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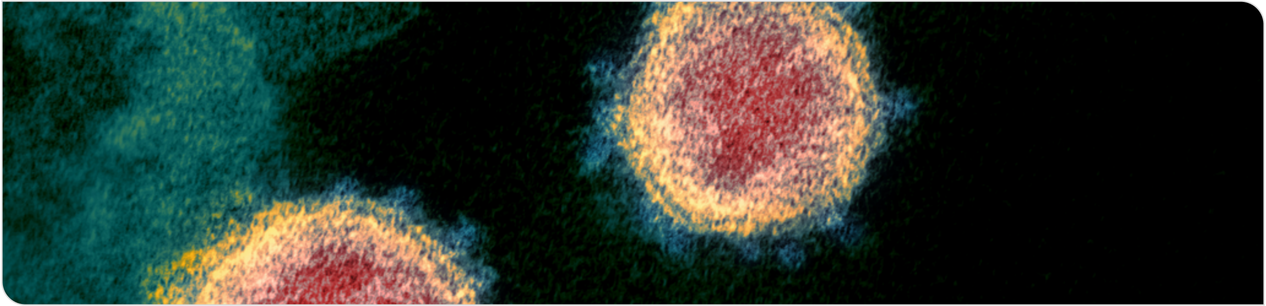
Collaborative nowcasting of COVID-19 hospitalization incidences

DAGStat

Johannes Bracher | Karlsruhe Institute of Technology / Heidelberg Institute for Theoretical Studies



Contributors

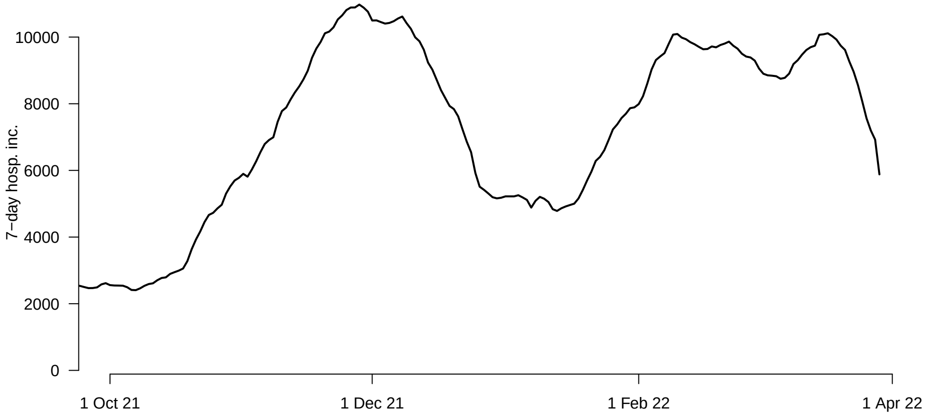
This is joint work with

- Daniel Wolffram, Davide Hailer, Tilmann Gneiting, Melanie Schienle (KIT/HITS)
- Helmut Küchenhoff, Diella Syliqi, Maximilan Weigert (LMU Munich)
- Sam Abbott, Sebastian Funk (London School of Hygiene and Tropical Medicine)
- Jan van de Kassteele (RIVM Bilthoven)
- Matthias an der Heiden, Alexander Ullrich (Robert Koch Institut)
- Stefan Heyder, Thomas Hotz (TU Ilmenau)
- Felix Günther (University of Stockholm)

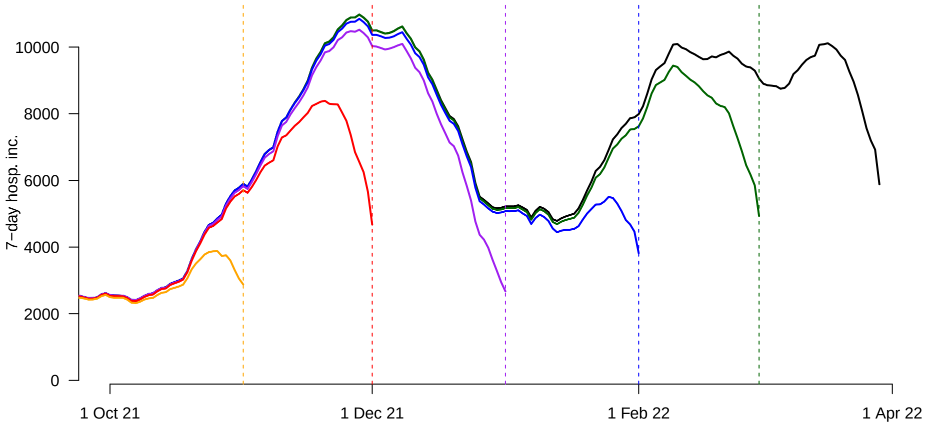
with contributions by

- Sören Müller-Hansen (Süddeutsche Zeitung)

