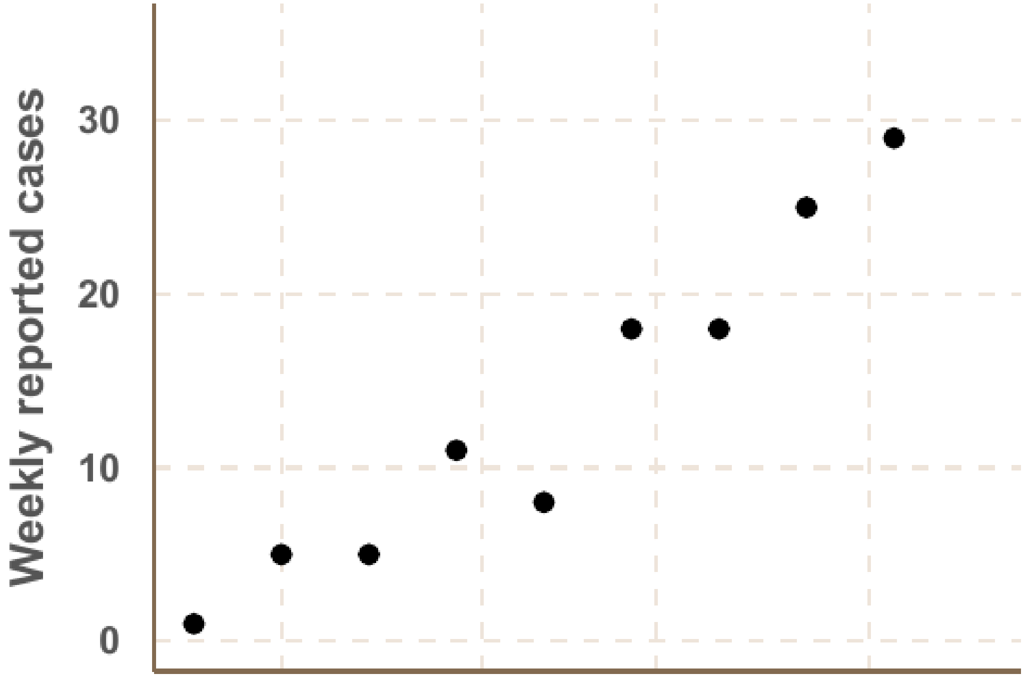
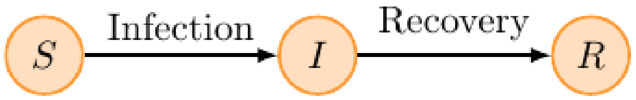
Real-time modelling and forecasting during infectious disease outbreaks

Sebastian Funk
22 March, 2018
recon gathering, London

LONDON SCHOOL of HYGIENE &TROPICAL MEDICINE
cmmid
centre for the mathematical modelling of infectious diseases

