

Evaluating an epidemiologically motivated surrogate model of a multi-model ensemble

EU COVID-19 Modelling Hub November meeting

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Multi-model and multi-team ensemble forecasts have become widely used to generate reliable short-term forecasts. Whilst there is robust and consistent evidence that multi-team ensemble forecasts provide reliable and performant forecasts across domains they also have a range of downsides. The most significant is the difficulty in interpreting them. Here we develop a parsimonious forecast model based on observations of ensemble behaviour and evaluate its predictive performance.

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Talk overview

Who am I

So what are we talking about?

The surrogate model

Implementation

Results

Summary

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Who am I?

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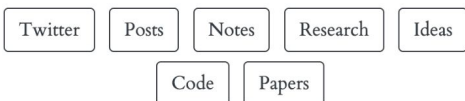
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Sam Abbott



Hi there 🙋

I'm an infectious disease researcher interested in real-time analysis, forecasting, semi-mechanistic modelling, and open source tool development. More on my research interests [here](#).

NOW

- Working at the London School of Hygiene and Tropical Medicine in the [Epiforecasts](#) group;
- ⭐ Crafting extensions to [epinowcast](#) 📦;
- 📁 Currently working on:
 - [Evaluating a simplified forecast model in comparison to the ECDC forecasting hub ensemble](#)
 - [Evaluating the use of real-time sequences for short-term forecasting](#)
 - [Evaluating a new method for nowcasting right truncated count data](#).

BIO

- 🏢 I'm currently working at London School of Hygiene and Tropical Medicine
- 🎓 I did my [PhD](#) at the University of Bristol
- ⚙️ I use daily: [R](#), [stan](#)
- 🛠️ I like to perform analysis using novel models on interesting data and generalise those approaches into software 📦
- 🌐 I'm mostly active within the R Community
- 🌱 (Very slowly) Learning all about Julia and Turing.jl
- 📖 Reading: [Modeling Discrete Time-to-Event Data](#)
- 🗣️ Ping me about statistical modelling of infectious diseases, real-time analysis of infectious diseases, estimating transmission dynamics in real-time, and team science opportunities
- 📧 Reach me: sam.abbott@lshtm.ac.uk

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So what are we talking about?

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So what are we talking about?

- Multi-model, multi-team, ensembles have become increasingly popular as an approach to increase the robustness and performance of infectious disease forecasts.
- Ensemble forecasts from these projects have a range of downsides including the considerable organisational and resource cost required to produce them.
- Emulation approaches are widely used in climate models as a solution to high compute requirements but are generally non-parametric.

So what are we talking about? The surrogate model

- We also want to understand our models.
- Can we create a model that:
 - behaves like the ensemble
 - isn't a black box and
 - for a low cost of human and computational resources?

So what are we talking about? Okay how

- Review the Hub ensemble and derive a set of observed behaviours.
- Review our previous forecast efforts and those of others to explore the kinds of assumptions we commonly make in our models.
- Make a set of assumptions we think will produce the behaviour we have observed.
- Define this model and implement into an automated GitHub Actions based framework (?).
- Evaluate in real-time for 6 months in comparison to the Hub ensemble.

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The surrogate model

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Insights from the European Forecast Hub

- Ensemble is an unweighted quantile median of independent forecasts
- Forecasts come from a range of models based on mechanistic, statistical, hybrid, and human judgement frameworks.
- Typically robust to daily reporting artefacts
- Some ability to forecast future changes in trend that were not clearly present in the observed data
- Highly auto-correlated over time and generally less reactive during periods of stability.
- Relatively sharp forecasts with a noticeable bias away from forecasts significantly larger than currently observed cases.

Insights from our submitted models

- Focussed on trying to minimally represent the infection process whilst retaining statistical flexibility
- Negative Binomial likelihood with a log link.
- Used daily data with adjustment for days of the week effects.
- Adjustment for changes in the susceptible population.
- Generally captured changes in trend quite well but were very susceptible to outliers, and typically overpredicted during periods of growth.

Citation: Bosse NI, Abbott S, Bracher J, Hain H, Quilty BJ, Jit M, et al. (2022) Comparing human and model-based forecasts of COVID-19 in Germany and Poland. PLoS Comput Biol 18(9): e1010405. <https://doi.org/10.1371/journal.pcbi.1010405>

Model assumptions

Table 1. Observations on the relative performance of the Forecast Hub ensemble compared to our forecast submissions.

No.	Observation
1	Robust to daily reporting artefacts
2	Some ability to forecast future trend changes
3	Less reactive to apparent observed changes in trend
4	Sharper forecasts
5	A tendency towards underprediction
6	Modelling the reporting process appears to have little impact

Table 2. Assumptions/simplifications based on observations of the relative performance of Forecast Hub ensembles compared to our forecast submissions.