COVID-19 hospitalization incidence in Germany



COVID-19 hospitalization incidence in Germany

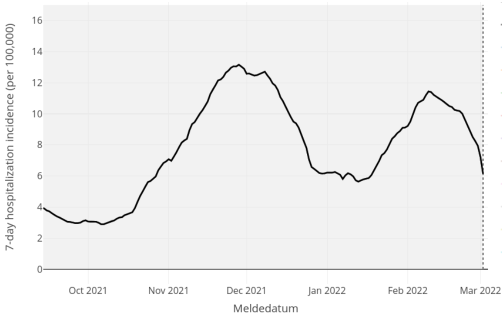


Seven day hospitalization incidence

- **Definition:** The number of persons, who over a seven-day period
  - have been registered electronically as a COVID-19 case by a local health authority (*Meldedatum*).
  - and have been hospitalized (not necessarily during the seven-day period).
- This is **not** the number of new hospitalizations over the last seven days.
- This number does **not** take into account whether COVID-19 was the reason of hospitalization.
- **Most recent values are biased downwards due to two types of delays:**
  - delay between *Meldedatum* ($\approx$ positive test) and hospitalization.
  - delay between hospitalization and appearance in RKI data.

Nowcasting aims to correct the reporting dip

- Goal: **Estimate (predict) what preliminary/incomplete values will ultimately look like.**
  - Stratified for states and age groups.
  - In real time.
- In a way this is a *forecast* rather than a *nowcast*: some hospitalizations in question have not yet happened.



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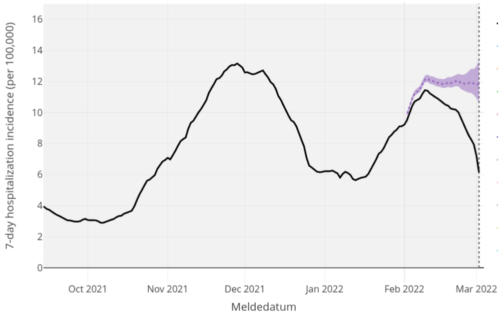

Multi-model nowcasting

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- Experience from e.g., weather forecasting shows that combining different models can improve predictions.
- We collect and combine probabilistic nowcasts from 8 independently run models.
- Daily subimssions to a public GitHub repository:

main hospitalization-nowcast-hub / data-processed / KIT-simple_nowcast / **2022-03-29-KIT-simple_nowcast.csv**

dwolffram Update Baseline ✓ Latest comm

1 contributor

5337 lines (5337 sloc) 472 KB

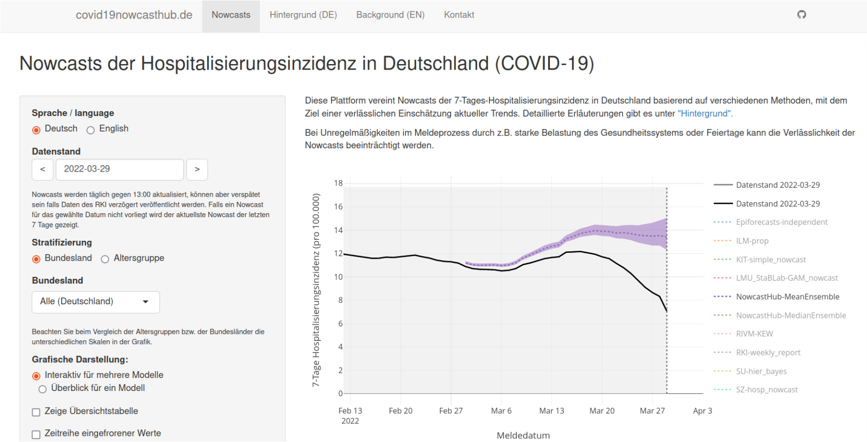
Search this file...