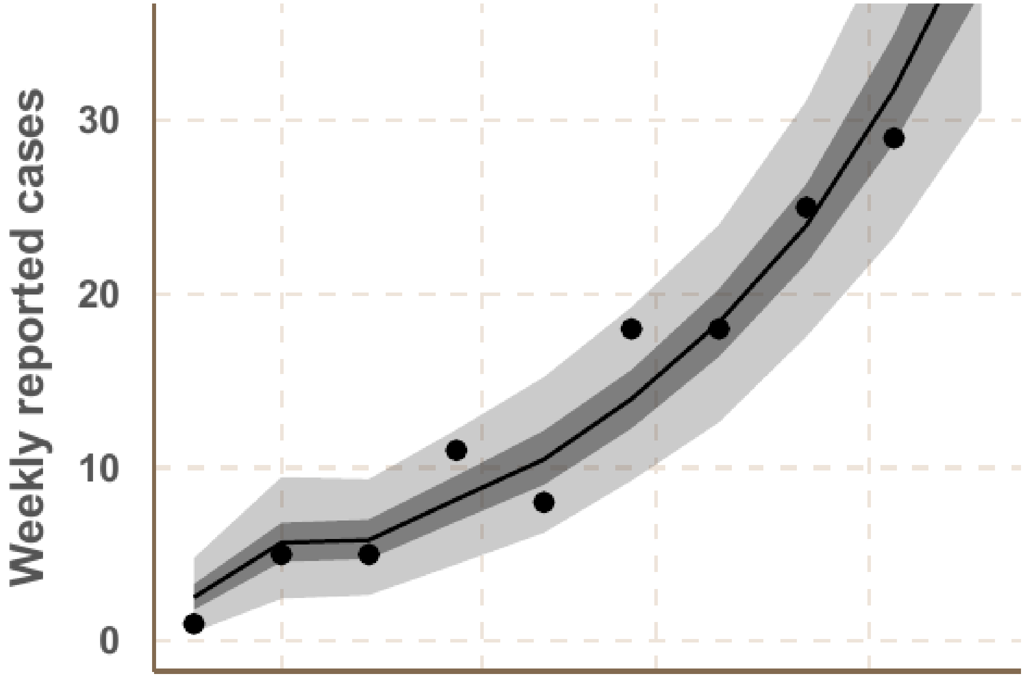

Weekly reported cases
30
20
10
0

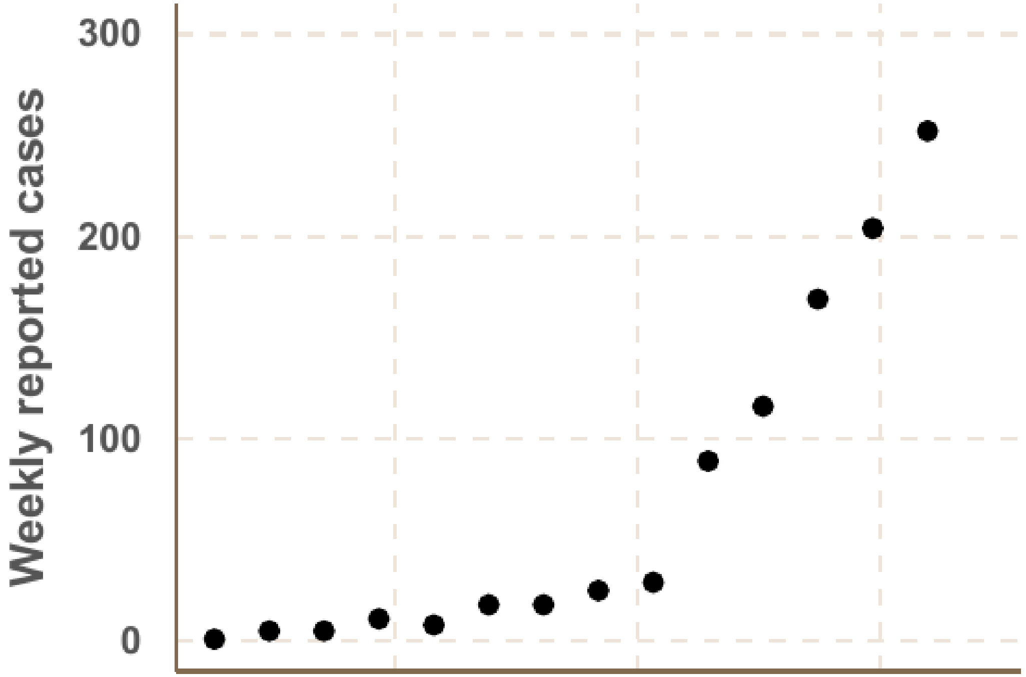


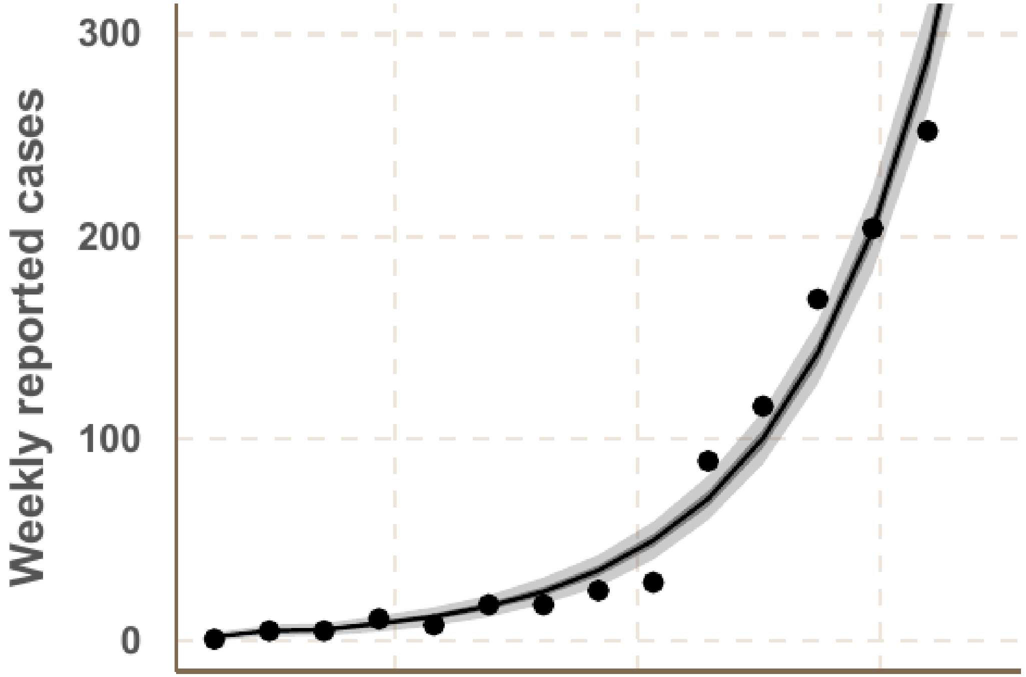
$$\dot{S} = -\beta \frac{S}{N} I$$

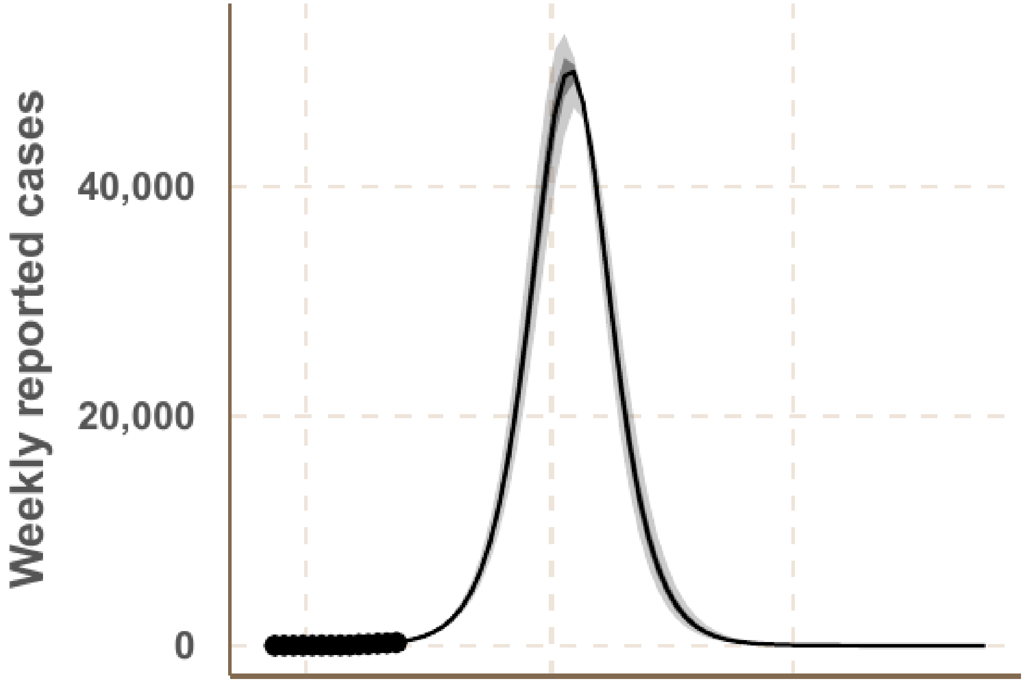
$$\dot{I} = +\beta \frac{S}{N} I - \gamma I$$

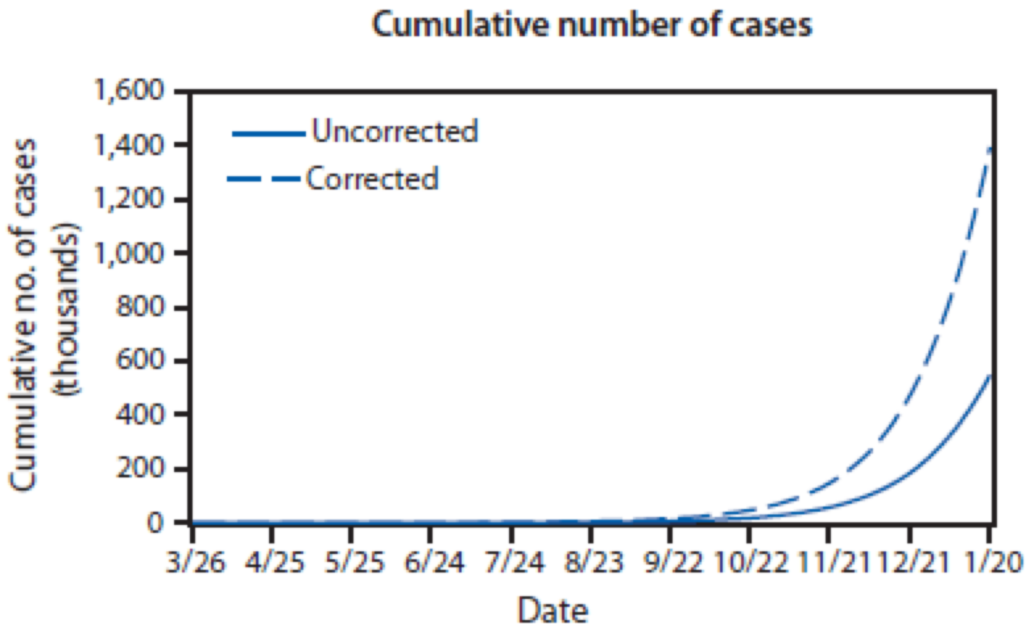
$$\dot{R} = +\gamma I$$


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



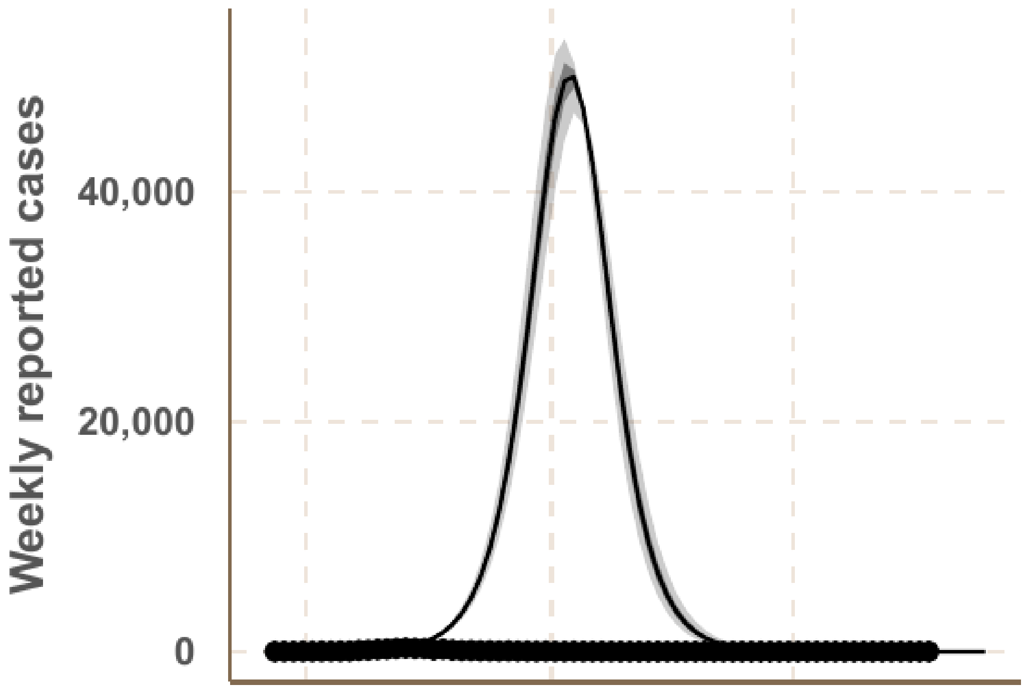
"[...] Liberia and Sierra Leone will have approximately

