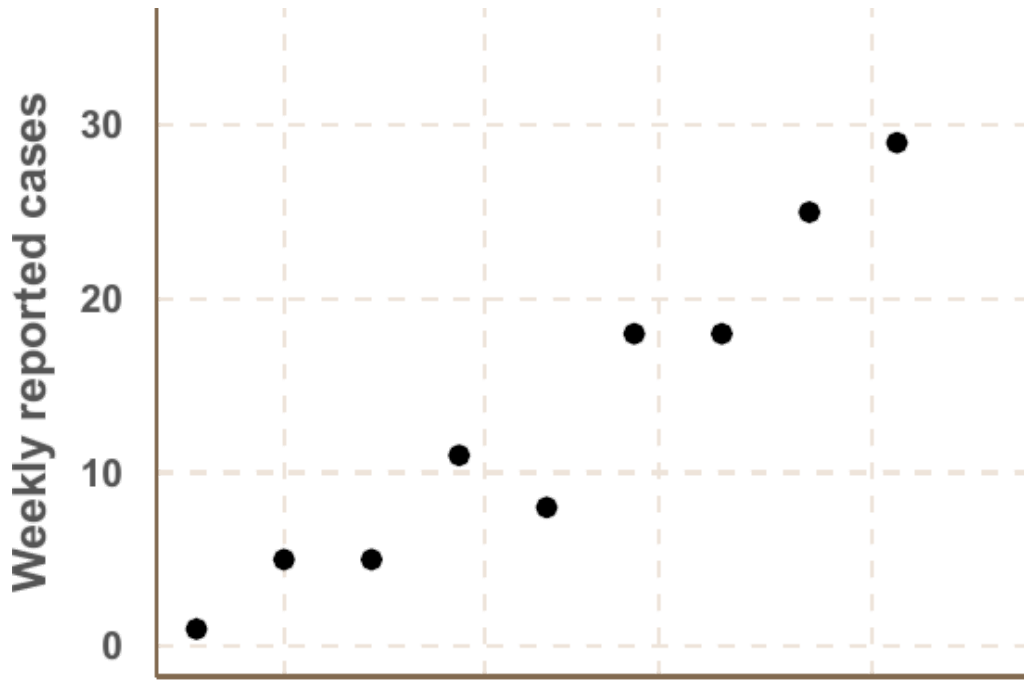
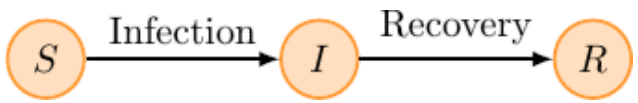
Real-time modelling and forecasting during infectious disease outbreaks