Assumption	Observation
Reported cases can be modelled using weekly data and a generative process discretised by week	1, and 2
Reported cases can be modelled as if they represented infections	6
The growth rate of infections can be represented as an auto-regressive process with an order of 1 week	3 and 4
Unobserved interventions and more general changes in transmission towards a stable state can be represented using a multiplicative decay parameter	2, and 5

Model definition

$$\lambda_0 \sim \text{LogNormal}(\log C_0, 0.025 \times \log C_0)$$

$$\lambda_t = C_{t-1} e^{r_t}, t > 0$$

$$C_t | \lambda_t \sim \text{NB}(\lambda_t, \phi)$$

where the mean and variance of the negative binomial are given by

$$\mathbb{E}[C_t | \lambda_t] = \lambda_t \quad \text{and} \quad \text{Var}[C_t | \lambda_t] = \lambda_t + \frac{\lambda_t^2}{\phi}.$$

$$r_0 \sim \text{Normal}(0, 0.25)$$

$$r_t = (\mathbf{1}_{r_{t-1} > 0} \xi_+ + \mathbf{1}_{r_{t-1} \leq 0} \xi_-) r_{t-1} + \varepsilon_t$$

$$\varepsilon_t = \mathbf{1}_{t > 0} \beta \varepsilon_{t-1} + \eta_t$$

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Implementation

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Implementation

What did we do?

- Submitted to the European Forecast Hub from February 2022
- Model written using stan and as an extension of the forecast.vocs package
- Model deployed using GitHub Actions during development to ensure computational resources are appropriately restricted.
- Model submitted in an automated fashion using the ECDC hub GitHub Actions framework with no manual interventions during the submission period.
- Evaluation fully reproducible ensuring that the complete analysis can be replicated by others if interested in developing a model with similar resource constraints.