1	location	age_group	forecast_date	target_end_date	target	type	quantile	value	pathogen
2	DE	00+	2022-03-29	2022-03-29	0 day ahead inc hosp	mean	NA	10642	COVID-19
3	DE	00+	2022-03-29	2022-03-29	0 day ahead inc hosp	quantile	0.025	8521	COVID-19
4	DE	00+	2022-03-29	2022-03-29	0 day ahead inc hosp	quantile	0.1	9131	COVID-19
5	DE	00+	2022-03-29	2022-03-29	0 day ahead inc hosp	quantile	0.25	9753	COVID-19
6	DE	00+	2022-03-29	2022-03-29	0 day ahead inc hosp	quantile	0.5	10534	COVID-19
7	DE	00+	2022-03-29	2022-03-29	0 day ahead inc hosp	quantile	0.75	11413	COVID-19
8	DE	00+	2022-03-29	2022-03-29	0 day ahead inc hosp	quantile	0.9	12292	COVID-19

`https://github.com/KITmetricslab/hospitalization-nowcast-hub/tree/main/data-truth/COVID-19`

Interactive online platform

`https://covid19nowcasthub.de/`



Interactive online platform

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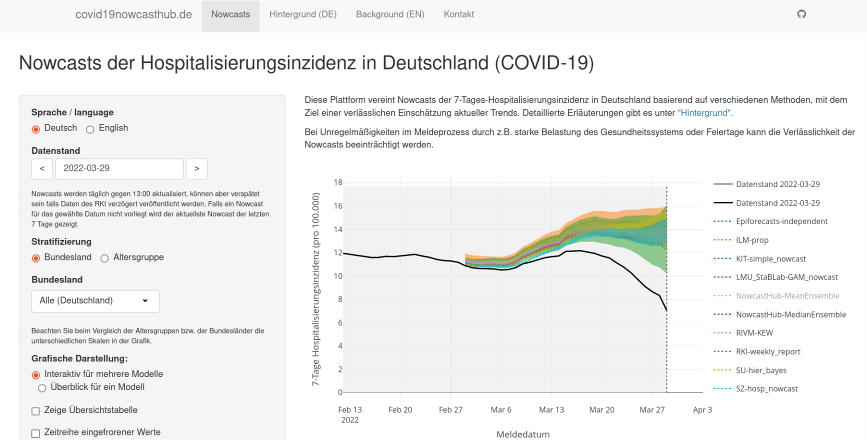


The statistical problem: completing the reporting triangle

Example with maximum reporting delay of 5 days. On day t^*, the black cells are known, the blue cells need to be estimated.

day	$d = 0$	$d = 1$	$d = 2$	$d = 3$	$d = 4$	$d = 5$	total
1	$x_{1,0}$	$x_{1,1}$	$x_{1,2}$	$x_{1,3}$	$x_{1,4}$	$x_{1,5}$	x_1
2	$x_{2,0}$	$x_{2,1}$	$x_{2,2}$	$x_{2,3}$	$x_{2,4}$	$x_{2,5}$	x_2
$\vdots$							
$t^* - 5$	$x_{t^*-5,0}$	$x_{t^*-5,1}$	$x_{t^*-5,2}$	$x_{t^*-5,3}$	$x_{t^*-5,4}$	$x_{t^*-5,5}$	x_{t^*-5}
$t^* - 4$	$x_{t^*-4,0}$	$x_{t^*-4,1}<$	$x_{t^*-4,2}$	$x_{t^*-4,3}$	$x_{t^*-4,4}$	$x_{t^*-4,4}$	x_{t^*-4}
$t^* - 3$	$x_{t^*-3,0}$	$x_{t^*-3,1}$	$x_{t^*-3,2}$	$x_{t^*-3,3}$	$x_{t^*-3,4}$	$x_{t^*-3,5}$	x_{t^*-3}
$t^* - 2$	$x_{t^*-2,0}$	$x_{t^*-2,1}$	$x_{t^*-2,2}$	$x_{t^*-2,3}$	$x_{t^*-2,4}$	$x_{t^*-2,5}$	x_{t^*-2}
$t^* - 1$	$x_{t^*-1,0}$	$x_{t^*-1,1}$	$x_{t^*-1,2}$	$x_{t^*-1,3}$	$x_{t^*-1,4}$	$x_{t^*-1,5}$	x_{t^*-1}
t^*	$x_{t^*,0}$	$x_{t^*,1}$	$x_{t^*,2}$	$x_{t^*,3}$	$x_{t^*,4}$	$x_{t^*,5}$	x_{t^*}