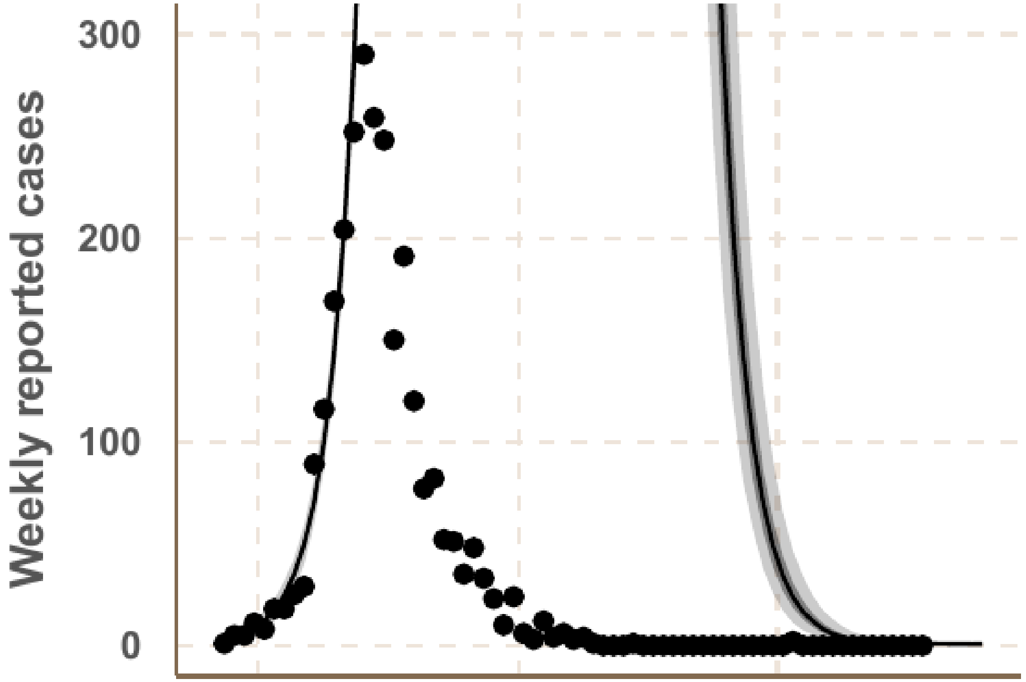
Ebola

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

What really happened

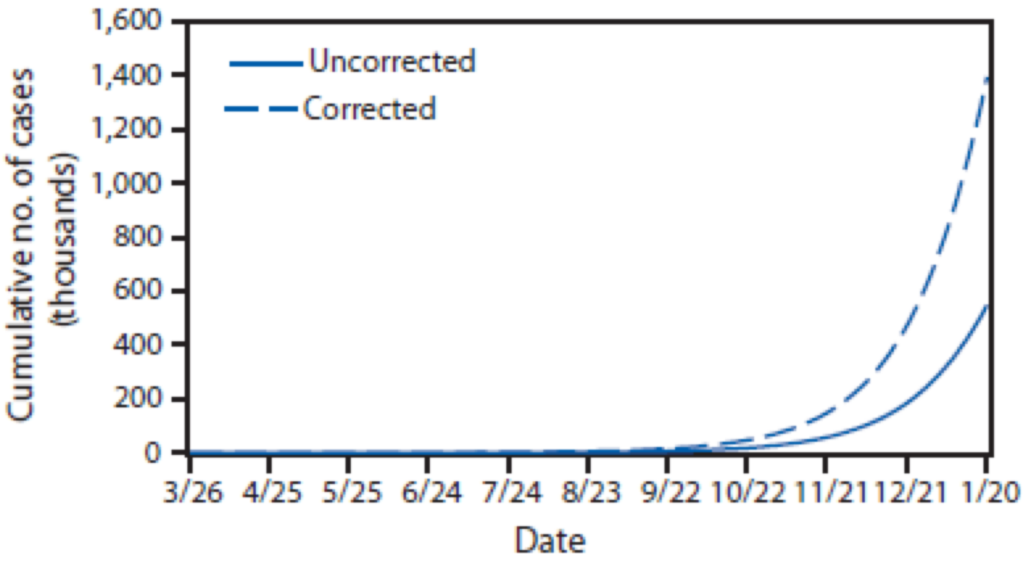

Weekly reported cases
40,000
20,000
0


Weekly reported cases
300
200
100
0

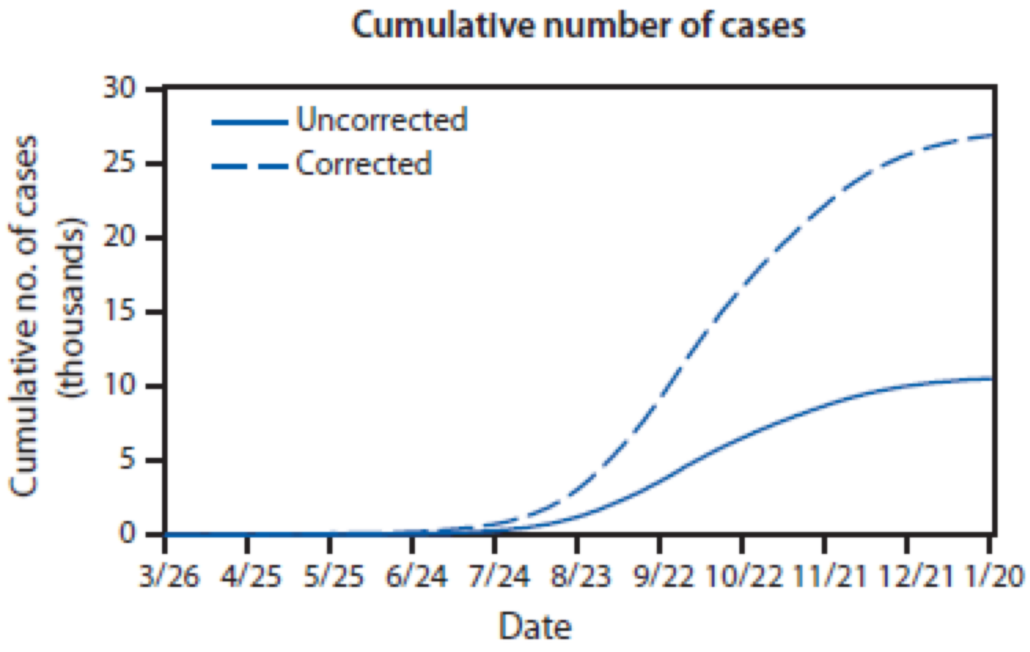
Models overestimate Ebola cases

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

Cumulative number of cases



"[...] 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

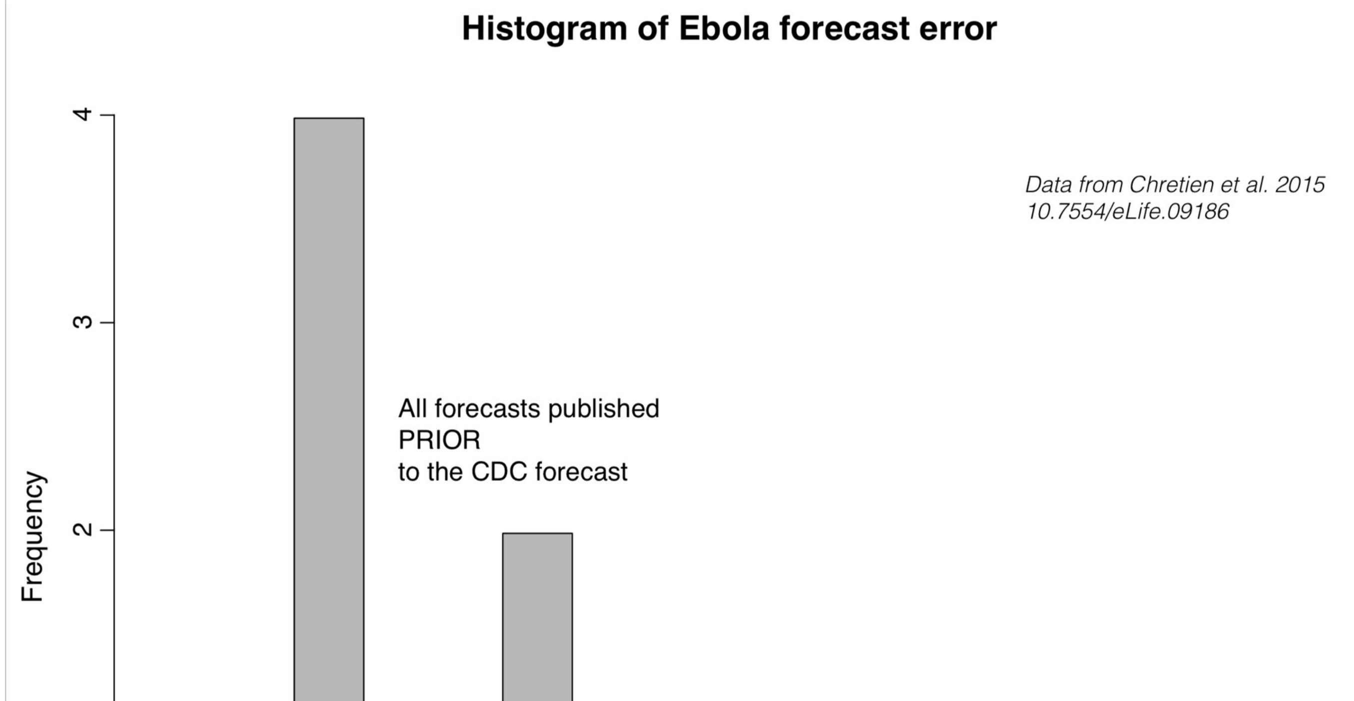
Pandemic Prediction and Forecasting Science and Technology Working Group