Sebastian Funk

22 March, 2018

recon gathering, London

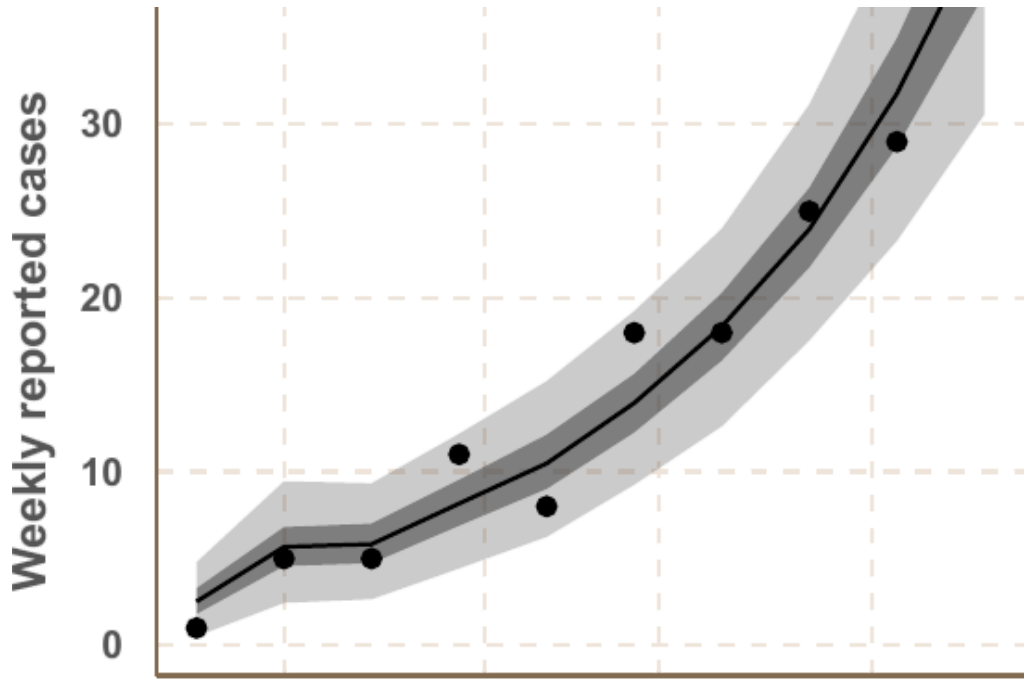

Weekly reported cases
30
20
10
0

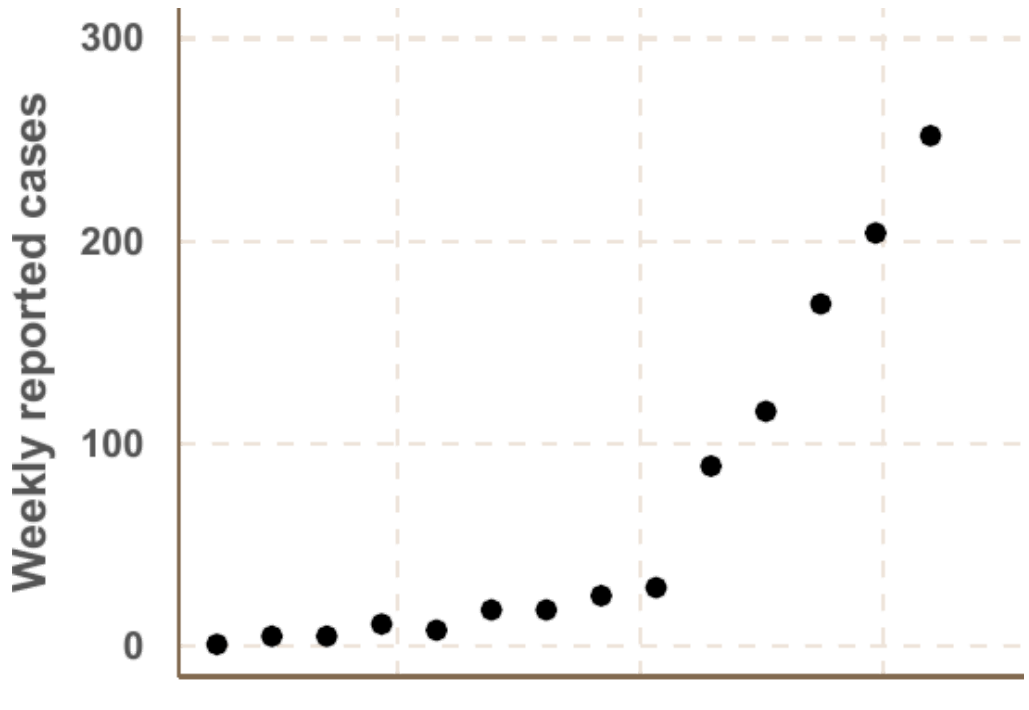


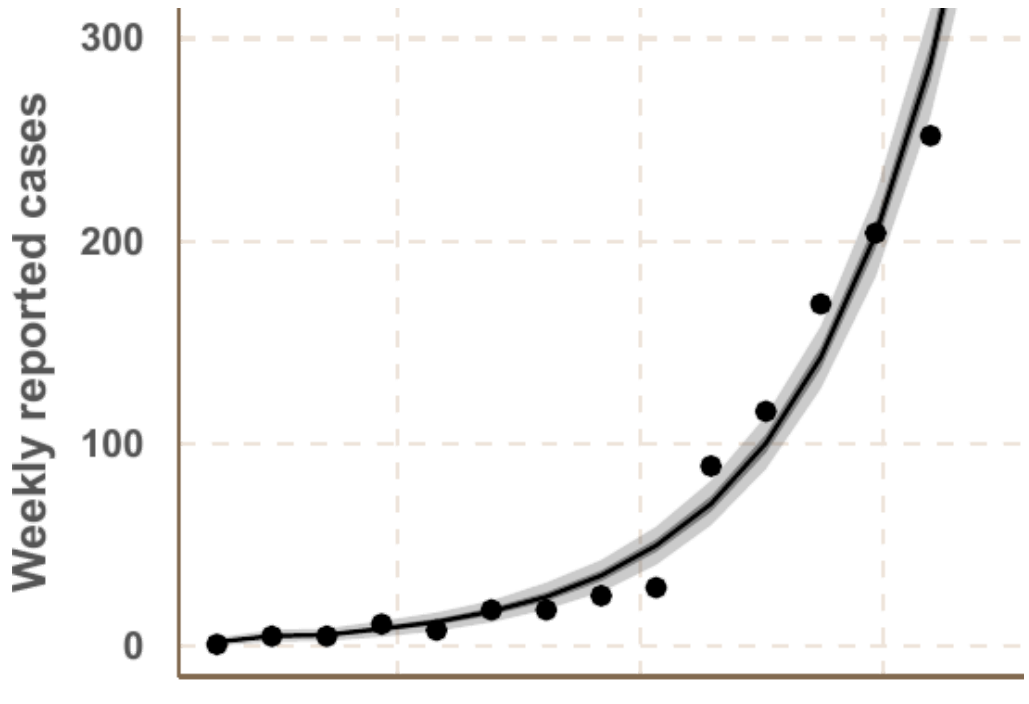
$$\dot{S} = -\beta \frac{S}{N} I$$

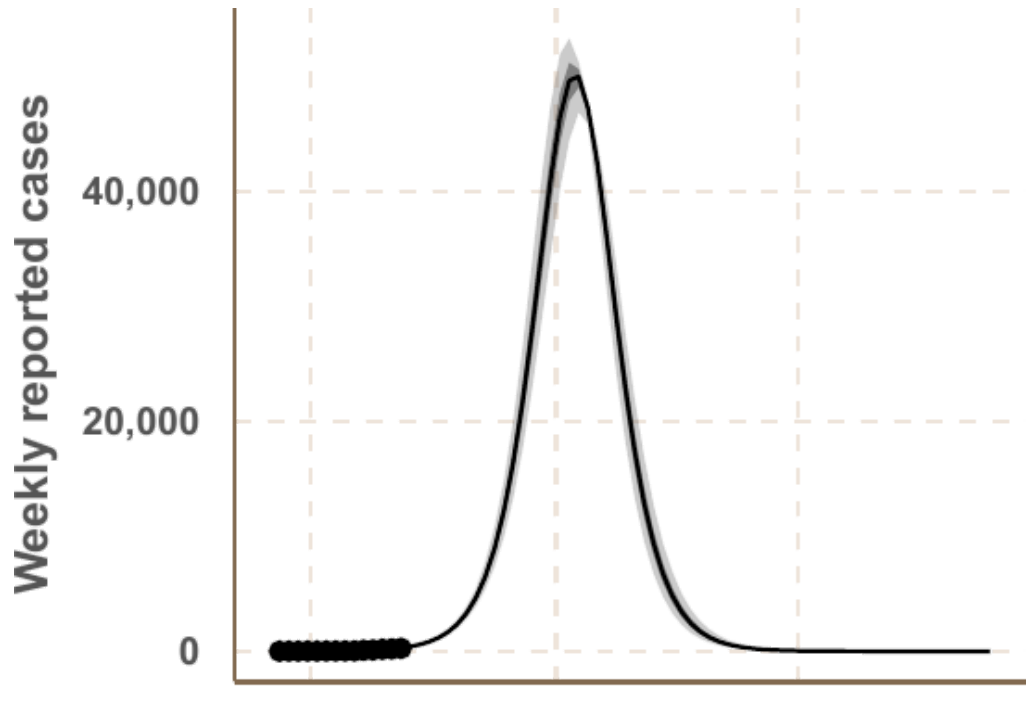
$$\dot{I} = +\beta \frac{S}{N} I - \gamma I$$

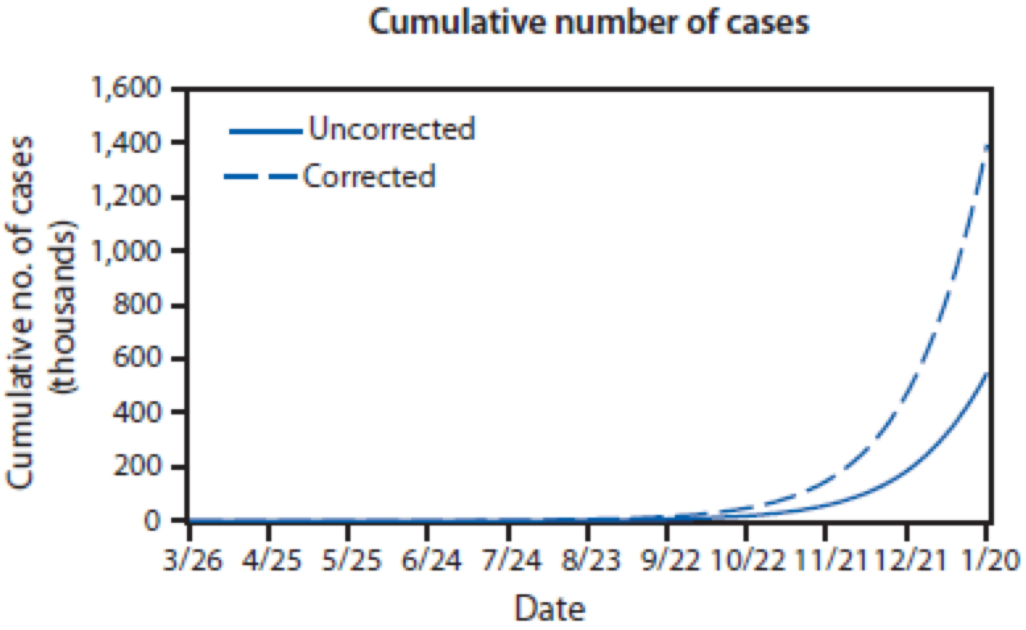
$$\dot{R} = +\gamma I$$


Weekly reported cases
30
20
10
0


Weekly reported cases
300
200
100
0


Weekly reported cases
300
200
100
0


Weekly reported cases
40,000
20,000
0



"[...] Liberia and Sierra Leone will have approximately

theguardian

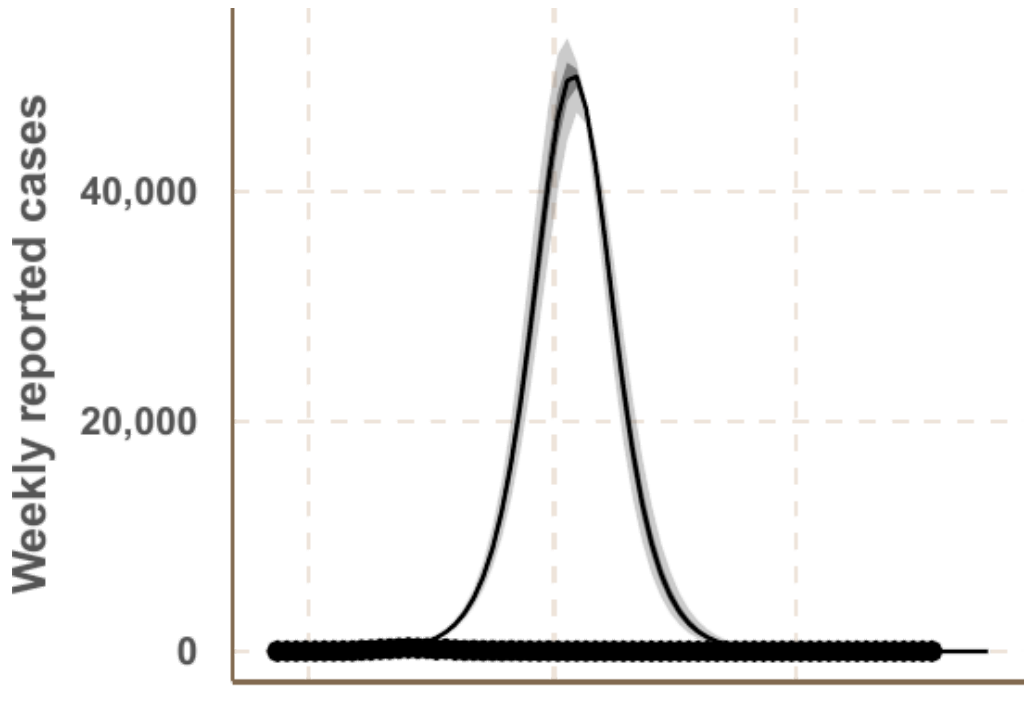
Ebola

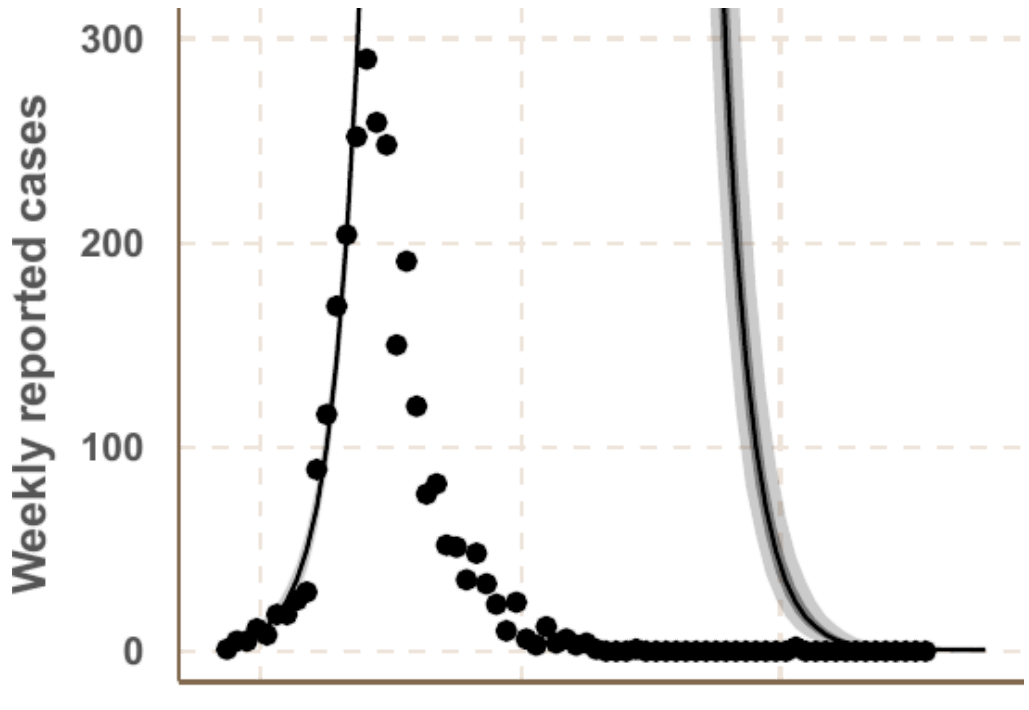
Up to 1.4m people could be infected with Ebola by January, CDC warns