Approaches taken by different teams

Three main sources of information on unknown values:

- incomplete hospitalization numbers for same day
- incomplete hospitalization numbers from surrounding days
- case numbers

Strategies to extrapolate the reporting triangle:

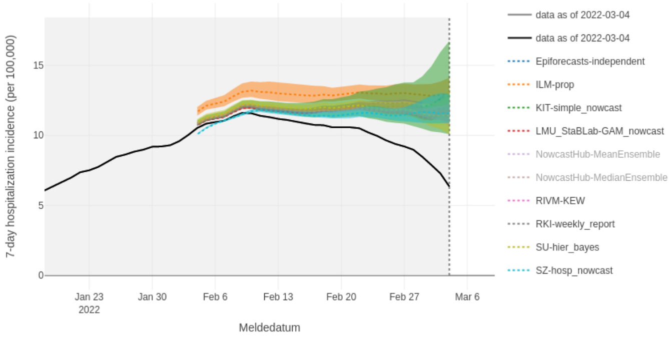
- Multiplication factors (KIT, RKI, SZ) ●
- Regression with splines for smooth time trends (RIVM Bilthoven, LMU Munich) ● ●
- Random walk / autoregression and parametric delay distributions (LSHTM, Stockholm University) ● ●
- Regression on case incidences (TU Ilmenau) ●

Additional difficulties

- Two types of within-week seasonality need to be taken into account:
  - seasonality in reporting of cases
  - seasonality in reporting of hospitalizations
- Delay patterns change over time, so choosing an appropriate data subset for trainint is important.
- Occasional major reporting issues can mess up things.

The ensemble

- The main output of the platform is an **ensemble nowcast**, i.e. combination of all available models.
- It is obtained as a simple quantile-wise mean (or median) of the different submissions.
- Intuition: We hope that similarly many models will be off upwards and downwards.



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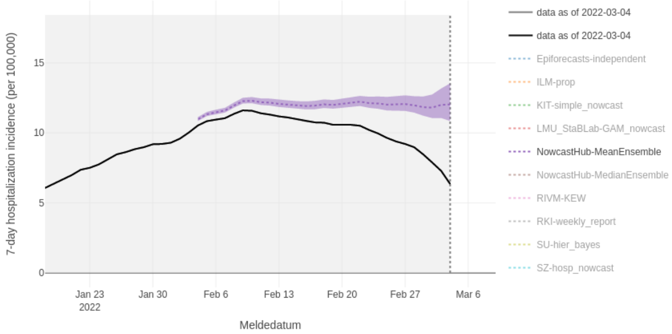
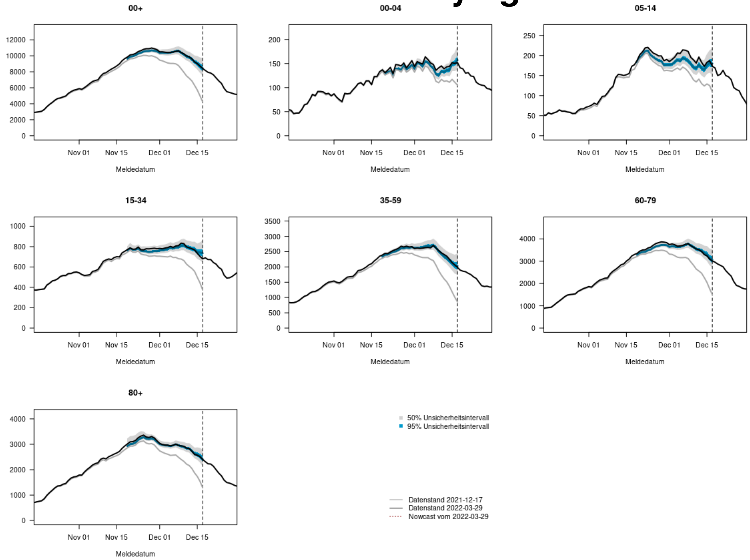
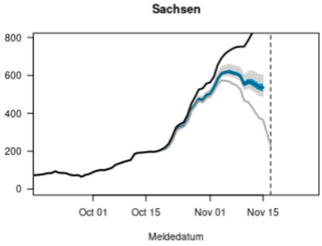


Nowcasts and later observed data nicely agree...

