National Center for Immunization & Respiratory Diseases

Connecting Forecasting Research to Decision-making Needs: Lessons Learned from CDC-organized Activities

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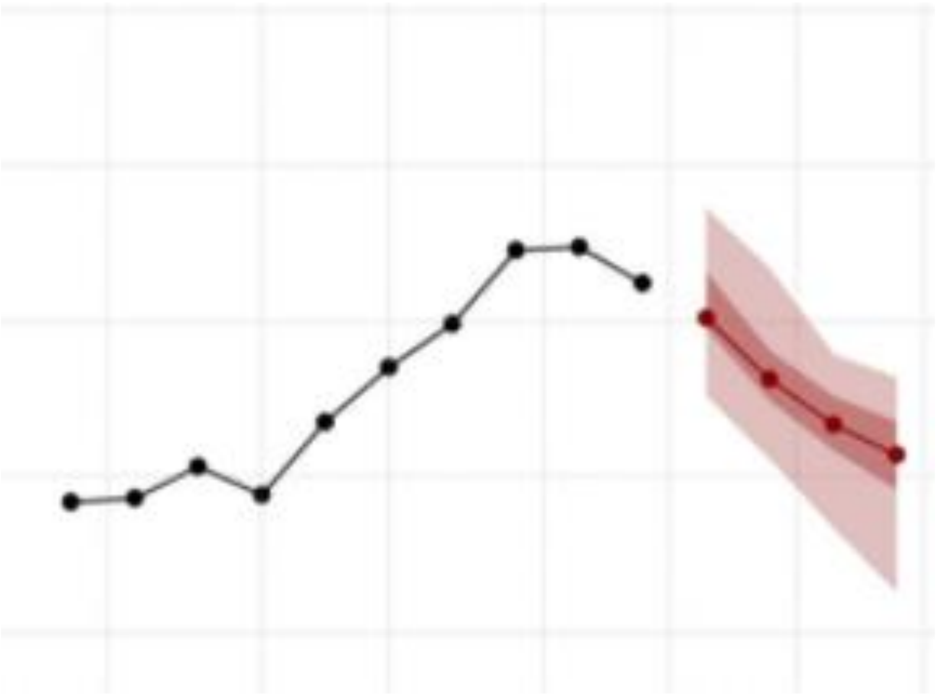


Why Forecast Epidemics and Pandemics?

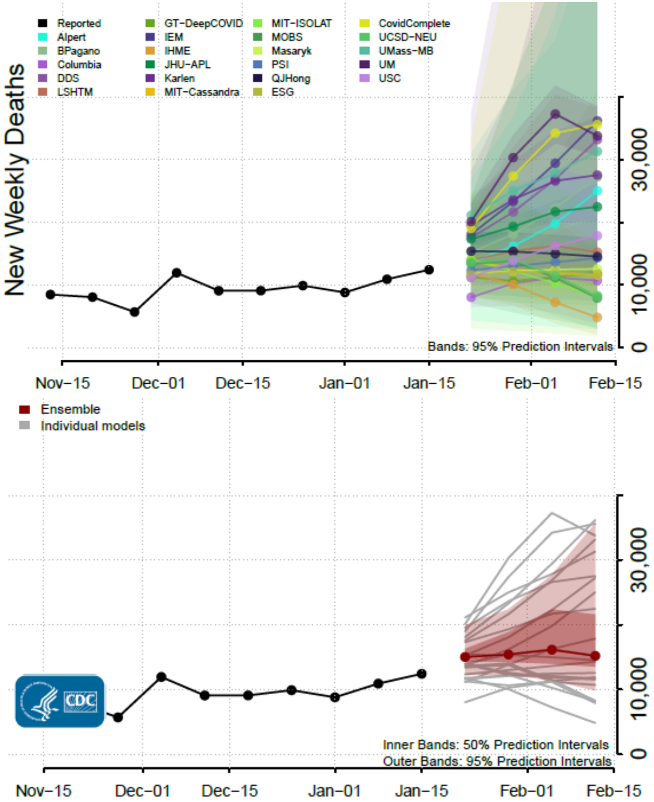
- Surveillance data provide insights into recent trends but do not show if and when changes may occur in the future
- A critical component of public health planning is anticipating changes in future trends to inform risk assessment, resource allocation, and healthcare preparedness
- Forecasts provide quantitative predictions of near-term most likely and plausible best- and worst-case futures

CDC Epidemic Prediction Initiative (established 2014)

- Objectives
  - Connect forecasting research to decision making needs
  - Evaluate forecast skill and facilitate forecasting research
  - Operationalize forecasting
- Forecasting projects
  - Influenza (2014–2020, 2022–2024)
  - Vector-borne: dengue (2015), Aedes mosquitoes (2019-2020), West Nile neuroinvasive disease (2020, 2022)
- Outcomes
  - Increased data availability and real-time forecasting
  - Forecast and evaluation standardization
  - Community building (e.g., CSTE, academia, industry)

COVID-19 Forecasting in the U.S.