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


Weekly reported cases
40,000
20,000
0

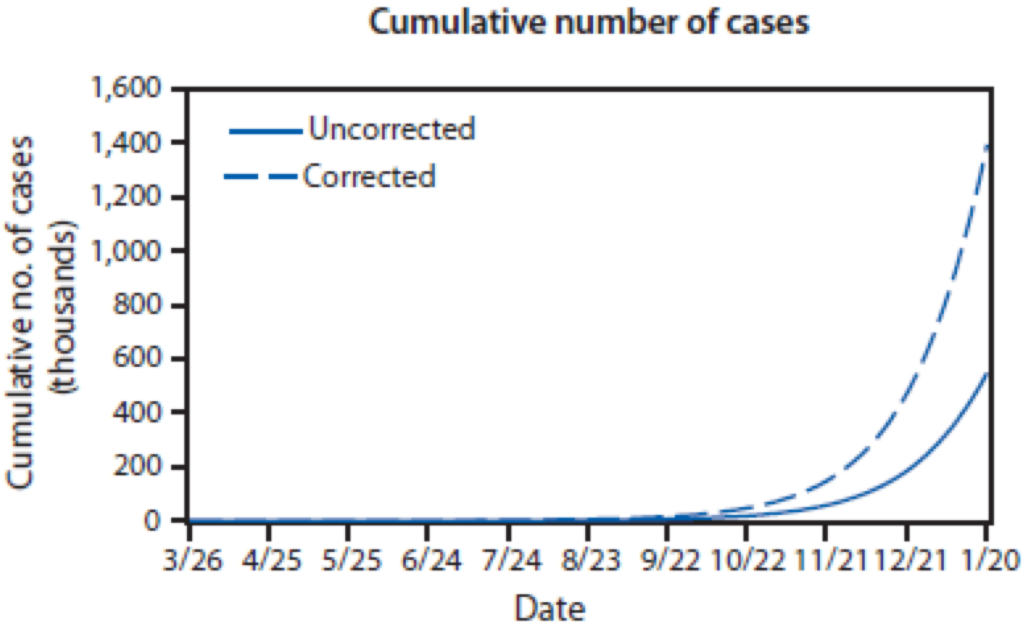

Weekly reported cases
300
200
100
0

nature International weekly journal of science

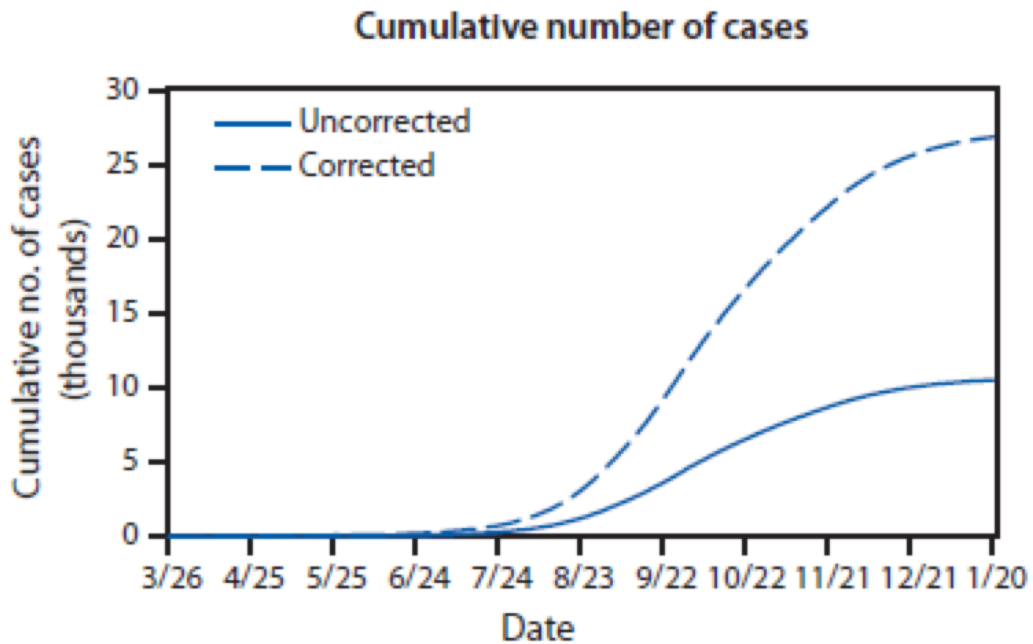
NATURE | NEWS

Models overestimate Ebola cases

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



"[...] Liberia and Sierra Leone will have approximately


Cumulative number of cases
Uncorrected
Corrected
Cumulative no. of cases (thousands)
30
25
20
15
10
5
0
3/26
4/25
5/25
6/24
7/24
8/23
9/22
10/22
11/21
12/21
1/20
Date

Towards Epidemic Prediction: Federal Efforts and Opportunities in Outbreak Modeling

PRODUCT OF THE

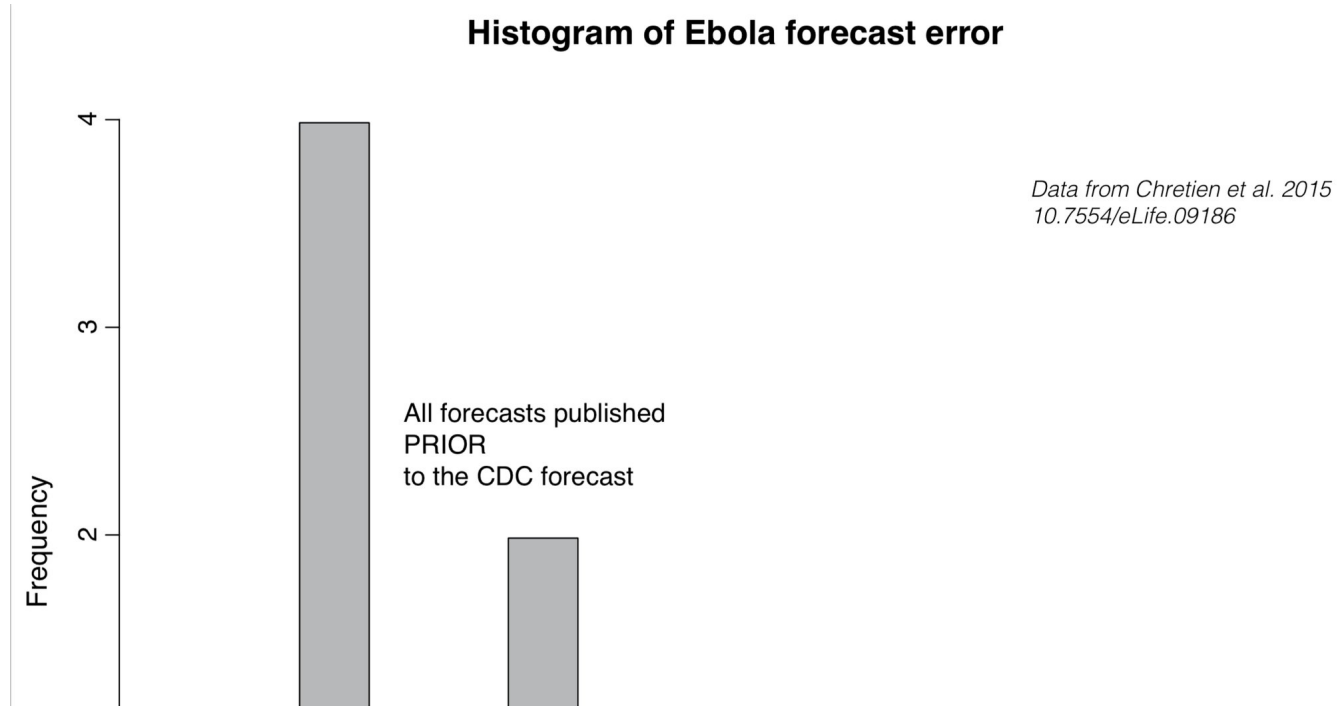
Pandemic Prediction and Forecasting
Science and Technology Working Group