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

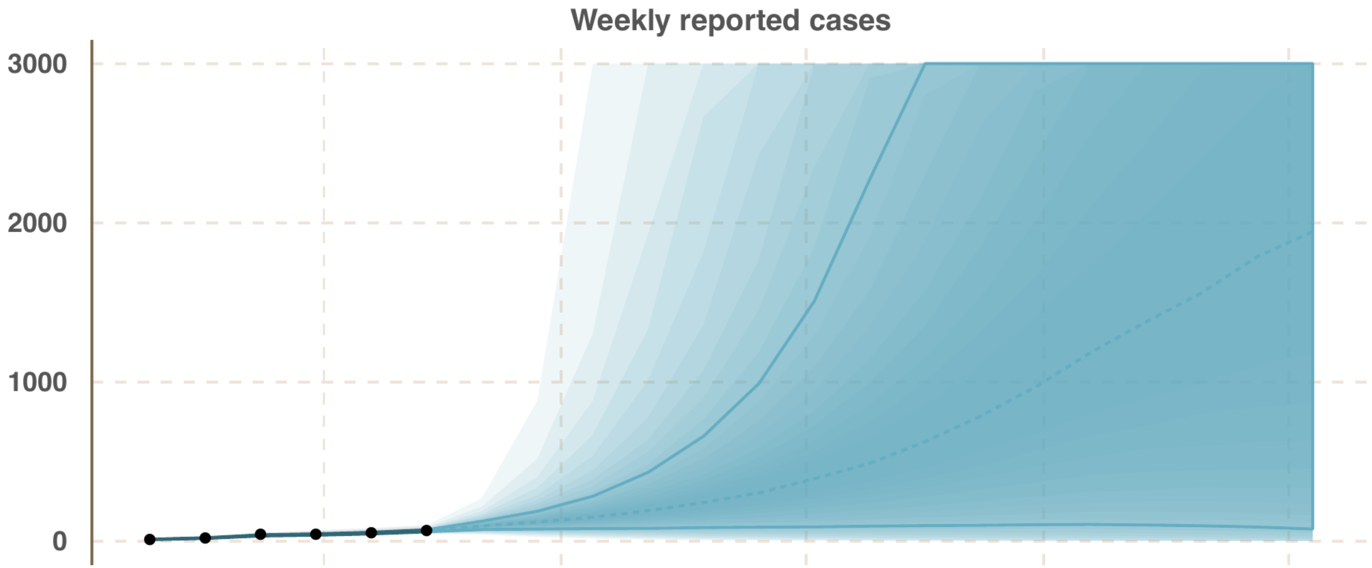
Frieden, 2015

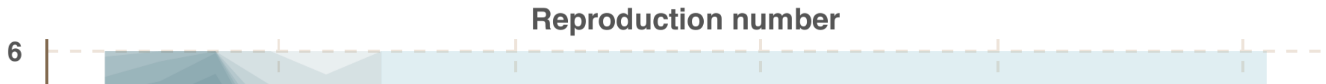
Key findings:

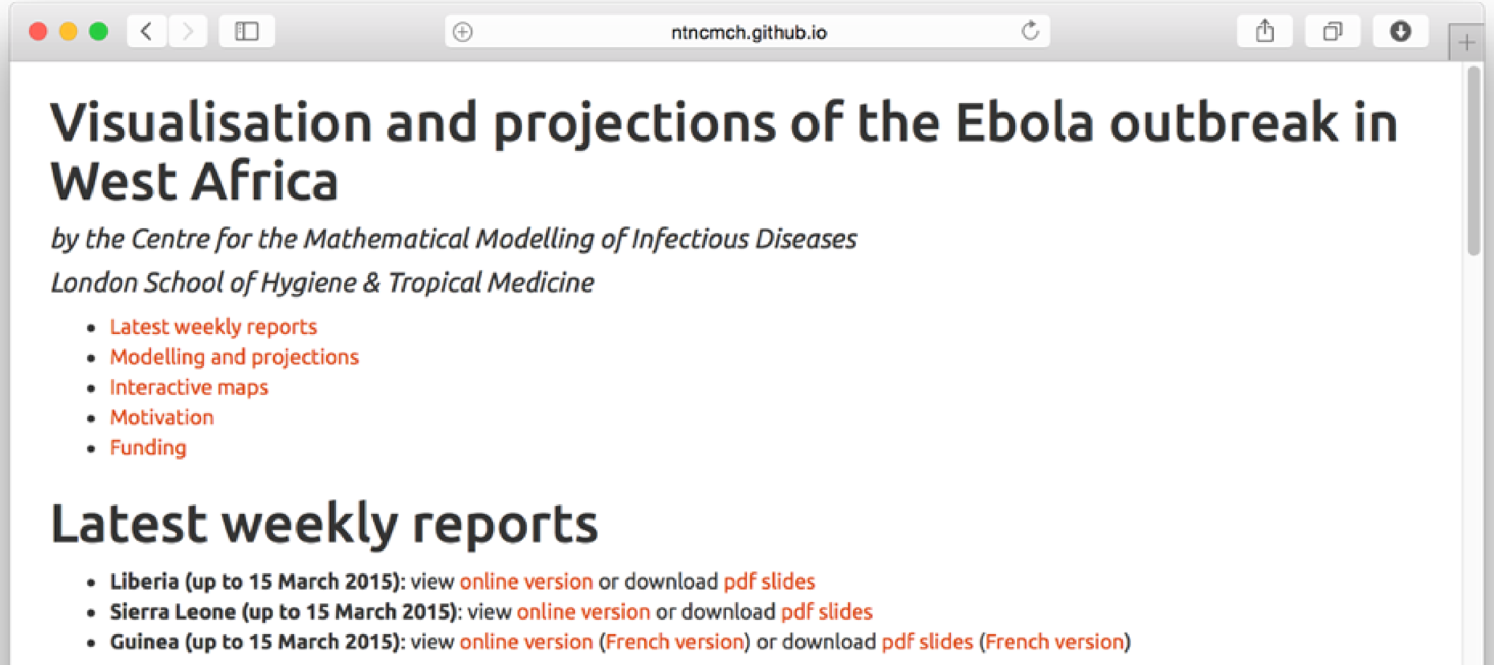
1. "cases were increasing exponentially, and the response needed was massive and urgent"
2. "the model predicted a severe penalty for delay"
3. "the model identified a tipping point at which the epidemic would [..] decline if enough Ebola patients were isolated effectively and decedents buried safely"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