- Built on the backbone of FluSight
- Began April 2020 and partnered with U Mass and CMU (CDC-funded Forecasting Centers of Excellence) to ensure forecasts solicited widely, stored openly, synthesized efficiently, communicated clearly, and evaluated honestly
- Cases (through 2021), hospitalizations, and deaths for nation, states/territories, and counties (cases only)
- 100+ academic, industry, and government teams participating
- Collected, disseminated, synthesized, and evaluated millions of real-time forecasts



Lessons Learned (or Reinforced) During COVID

1. Individual forecasts show high variability in skill but an ensemble forecast that combined these predictions was reliably one of the most accurate forecasts
2. Forecasts, including the ensemble, did not reliably predict changes in trends, especially for earlier outcomes (e.g., case reports)

Key Terms

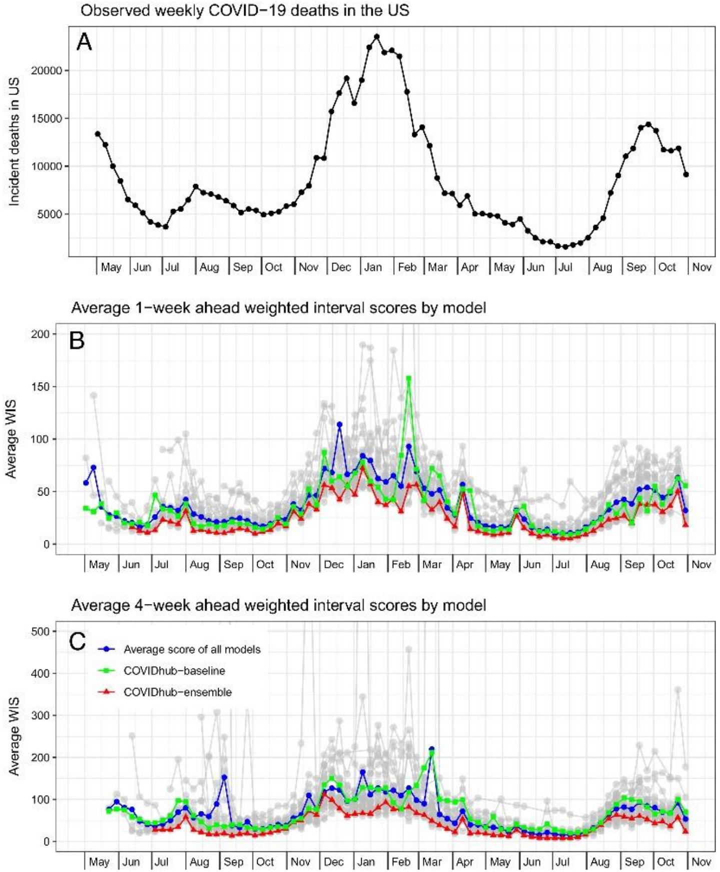
- **Baseline forecast**: A forecast generated for comparison. The COVID baseline model forecasted a median incidence equal to the last week, with uncertainty based on observation noise
- **Weighted Interval Score (WIS)**: Forecast skill metric that measures how consistent a collection of forecast prediction intervals is with an observed value. A lower value represents a better forecast
- **Coverage**: The percentage of times a prediction interval (such as 95%) correctly contains the observed value. It should be similar to the prediction interval
  - E.g., 95% of observations should fall within the 95% prediction interval

Lesson 1

Forecast skill varied but the ensemble was one of the most accurate forecasts

Performance between models varied but the ensemble was more accurate than most models