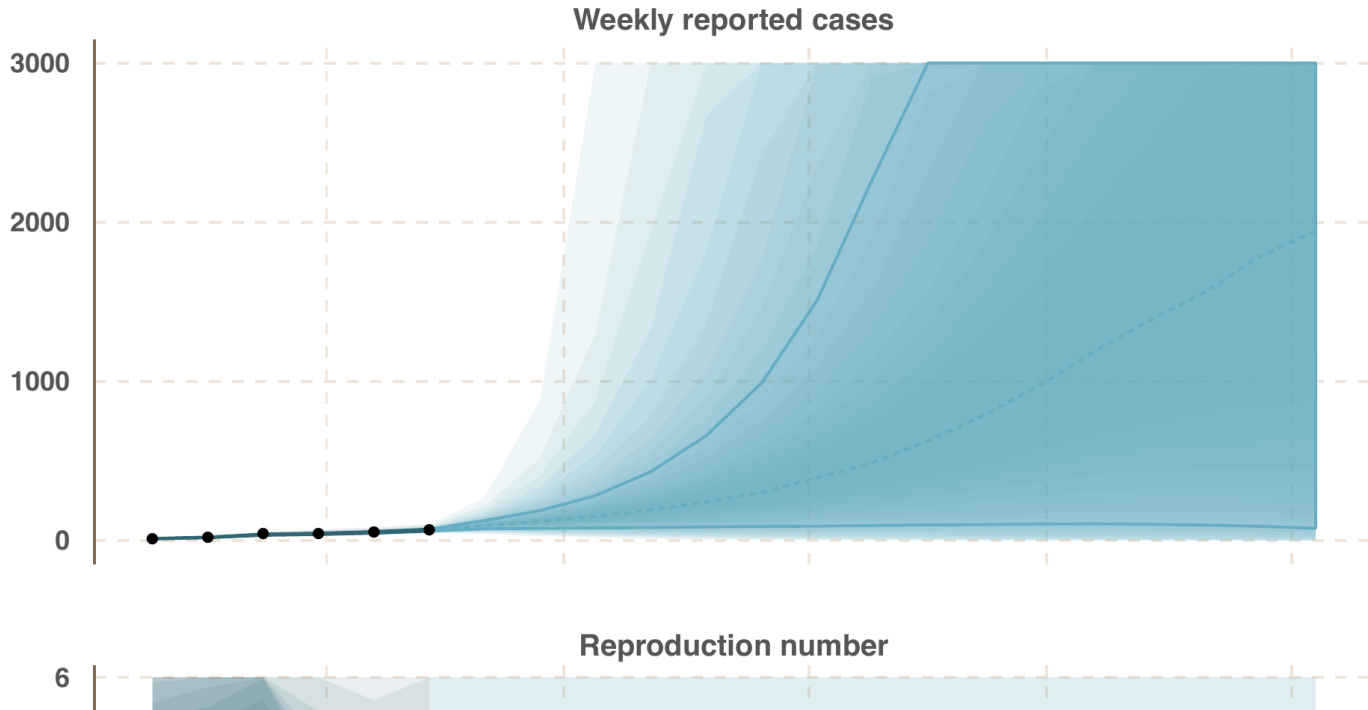
"A CDC model [...] was key to increasing the speed and scale of the US and global response.

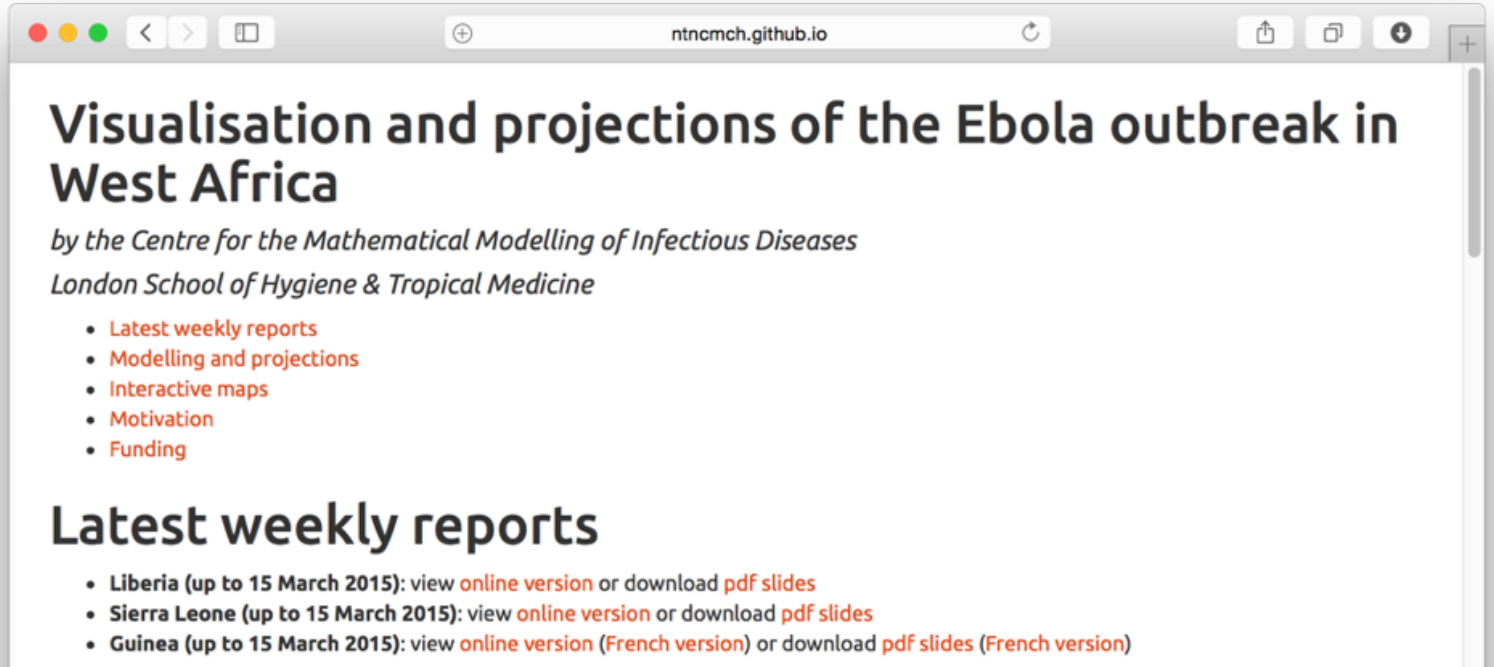
Frieden, 2015

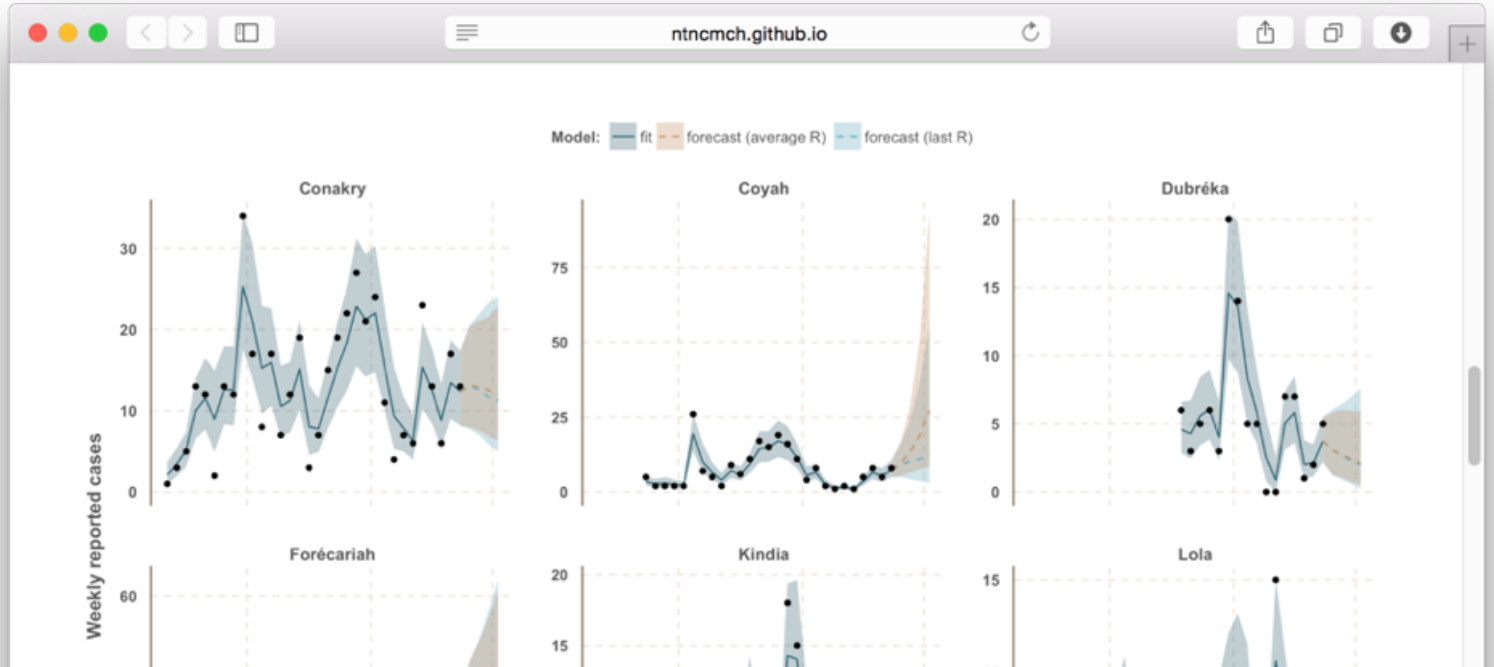
Key findings:

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"


Histogram of Ebola forecast error
Frequency
0
1
2
3
4
All forecasts published
PRIOR
to the CDC forecast
Data from Chretien et al. 2015
10.7554/eLife.09186


Weekly reported cases
3000
2000
1000
0
Reproduction number
6


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)