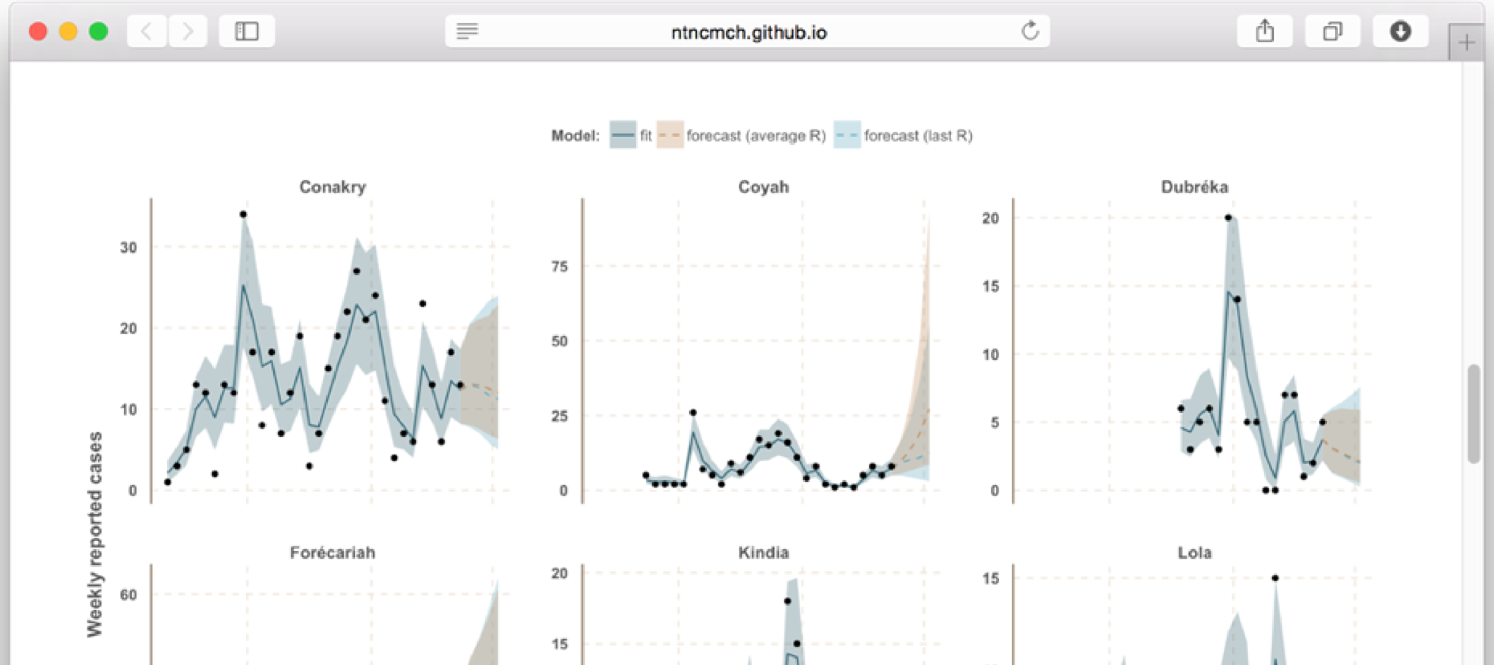


Histogram of Ebola forecast error
Frequency
4
3
2
All forecasts published
PRIOR
to the CDC forecast
Data from Chretien et al. 2015
10.7554/eLife.09186


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)

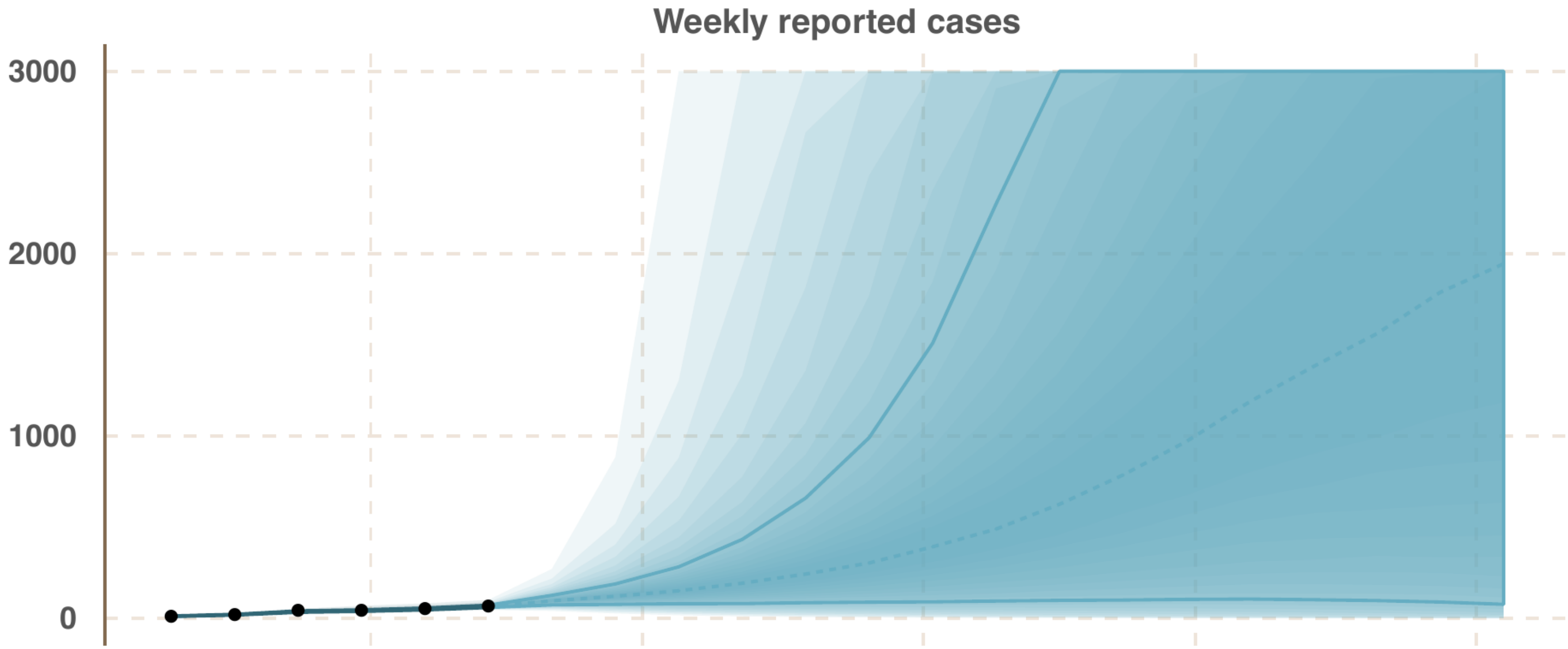

ntncmch.github.io
Model: fit forecast (average R) forecast (last R)
Conakry
Coyah
Dubréka
Forécariah
Kindia
Lola
Weekly reported cases