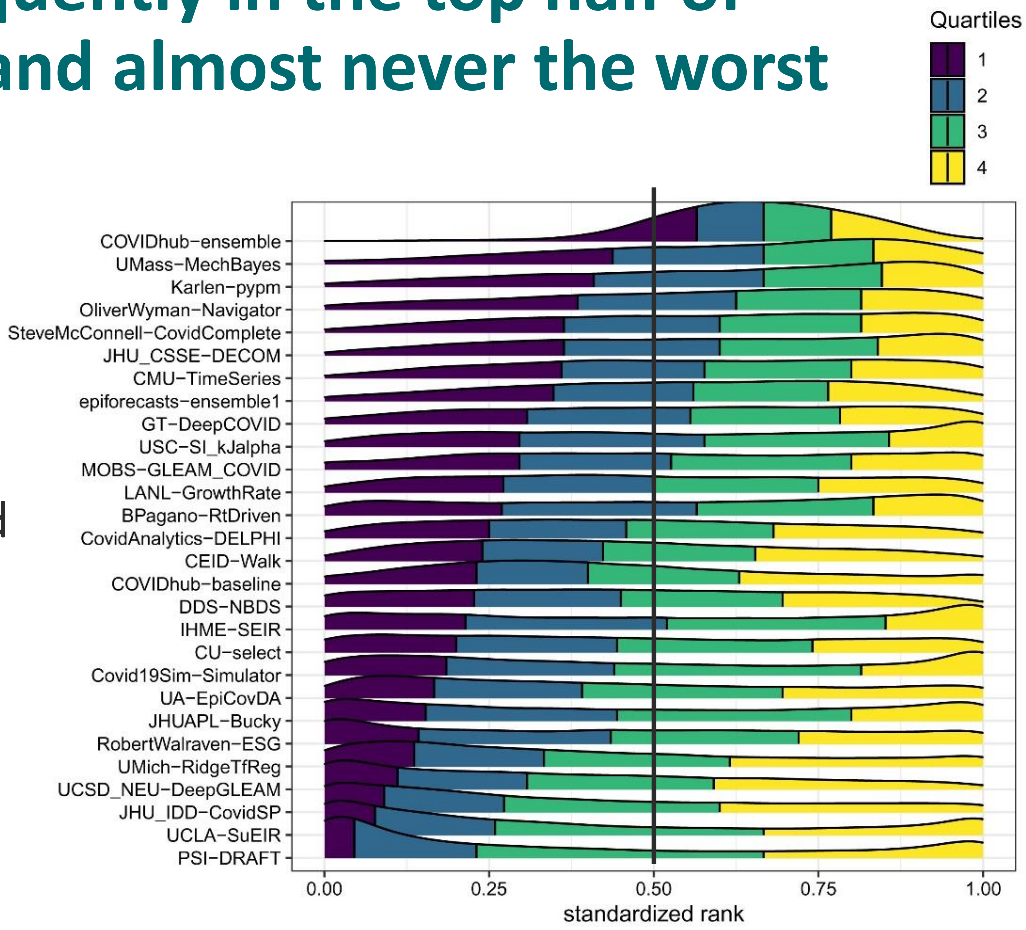
- The grey line is the WIS for individual models across all 50 states
- The blue line is the average for all models
- The green line is the baseline forecast
- The red line is the WIS for the ensemble model



https://www.pnas.org/doi/full/10.1073/pnas.2113561119

The ensemble was frequently in the top half of forecast performance and almost never the worst

- This figure compares each model's distribution of its WIS rank
- A rank of 1 indicates that the model had the best WIS for a particular location, target, and week, and 0 indicates it had the worst
- Yellow is the top quarter and purple is the bottom quarter



