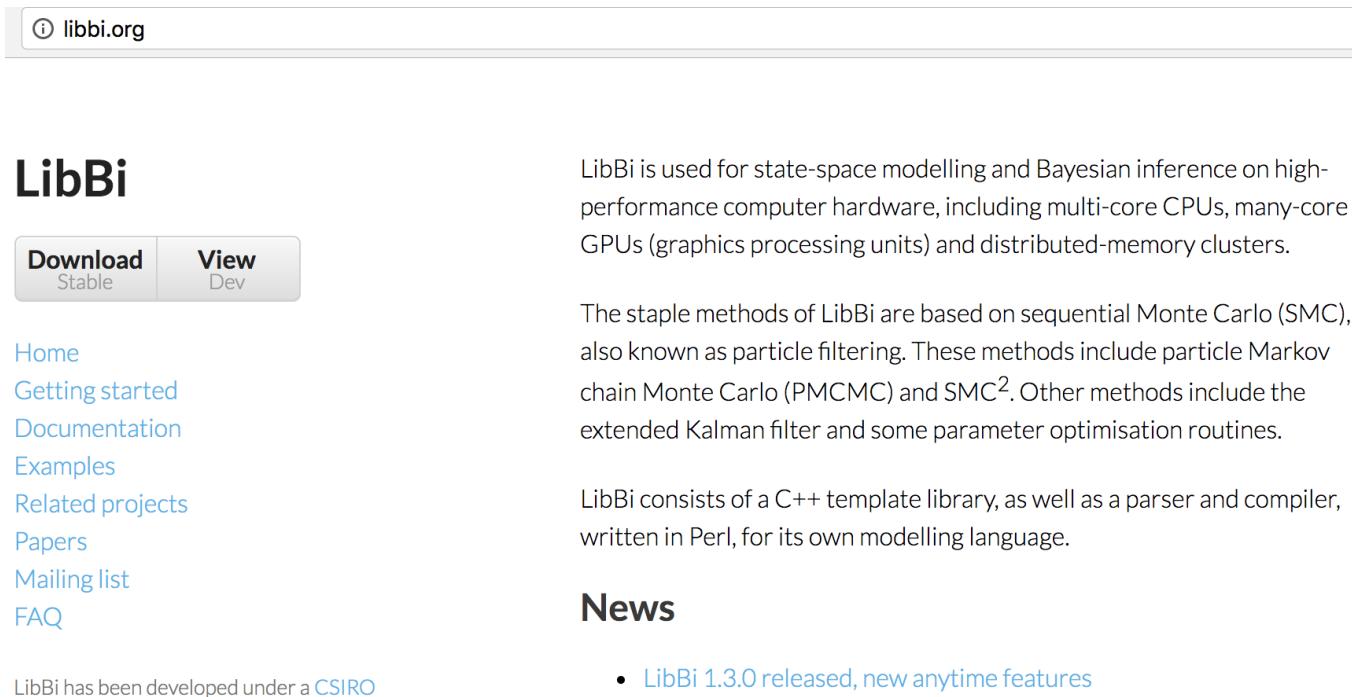
The staple methods of LibBi are based on sequential Monte Carlo (SMC), also known as particle filtering. These methods include particle Markov chain Monte Carlo (PMCMC) and SMC². Other methods include the extended Kalman filter and some parameter optimisation routines.

LibBi consists of a C++ template library, as well as a parser and compiler, written in Perl, for its own modelling language.

News

- LibBi 1.3.0 released, new anytime features

New tools



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libbi.org

LibBi

[Download](#) Stable [View](#) Dev

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Bayesian inference with state-space models in R



rbi: R Interface to LibBi

Provides a complete R interface to LibBi, a library for Bayesian inference (see <<http://libbi.org>> and <[doi:10.18637/jss.v067.i10](https://doi.org/10.18637/jss.v067.i10)> for more information). This includes functions for manipulating LibBi models, for reading and writing LibBi input/output files, for converting LibBi output to provide traces for use with the coda package, and for running LibBi from R.

Version:	0.9.0
Imports:	ncdf4 , data.table , reshape2
Suggests:	coda , R.rsp , testthat , stringi
Published:	2018-03-06
Author:	Pierre E. Jacob [aut], Anthony Lee [ctb], Lawrence M. Murray [ctb], Sebastian Funk [aut, cre]
Maintainer:	Sebastian Funk <sebastian.funk at lshtm.ac.uk>
BugReports:	https://github.com/libbi/RBi/issues
License:	GPL-3
URL:	https://github.com/libbi/RBi
NeedsCompilation:	no

Summary

- Real-time forecasts can aid decision making
- Meaningful forecasts are probabilistic
- Forecasts must be evaluated to establish reliability and limitations
- Some big challenges remain

Acknowledgements

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James Hensman (Lancaster), Lawrence Murray (Uppsala)



Thank you!

<http://sbfnk.github.io>
@sbfnk