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Results

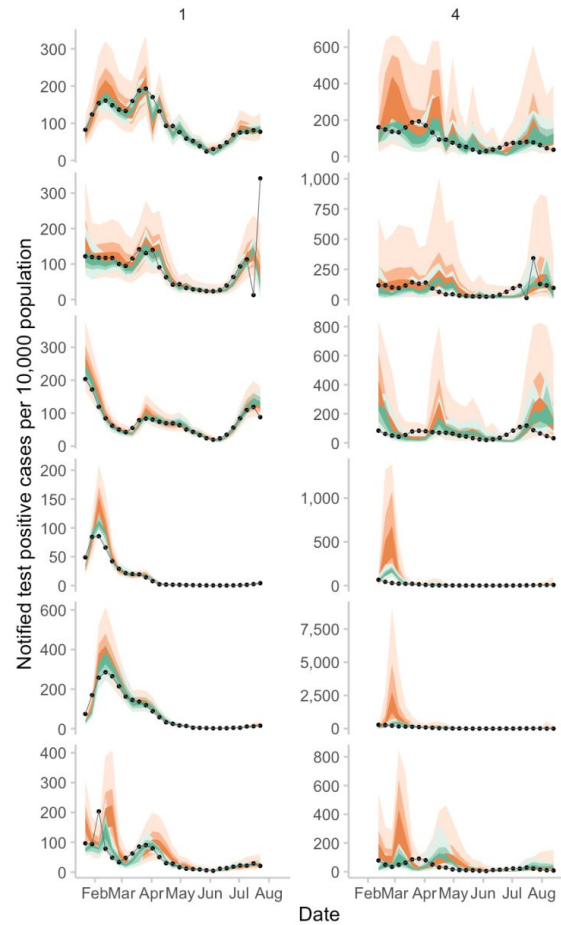
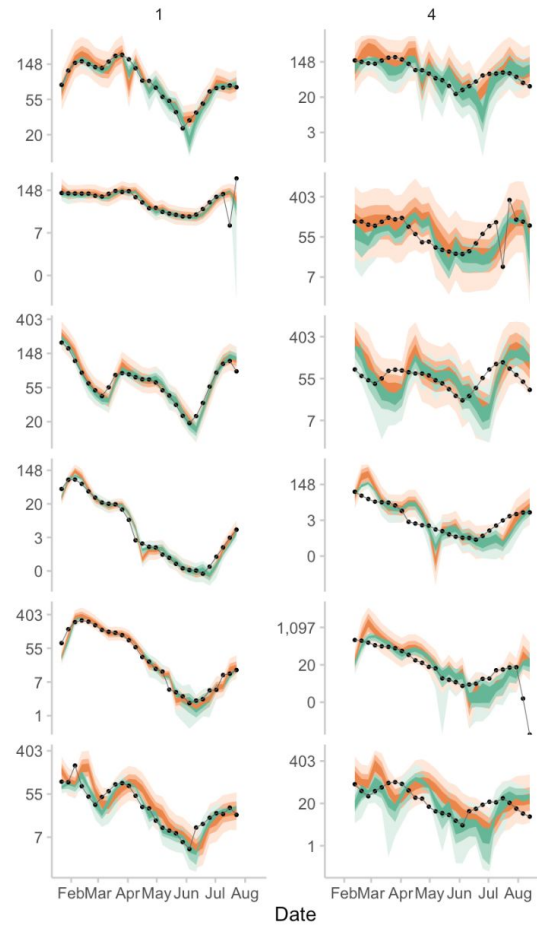
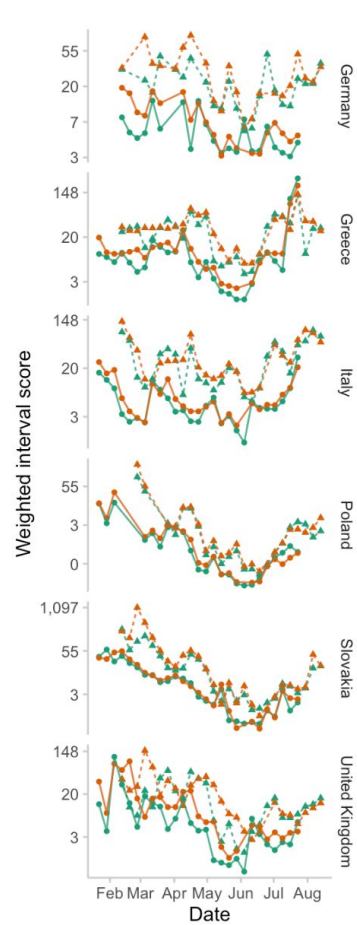
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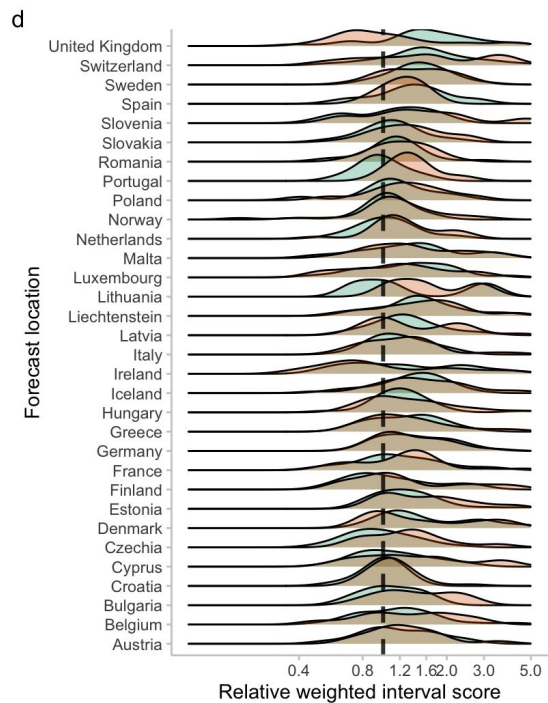
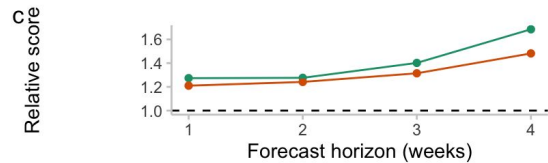
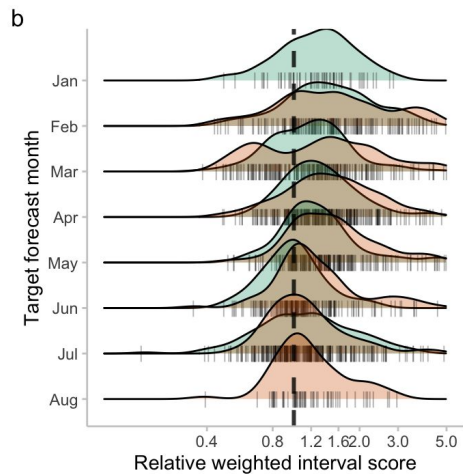
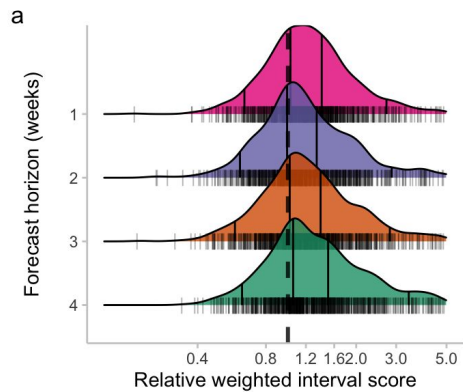
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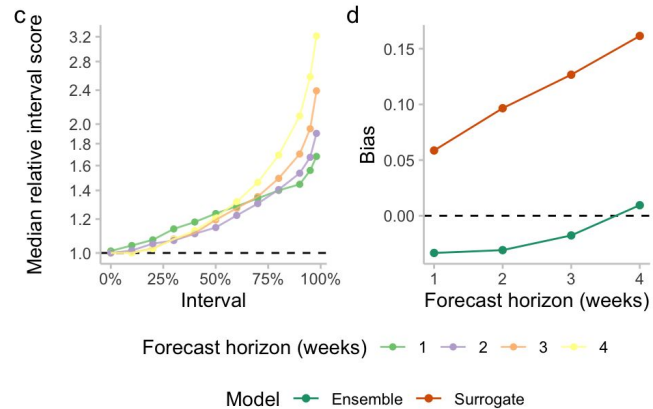
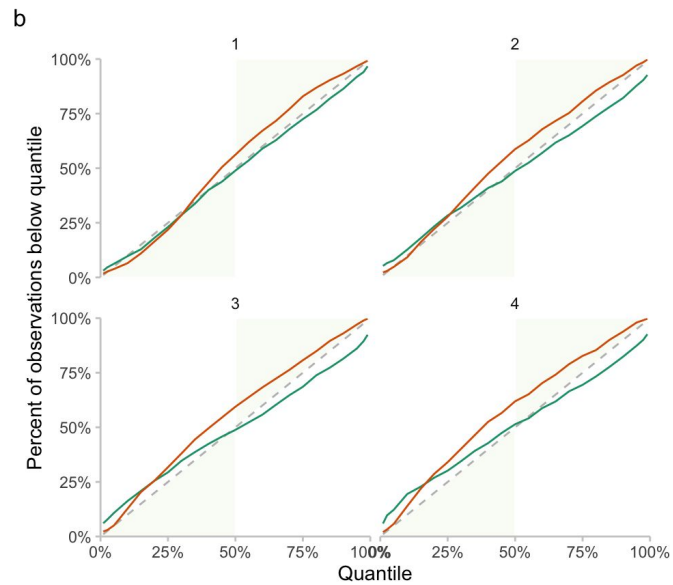
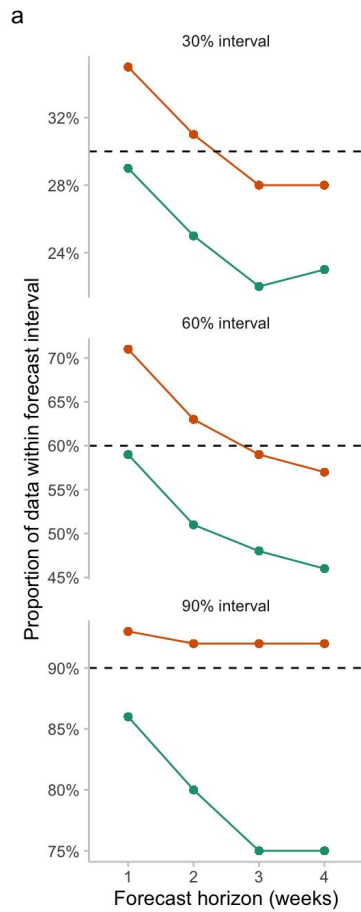
Model — Ensemble — Surrogate Forecast horizon (weeks) — 1 — 4



Metric

- Weighted interval score
- Absolute error

Forecast horizon (weeks) 1 4



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Summary

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Summary

So what are we talking about? Improving access to ensemble quality forecasts whilst also trying to understand how they work

What did we try and do. Develop an interpretable surrogate model based on our observations of the ensembles behaviour and our prior forecasting experience.

The surrogate model. A weekly AR(1) process with additional decay to a steady state.

Implementation. Fully automated and cloud based submission and a reproducible analysis framework.

Results. Some qualitative similarity but with increased uncertainty and generally quantitatively worse performance. Improved calibration vs the ensemble.

What is left to do? How can we do better? Should be trying to replicate ensemble based behaviour at all. Is it what we want?



Thanks to my lovely **co-authors** for doing all the work, our gorgeous reviewers, and you all for informing the ensemble that this is built on!



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