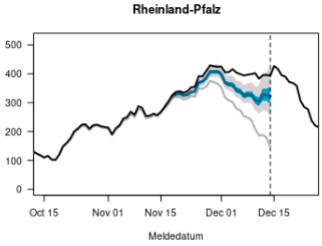


... except when they don't.

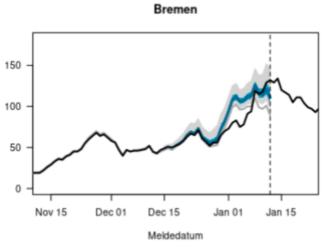
Saxony, 23 Nov 21



Rheinland-Pfalz, 14 Dec 21

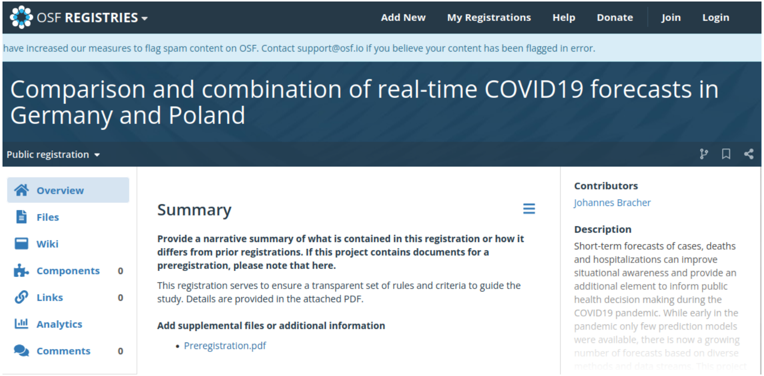


Bremen 12 Jan 22



Pre-registered evaluation study

- We are conducting a systematic evaluation study of real-time nowcasts from different methods.
- This study has been pre-registered (`https://osf.io/mru75/`) and runs from Nov 2021 through Apr 2022.



Preliminary evaluation of point and probabilistic nowcasts

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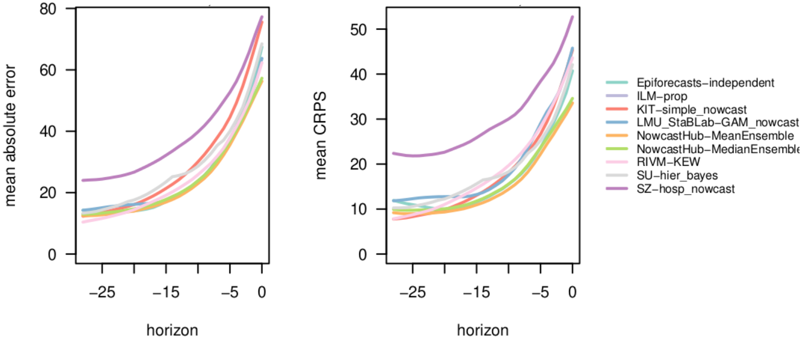
We use absolute errors and (approximate) CRPS to evaluate nowcasts probabilistically (lower is better).

Preliminary results (23 Nov – 10 Feb 22), averaged across states:

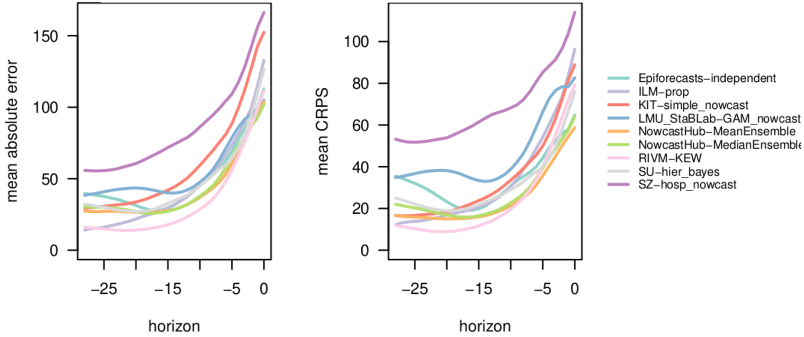


For reference: average observed value on the absolute scale is $\sim$ 500.
See also real-time evaluation by Sam Abbott:
`https://epiforecasts.io/eval-germany-sp-nowcasting/real-time-method-comparison/`

Preliminary evaluation of point and probabilistic nowcasts

We use absolute errors and (approximate) CRPS to evaluate nowcasts probabilistically (lower is better).