Uses of real-time forecasts in outbreaks

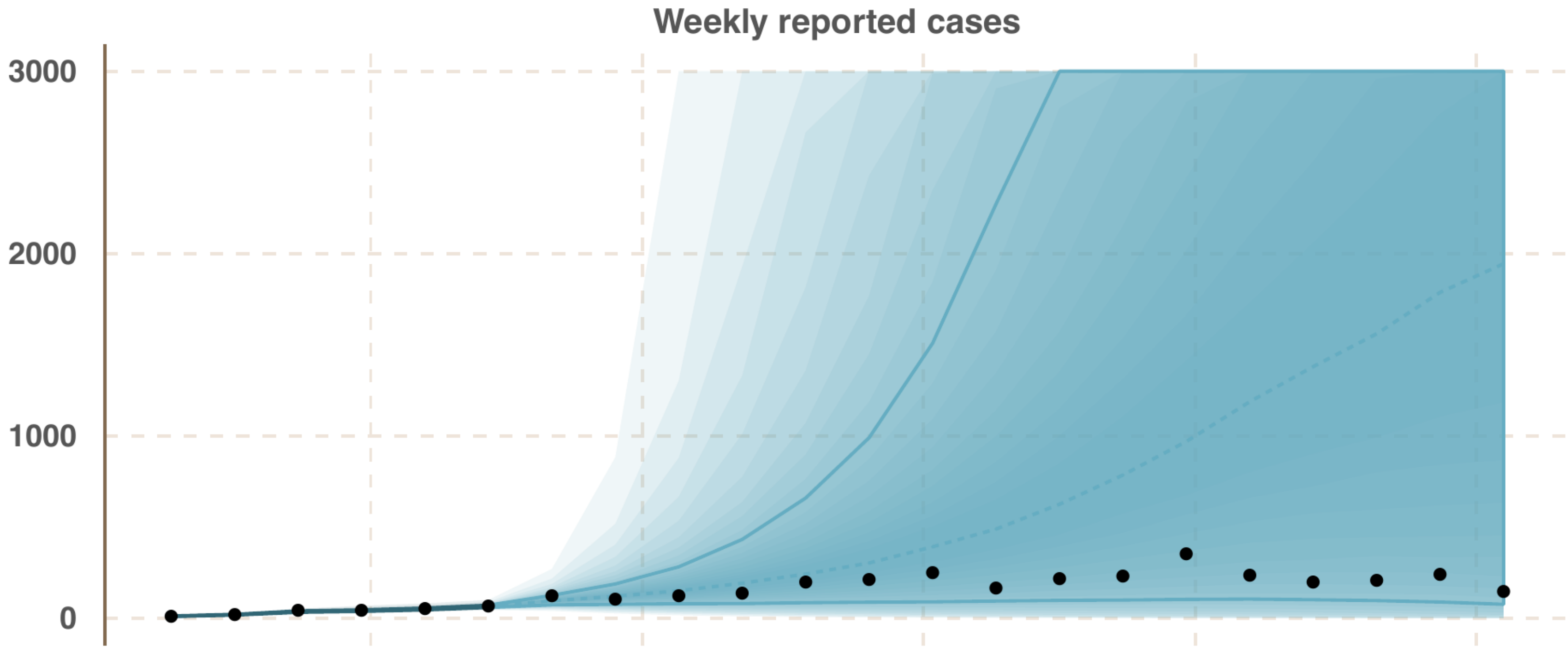
- Plan the scale of a response or intervention
- Allocate resources (e.g., geographically)
- Plan clinical trials

Challenges/opportunities

1. Evaluation of probabilistic forecasts



Weekly reported cases
3000
2000
1000
0


Weekly reported cases
3000
2000
1000
0

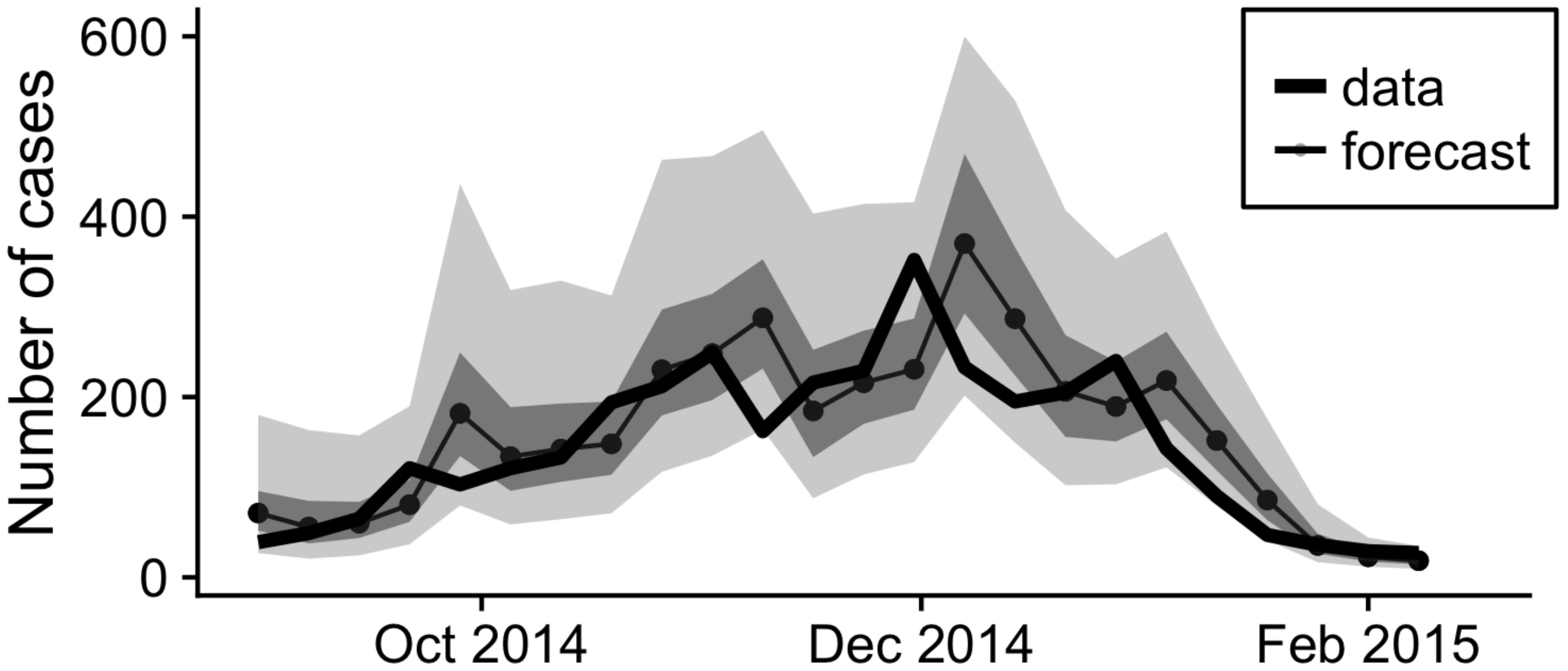
Today	Tomorrow	Thu 18 Jan	Fri 19 Jan	Sat 20 Jan	Sun 21 Jan	Mon 22 Jan
8 °C	6 °C	8 °C	6 °C	5 °C	6 °C	8 °C
2 °C	4 °C	2 °C	2 °C	0 °C	4 °C	4 °C
Yellow Warning	Yellow Warning	Yellow Warning				

Yellow warning — Snow & Ice between Tuesday 20:25 and Wednesday 11:00 See warning detail >