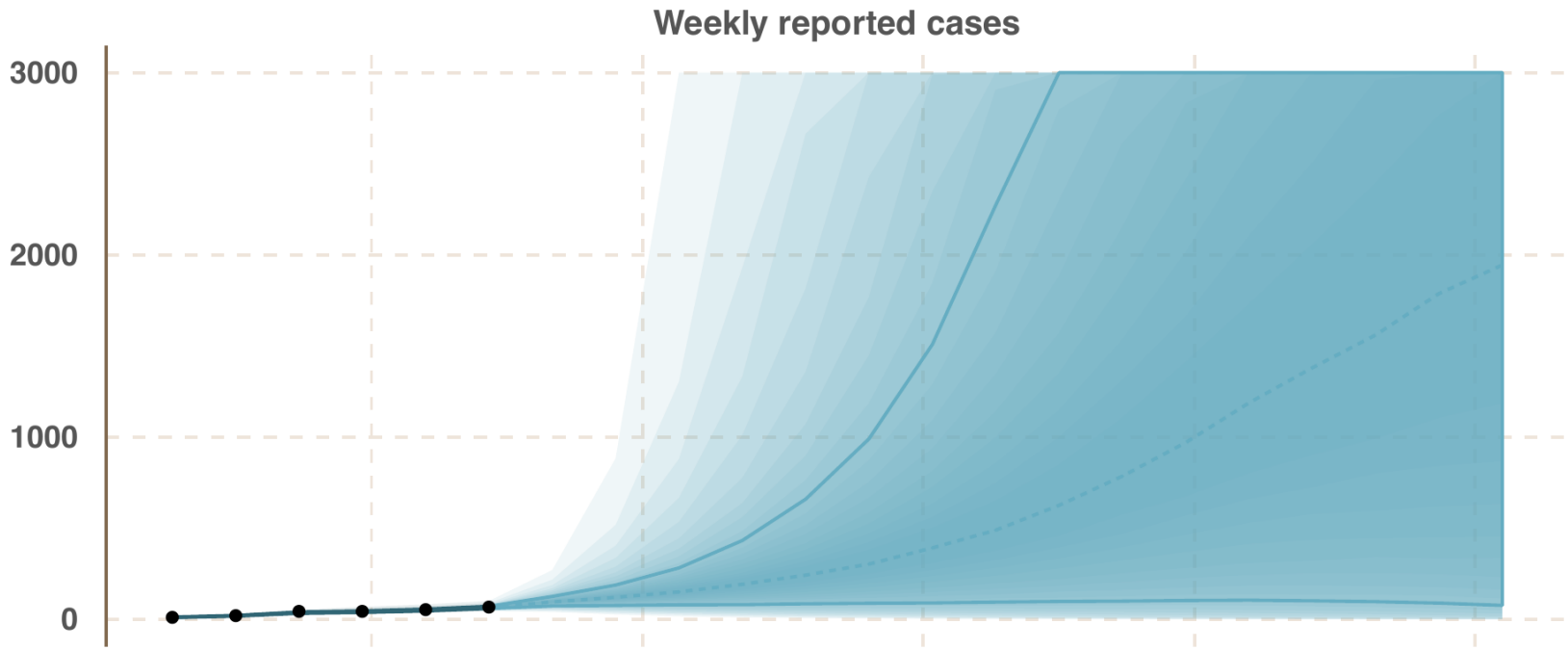

ntncmch.github.io
Model: fit forecast (average R) forecast (last R)
Conakry
Coyah
Dubréka
Forécariah
Kindia
Lola
Weekly reported cases

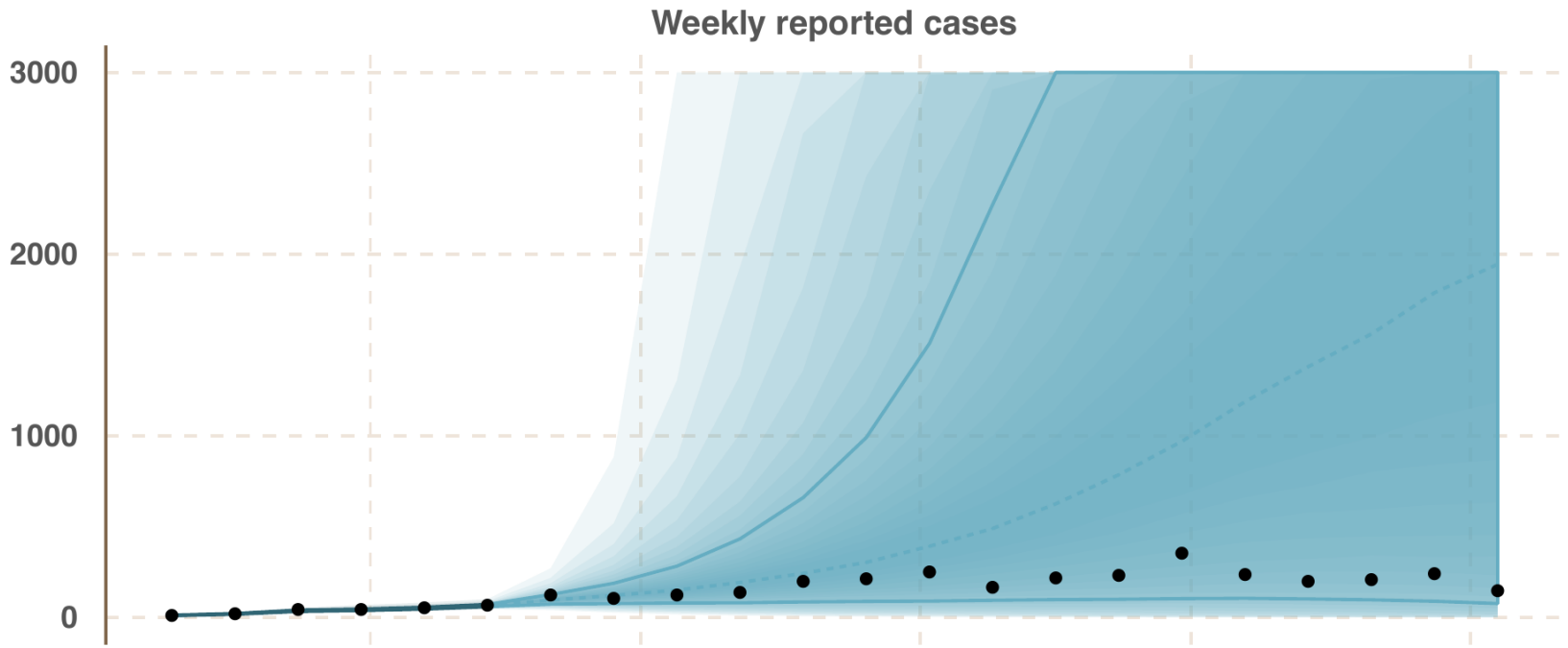
Uses of real-time forecasts in outbreaks

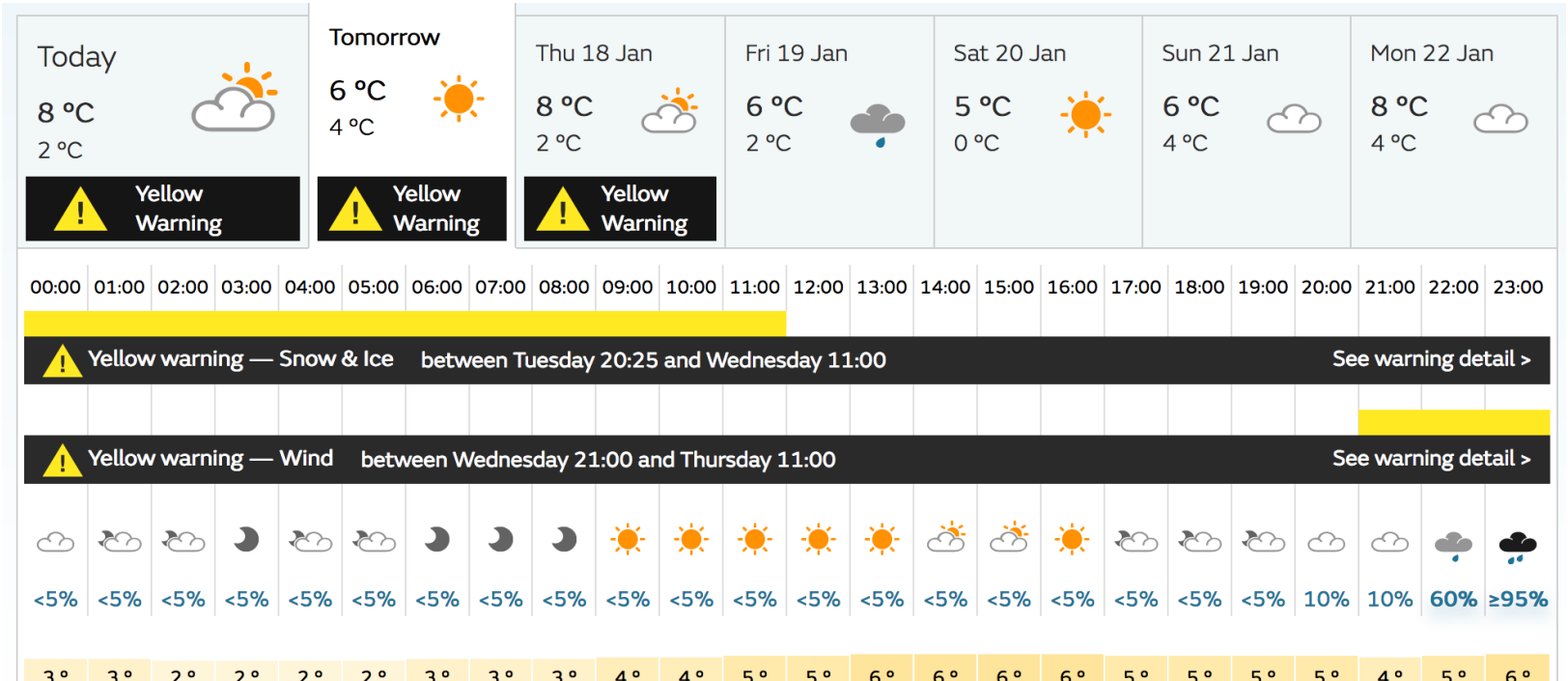
- Plan the scale of a response or intervention
- Allocate resources (e.g., geographically)
- Plan clinical trials