Results (until 10 Feb 22), averaged across age groups:



For reference: average observed value on the absolute scale is $\sim$ 1300.
See also real-time evaluation by Sam Abbott:
`https://epiforecasts.io/eval-germany-sp-nowcasting/real-time-method-comparison/`

Takeaways

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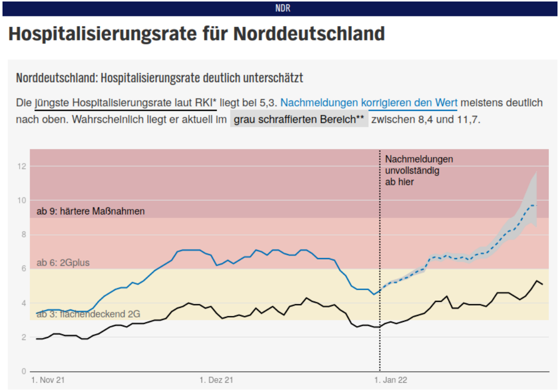
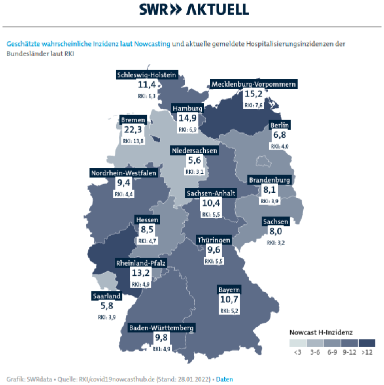
- In most cases, nowcasts have conveyed a good picture of actual trends.
- Most methods, however, have issued somewhat overconfident uncertainty intervals.
- In some instances (e.g., in Saxony in November), nowcasts have been strongly off. Sometimes we manage to warn users in these cases, sometimes this is hard to anticipate.
- Ensemble nowcasts improve somewhat, but not drastically upon individual models.
- **Collaborative work is rewarding and instructive.**

Dissemination

- The nowcasts have been used by numerous media outlets (Die Zeit, Süddeutsche Zeitung, Der Spiegel, Focus, Science Media Center Germany)





Thanks a lot to all contributors!

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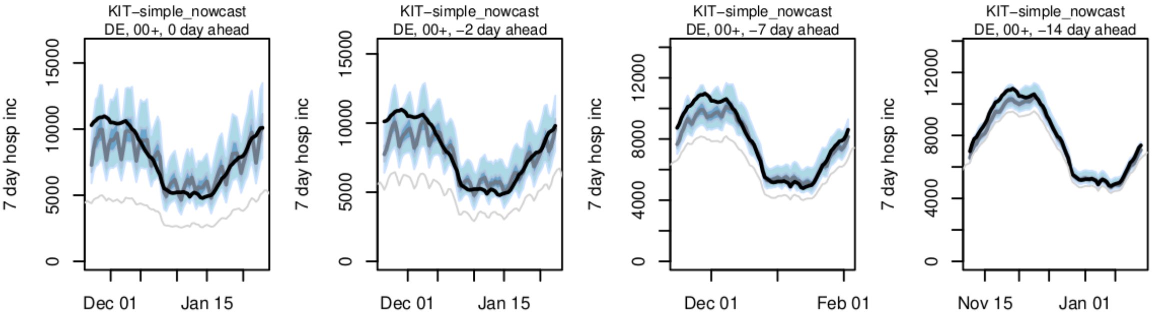
How well do the nowcasts work? (2)