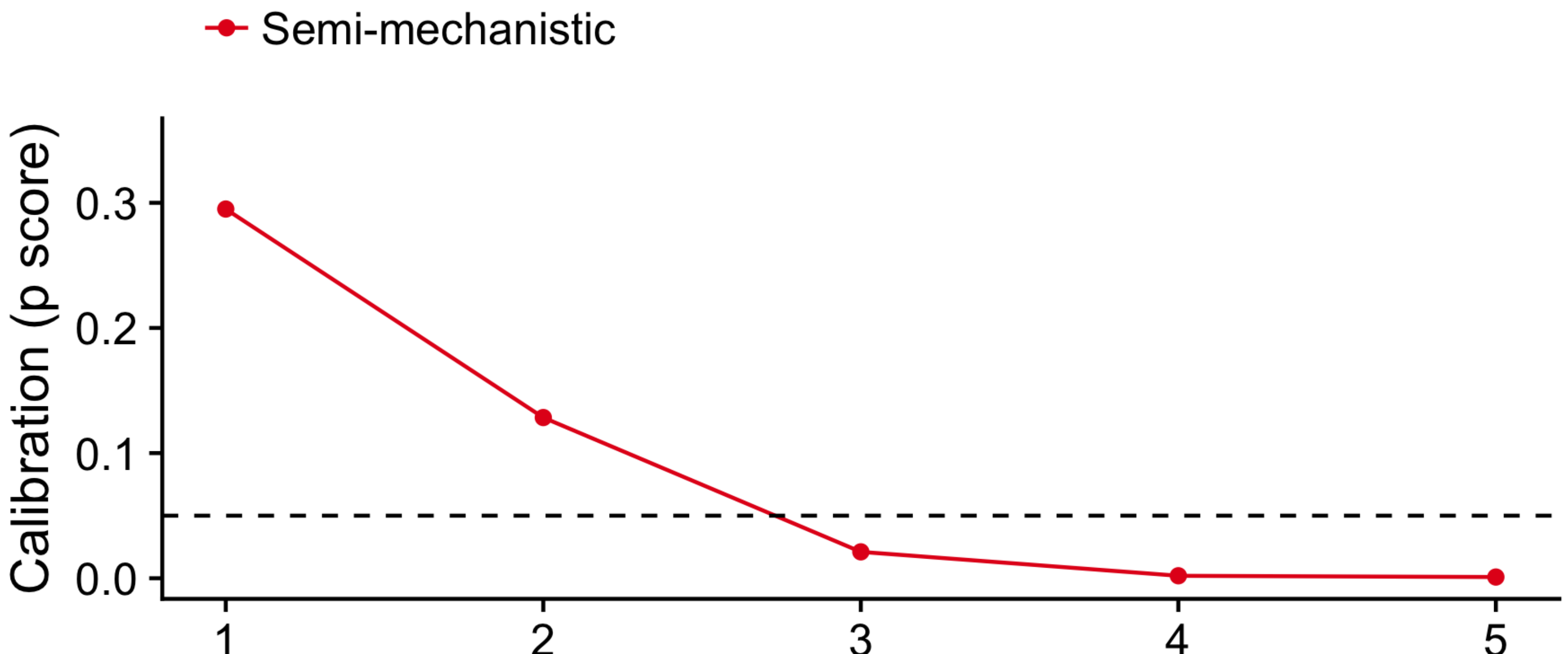
Yellow warning — Wind between Wednesday 21:00 and Thursday 11:00 See warning detail >

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
<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°