Challenges/opportunities

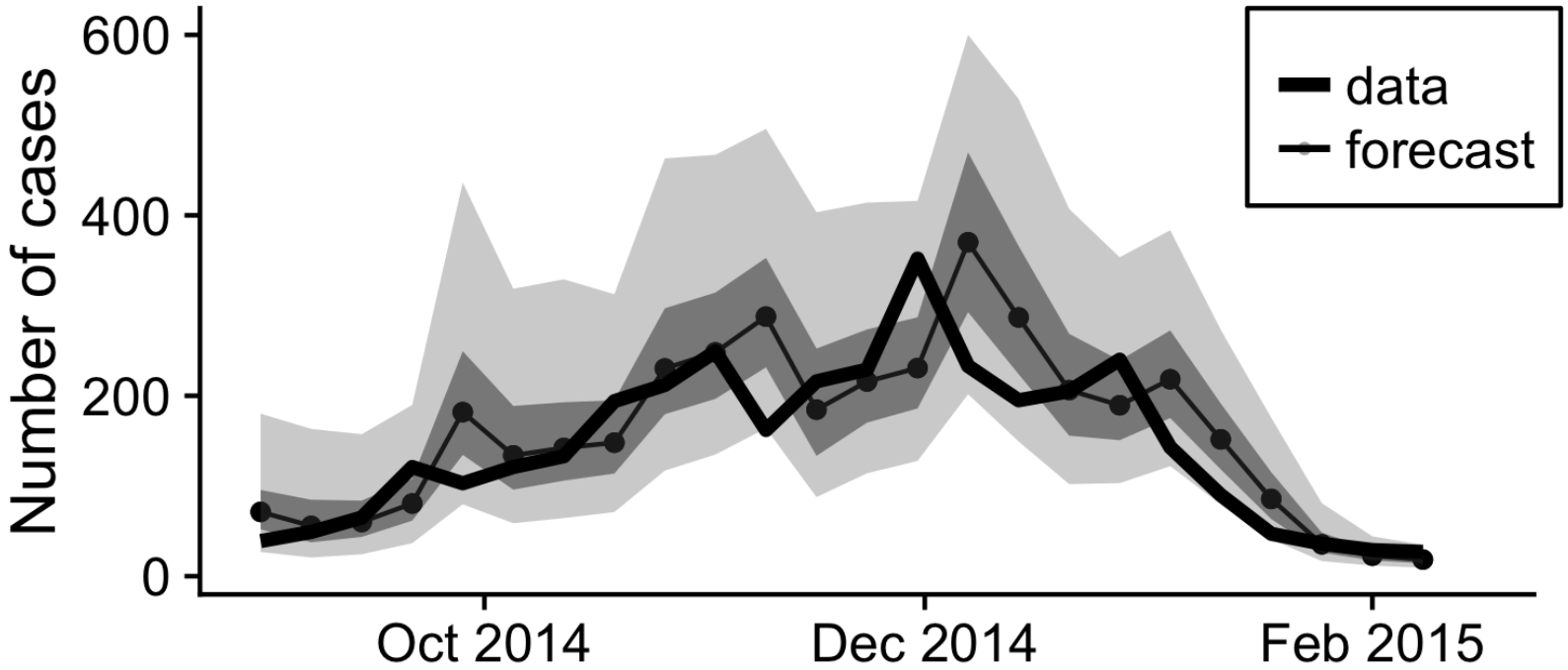
1. Evaluation of probabilistic forecasts


Weekly reported cases
3000
2000
1000
0

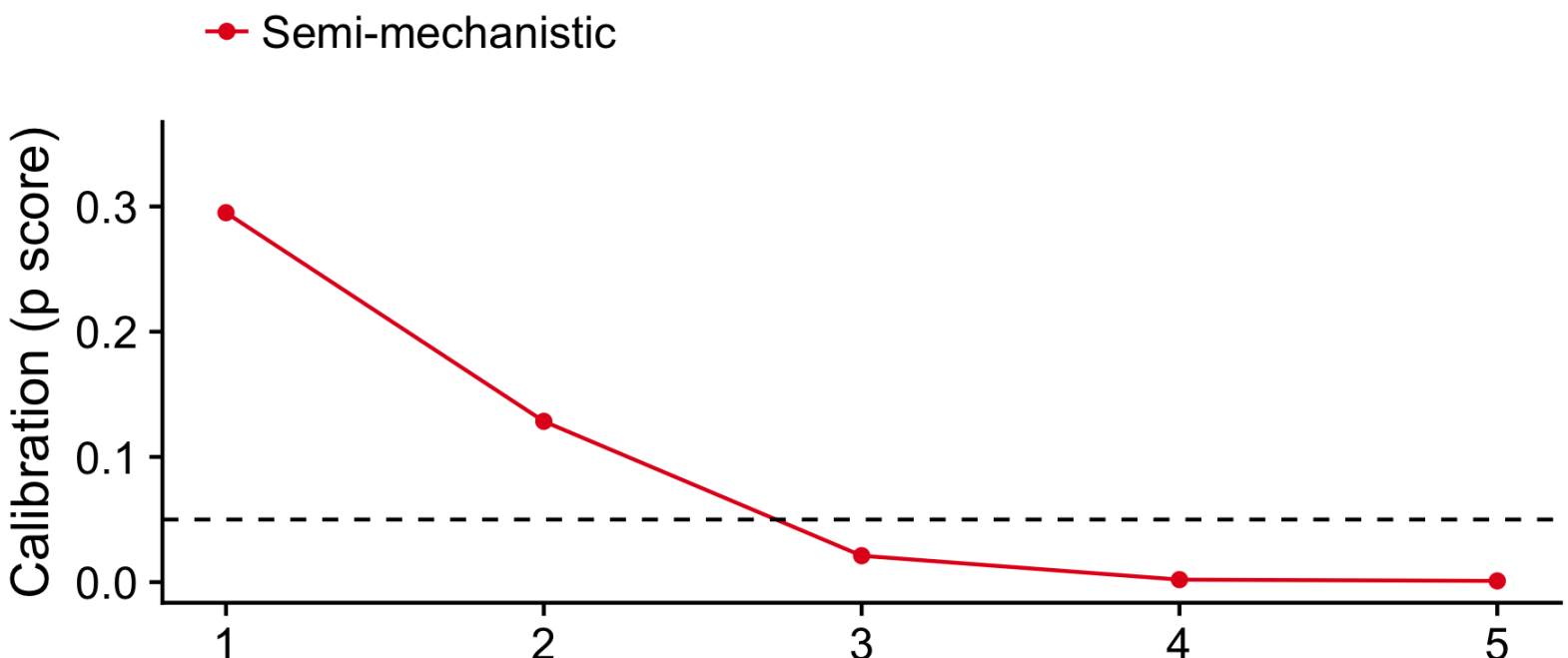

Weekly reported cases
3000
2000
1000
0


Today
8 °C
2 °C
Yellow Warning
Tomorrow
6 °C
4 °C
Yellow Warning
Thu 18 Jan
8 °C
2 °C
Yellow Warning
Fri 19 Jan
6 °C
2 °C
Sat 20 Jan
5 °C
0 °C
Sun 21 Jan
6 °C
4 °C
Mon 22 Jan
8 °C
4 °C
00:00 01:00 02:00 03:00 04:00 05:00 06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Yellow warning — Snow & Ice between Tuesday 20:25 and Wednesday 11:00 See warning detail >
Yellow warning — Wind between Wednesday 21:00 and Thursday 11:00 See warning detail >
<5% <5% <5% <5% <5% <5% <5% <5% <5% <5% <5% <5% <5% <5% <5% <5% <5% <5% <5% <5% <5% 10% 10% 60% ≥95%
3° 3° 2° 2° 2° 2° 3° 3° 3° 4° 4° 5° 5° 6° 6° 6° 6° 5° 5° 5° 5° 4° 5° 6°