https://www.pnas.org/doi/full/10.1073/pnas.2113561119

Reasons for Model Variation

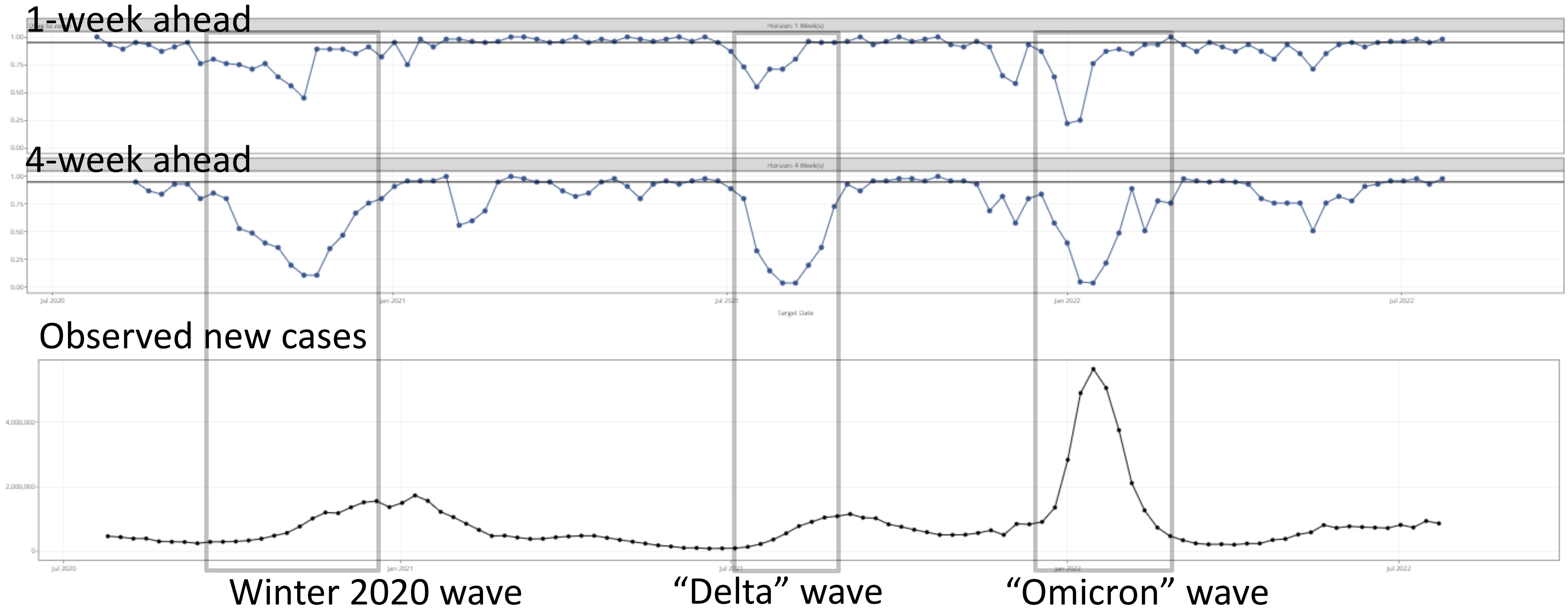
- Evaluated forecasts used different methods, data sources, and made varying assumptions about future transmission patterns
- Almost all models used case data as inputs to their forecast models, 10 models included data on COVID-19 hospitalizations, 10 models incorporated demographic data, and 9 models used mobility data
- 7 made explicit assumptions that social distancing and other behavioral patterns would change over the prediction period
- More evaluation needed to understand how behavioral, mobility, variant prevalence, or novel data streams forecasts

https://www.pnas.org/doi/full/10.1073/pnas.2113561119

Lesson 2

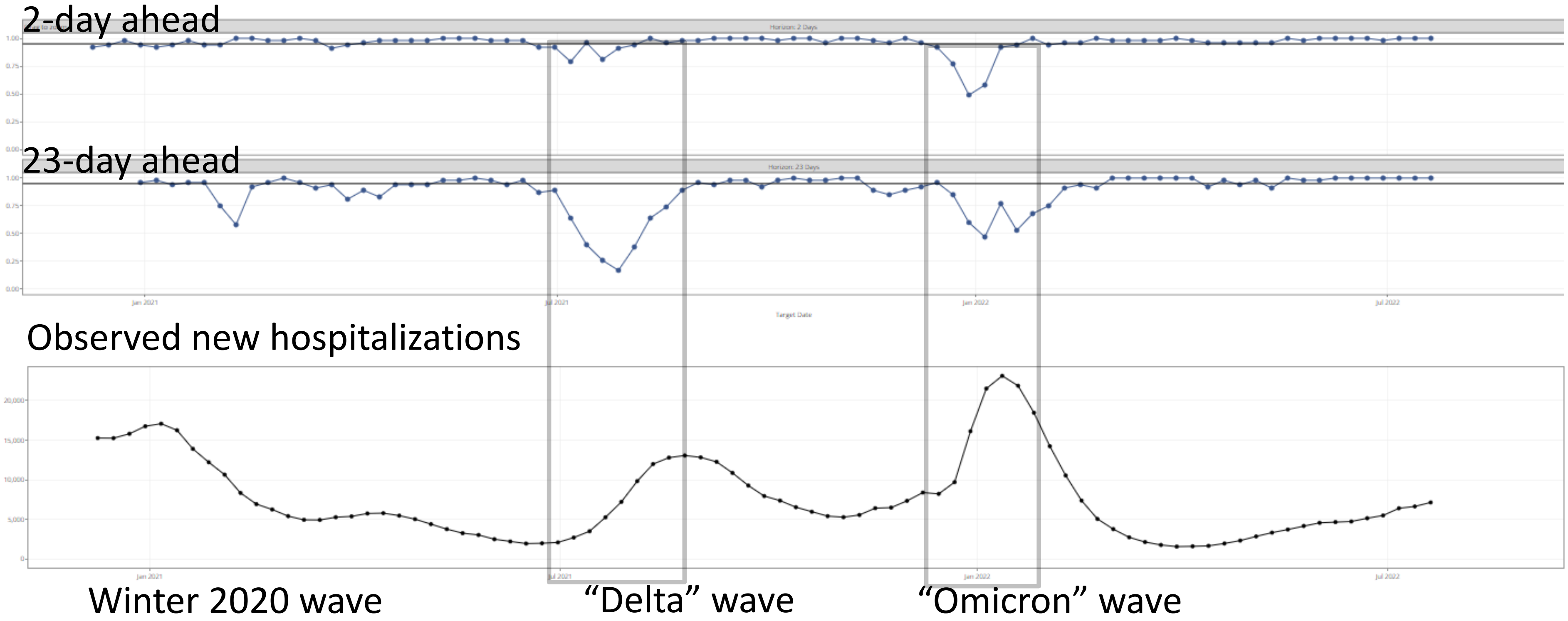
Forecasts, including the ensemble, do not always predict changes in trends, especially for earlier outcomes