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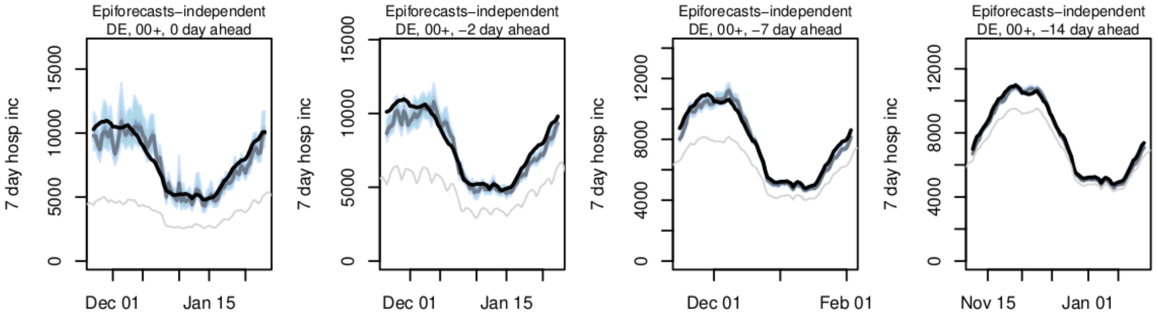

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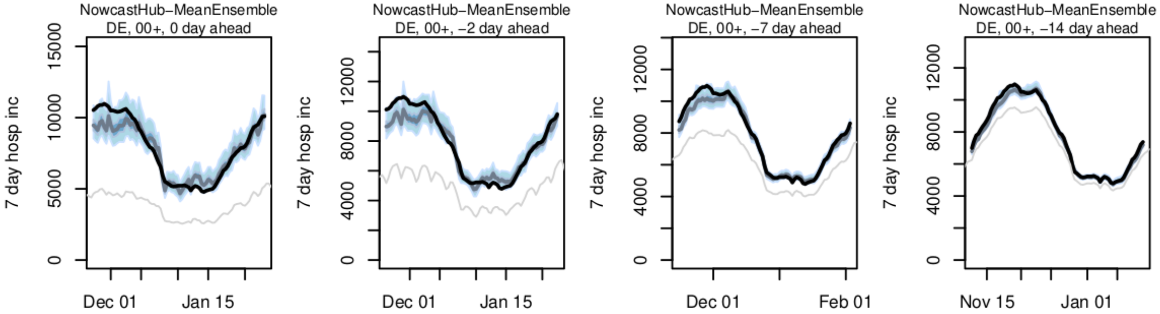
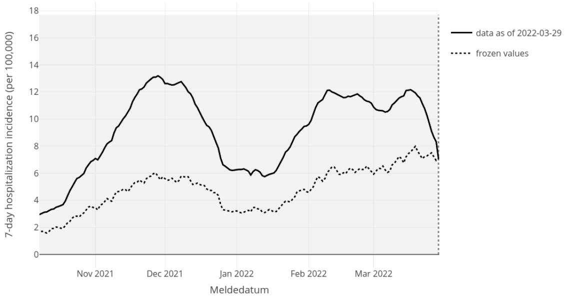


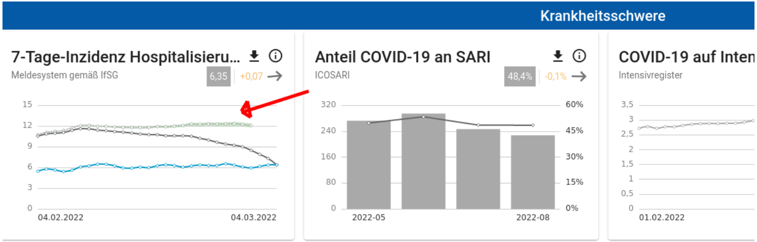
On a side note: “frozen values”

Official thresholds are based on *frozen values*:

- For each date use value as of that same date, without any retrospective completion
- All values are then “similarly incomplete” $\rightarrow$ trends interpretable
- Downsides:
  - reporting delays vary across Bundesländer
  - strong within-week seasonality



Corrected hospitalization incidences by Robert Koch Institute



Altersgruppen

Name	7-Tage-Inzidenz			Änderung 7-Tage-Inzidenz zu Vorwoche			Positivenanteil		
	Wert	Differenz	Trend	Wert	Differenz	Trend	Wert	Differenz	Trend
00-04	1.067,3	-43,18	↘	-4,02%	+4,43%	→	38,5%	+1,7%	↗
05-14	1.973,5	-361,57	↘	-15,48%	+2,86%	→	62,6%	-0,6%	→