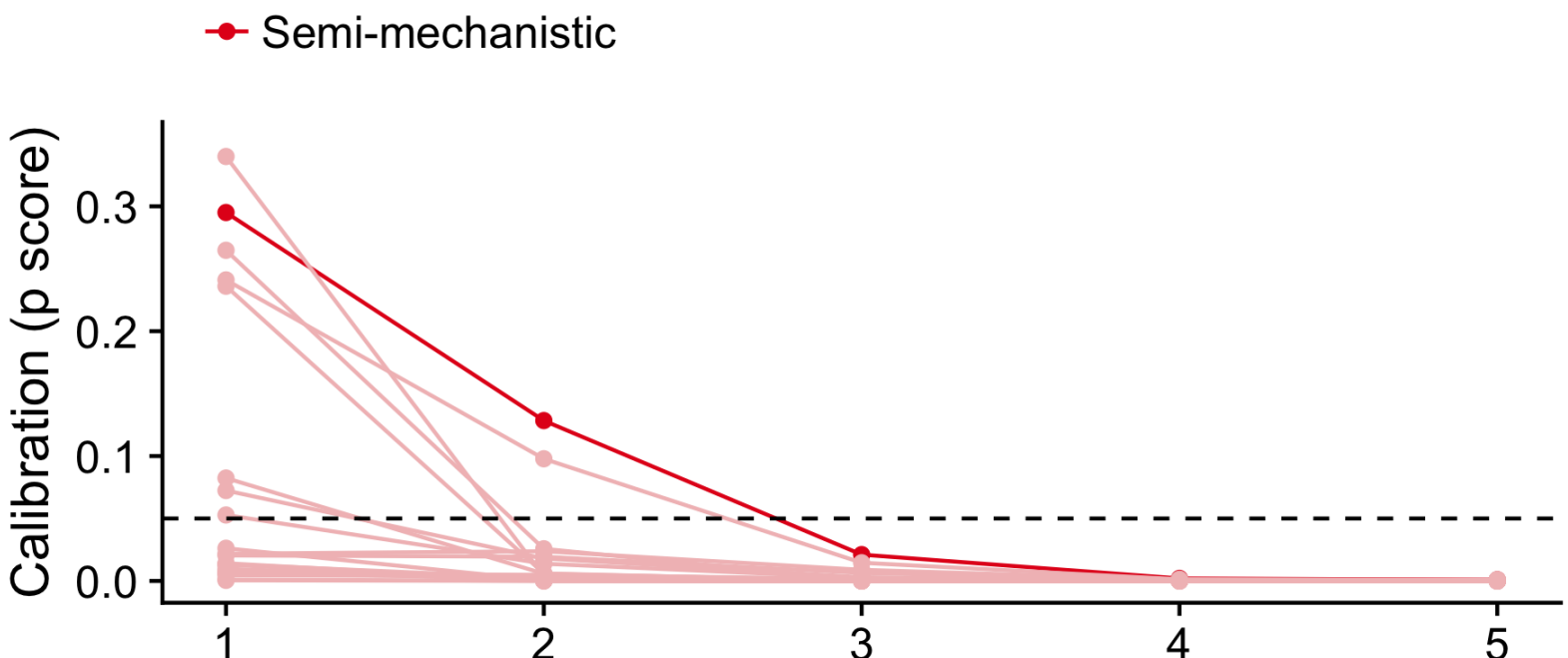
1-week forecasts



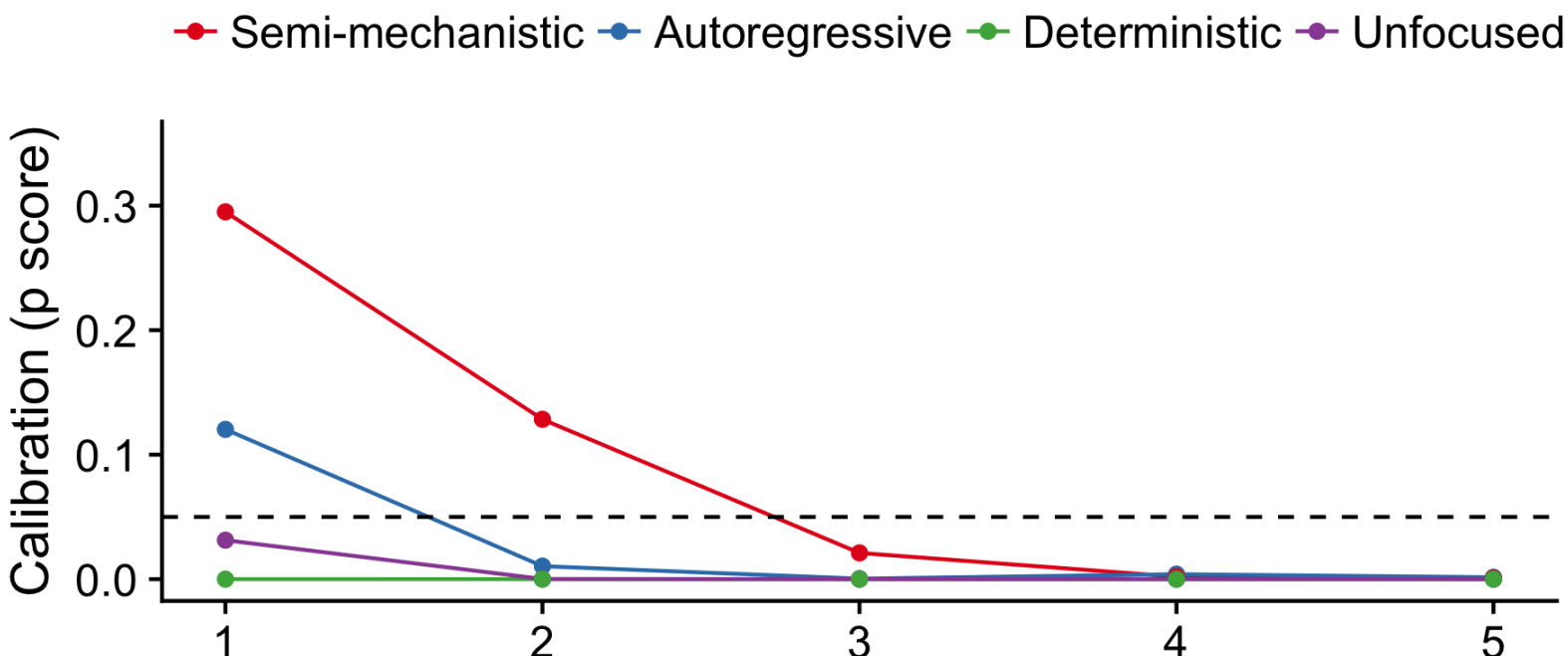
Calibration: Compatibility of forecasts and observations.



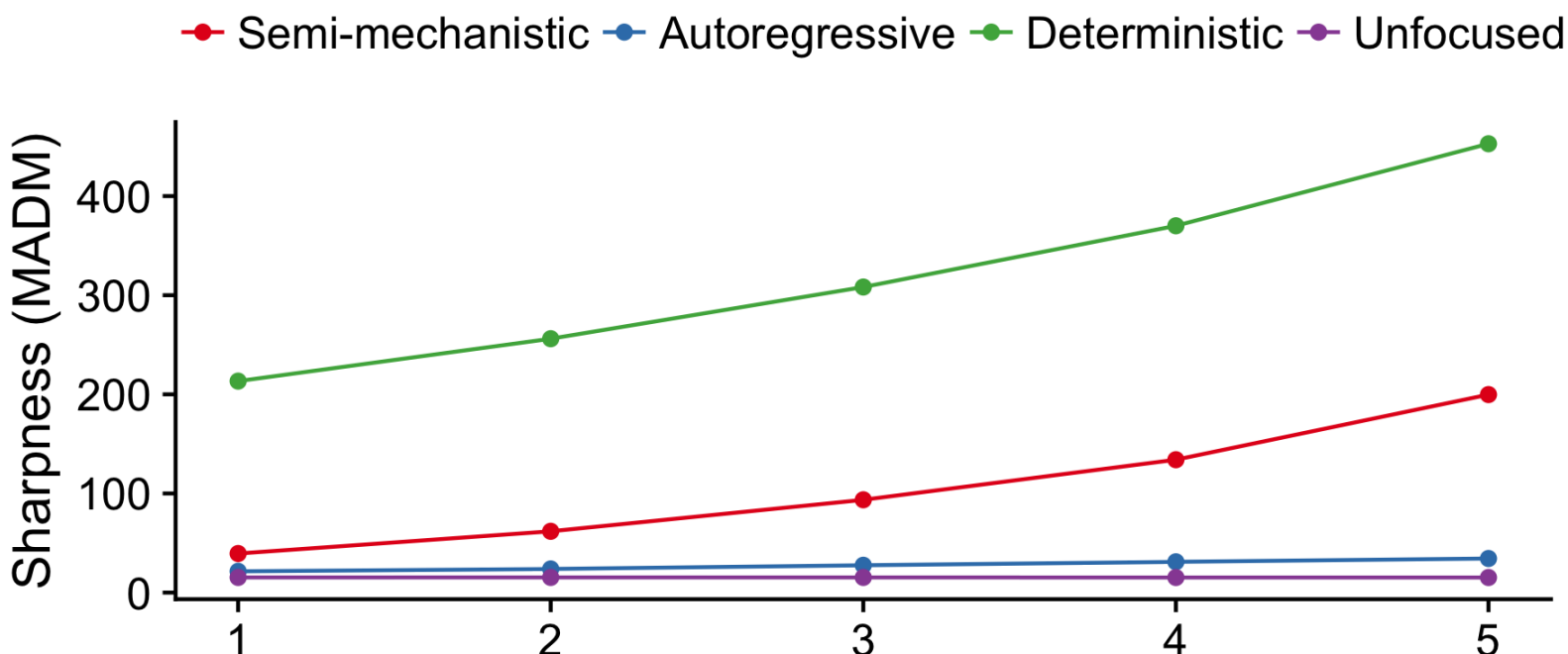
Calibration: Compatibility of forecasts and observations.



Calibration: Compatibility of forecasts and observations.