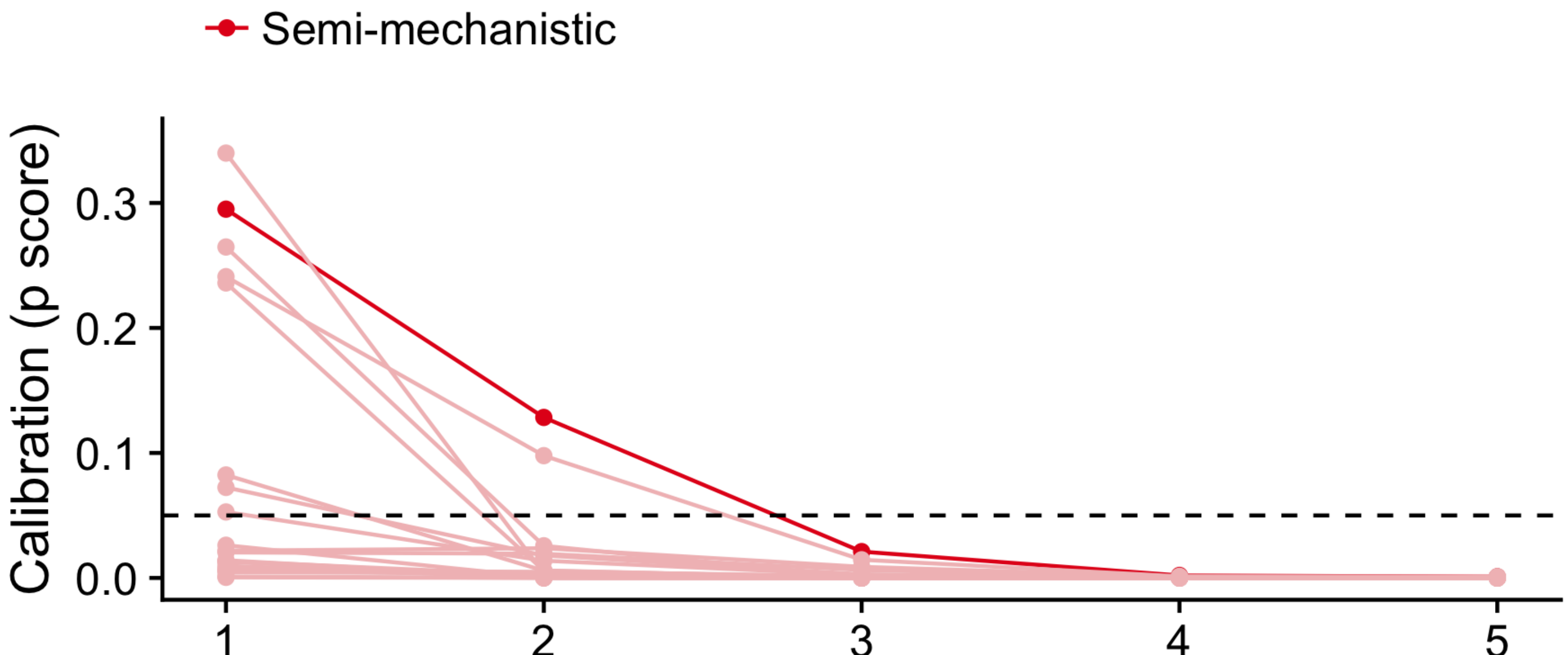
1-week forecasts



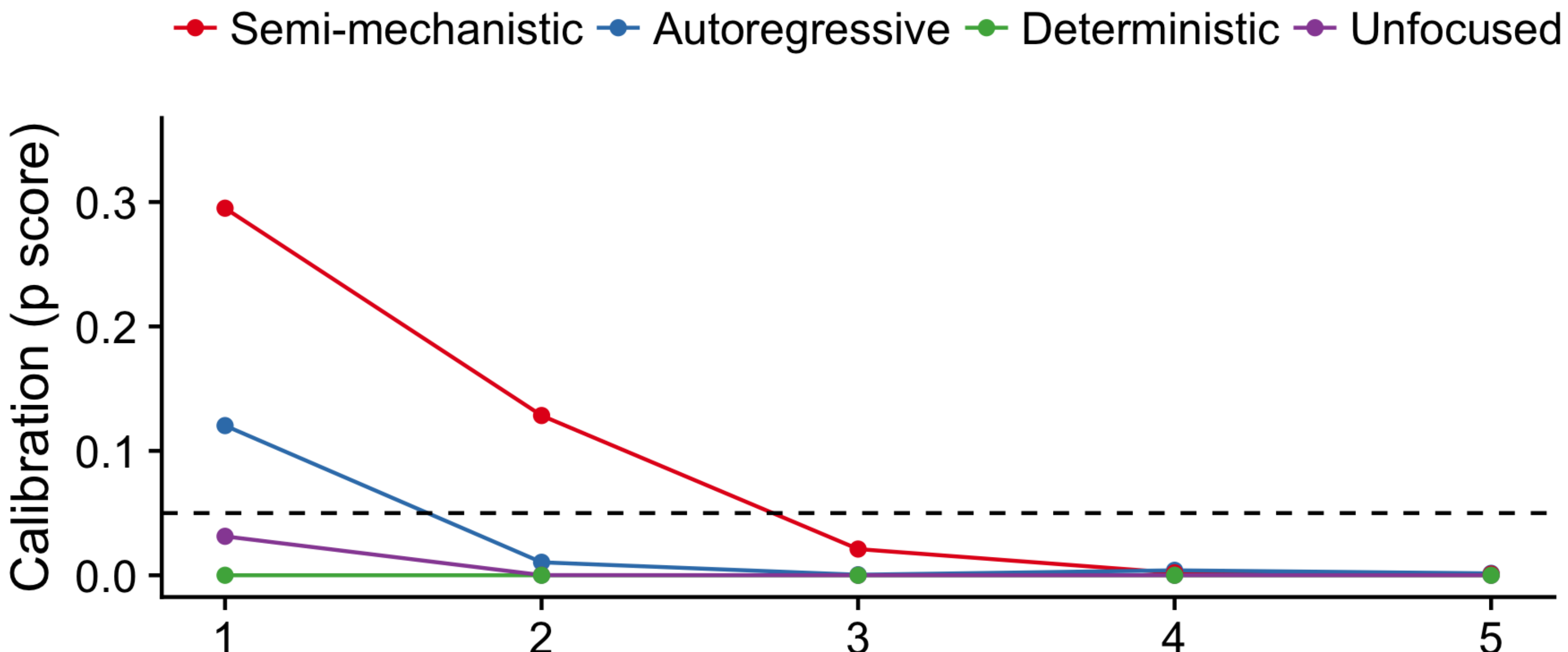
Calibration: Compatibility of forecasts and observations.



Calibration: Compatibility of forecasts and observations.



Calibration: Compatibility of forecasts and observations.

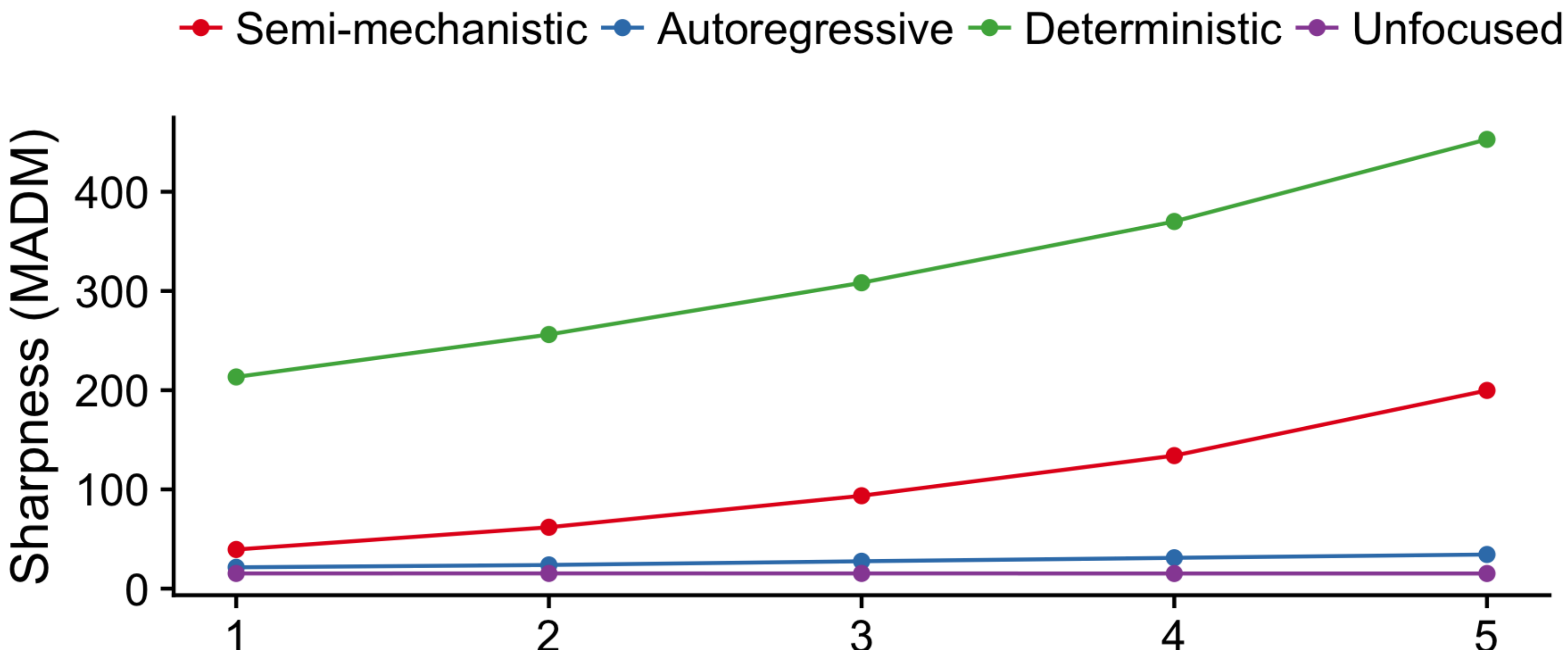


"Evaluate predictive performance on the basis of *maximising the sharpness of the predictive distribution*

subject to calibration"

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

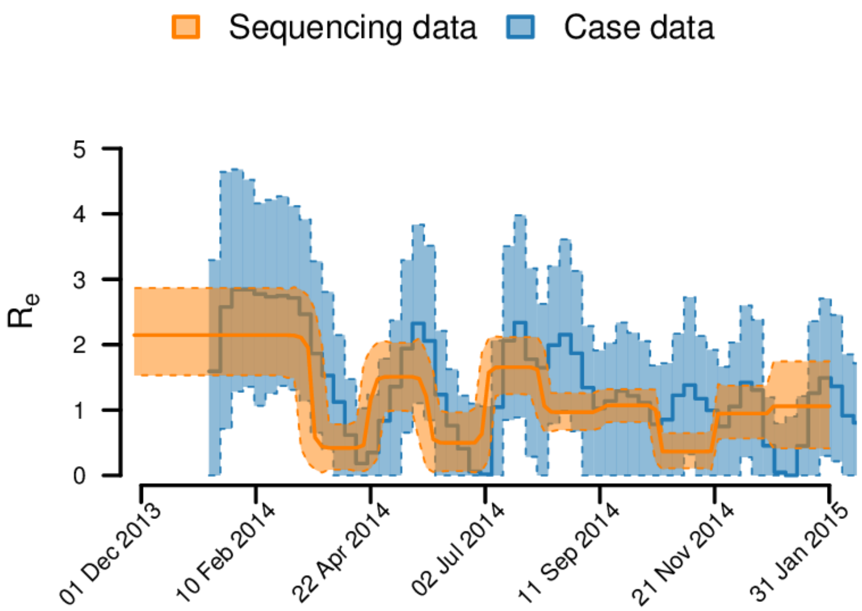
Sharpness



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

2. Integration of different data sources

Need to start looking at
all available **data streams**
(individual/behavioural/spatial/genetic)


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

3. Forecasting for decision making

Acknowledgements

Anton Camacho, Adam Kucharski, Roz Eggo, John Edmunds (LSHTM)
Bruce Reeder, Etienne Gignoux, Iza Ciglenecki, Amanda Tiffany (MSF)
James Hensman (prowler.io), Lawrence Murray (Uppsala)

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