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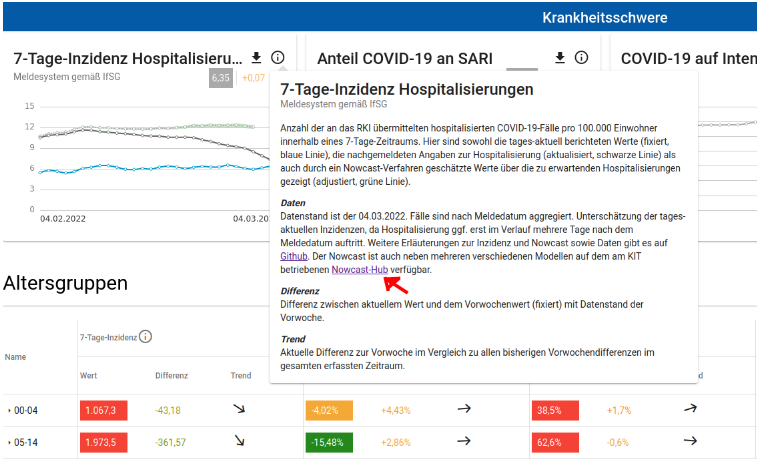

Example 1: The KIT model (“baseline”)

Three simple steps (similar to e.g. England and Verrall 2002):

- Fill in missing entries of reporting triangle using simple multiplication scheme:

day	$d = 0$	$d = 1$	$d = 2$	$d = 3$	total
1	$x_{1,0}$	$x_{1,1}$	$x_{1,2}$	$x_{1,3}$	x_1
2	$x_{2,0}$	$x_{2,1}$	$x_{2,2}$	$x_{2,3}$	x_2
$\vdots$					
$t^* - 2$	$x_{t^*-2,0}$	$x_{t^*-2,1}$	$x_{t^*-2,2}$	$x_{t^*-2,3}$	x_{t^*-2}
$t^* - 1$	$x_{t^*-1,0}$	$x_{t^*-1,1}$	$x_{t^*-1,2}$	$x_{t^*-1,3}$	x_{t^*-1}
t^*	$x_{t^*,0}$	$x_{t^*,1}$	$x_{t^*,2}$	$x_{t^*,3}$	x_{t^*}

E.g., $x_{t^*,1} = \frac{\sum_{i=1}^{t^*-1} x_{t^*-i,1}}{\sum_{i=1}^{t^*-1} x_{t^*-i,0}} \times x_{t^*,0}$

- Compute the same “estimates” for past time points, using data available up to the respective day.
- Obtain prediction intervals from past nowcast errors. *This is actually more tricky than it sounds.*

Example 2: The SU model (slide by F. Guenther)

Nowcasting - Bayesian hierarchical model

Notation

Main assumptions: (1) hospitalization curve is somewhat "smooth"
(2) delay patterns between infection and hospitalization constant
No assumptions on time-constant case hospitalization rate.

- $\lambda_{t,s}$: expected number of hospitalizations in strata s with infection registration at day $t = 0, \ldots, T$
- $p_{t,d,s}$: probability of individual (from group s) with registration at day t to be reported as hospitalized with delay $d = 0, \ldots, D$ (of all individuals that will become hospitalized)

delay distribution is modelled in a parametric fashion

Bayesian hierarchical model

Building up on Höhle [1], McGough [2], and Günther [3]

Latent random walk governing the overall hospitalization curve (= smoothness assumpt.)

$$\log(\lambda_{t,s}) | \lambda_{t-1,s} \sim \mathrm{N}(\log(\lambda_{t-1,s}) + \beta_{wd(t)}, \sigma_s^2)$$

$$n_{t,d,s} | \lambda_{t,s}, p_{t,d,s} \overset{iid}{\sim} \mathrm{NB}(\lambda_{t,s} \cdot p_{t,d,s}, \phi_s)$$

Hospitalizations with different delays modelled depending on delay distribution and latent random walk

- $n_{t,d,s}$: observed data for all $t + d \leq T$
- $p_{t,d}$ modelled discrete time hazard model