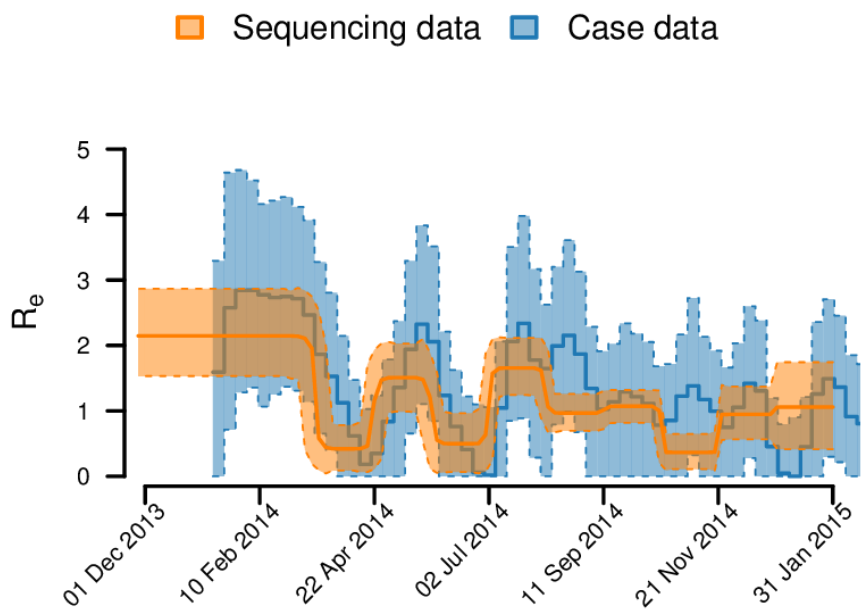


Sharpness

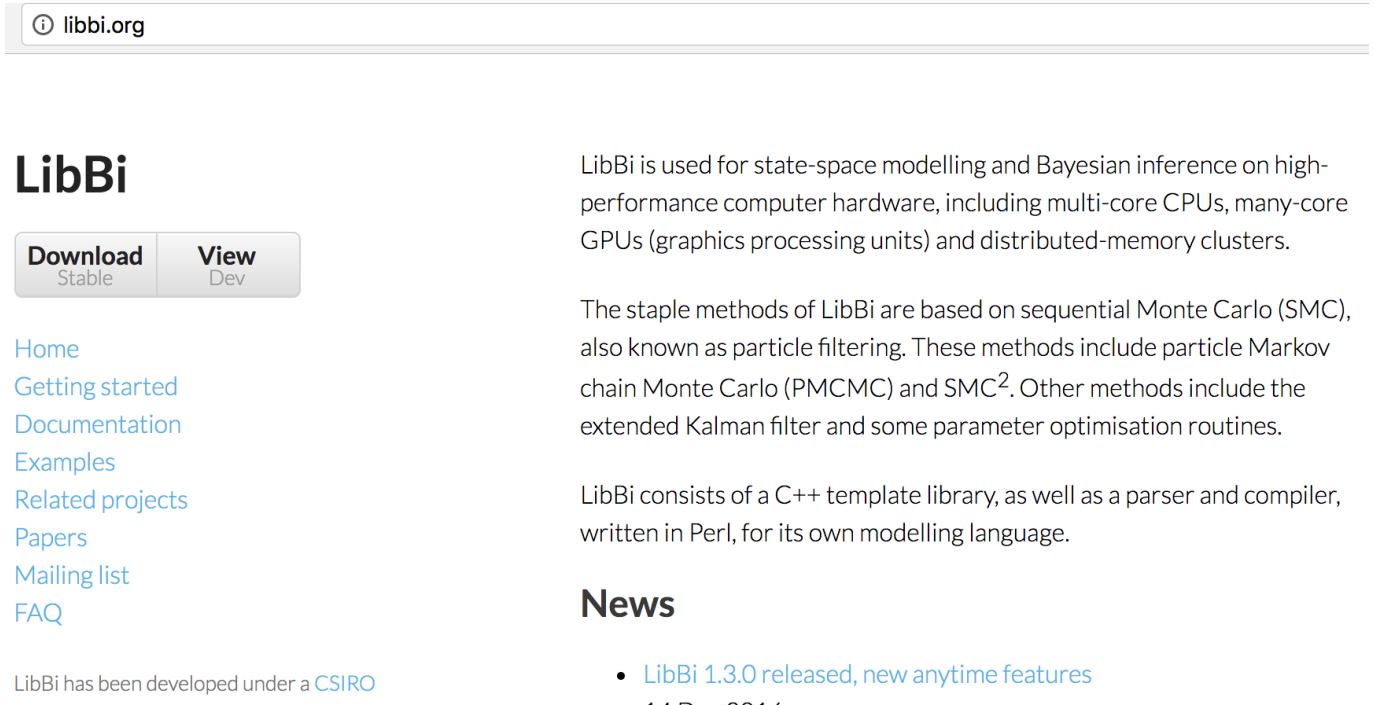

Semi-mechanistic
Autoregressive
Deterministic
Unfocused
Sharpness (MADM)
400
300
200
100
0
1
2
3
4
5

2. Integration of different data sources

Improve forecasts by
all available **data streams**
(individual/behavioural/spatial/genetic)?


Sequencing data
Case data
R_e
5
4
3
2
1
0
01 Dec 2013
10 Feb 2014
22 Apr 2014
02 Jul 2014
11 Sep 2014
21 Nov 2014
31 Jan 2015

New tools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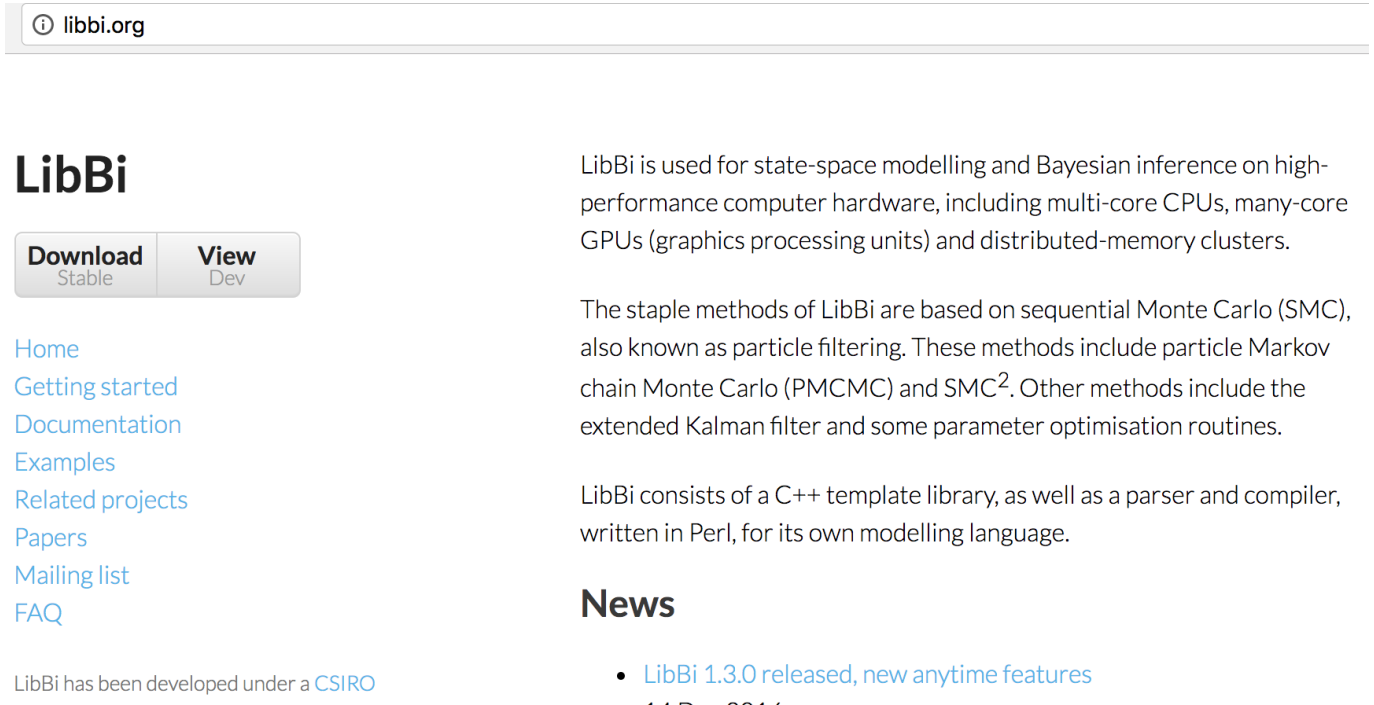
LibBi has been developed under a CSIRO
LibBi is used for state-space modelling and Bayesian inference on high-performance computer hardware, including multi-core CPUs, many-core GPUs (graphics processing units) and distributed-memory clusters.
The staple methods of LibBi are based on sequential Monte 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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News
LibBi 1.3.0 released, new anytime features

3. Forecasting for decision making

Acknowledgements

Anton Camacho, Adam Kucharski, John Edmunds, Rachel Lowe,
Roz Eggo (LSHTM), Louis du Plessis (Oxford),

Tilmann Gneiting (Heidelberg), James Hensman (prowler.io),
Lawrence Murray (Uppsala)

MRC Medical Research Council

elrha enhancing learning & research for humanitarian assistance

wellcome trust

r2hc research for health in humanitarian crises

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

Assessing the performance of real-time epidemic forecasts
S E. A. Camacho, A. J. Kucharski, R. Lowe, R. M. Eggo, W. J. Edmunds