Case ensemble forecast coverage (95% prediction interval)



https://delphi.cmu.edu/forecast-eval/

Hospital ensemble forecast coverage (95% prediction interval)



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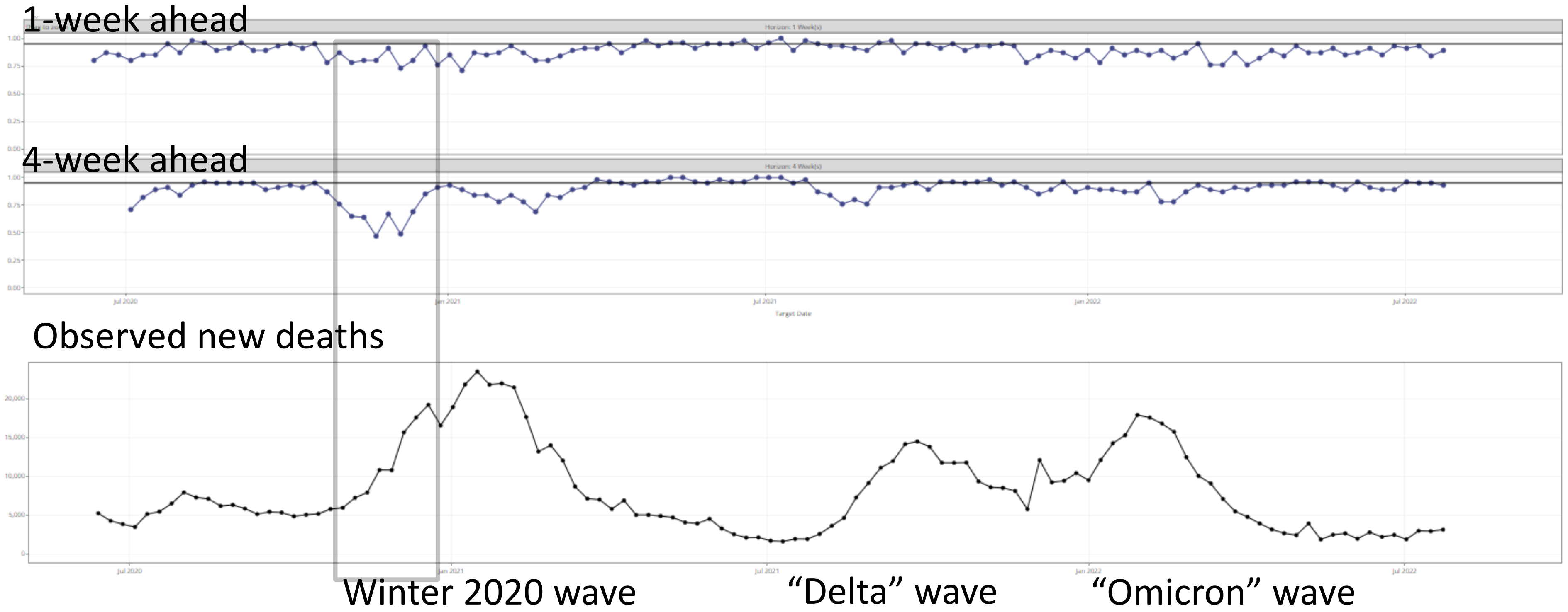
New deaths ensemble forecast coverage (95% prediction interval)



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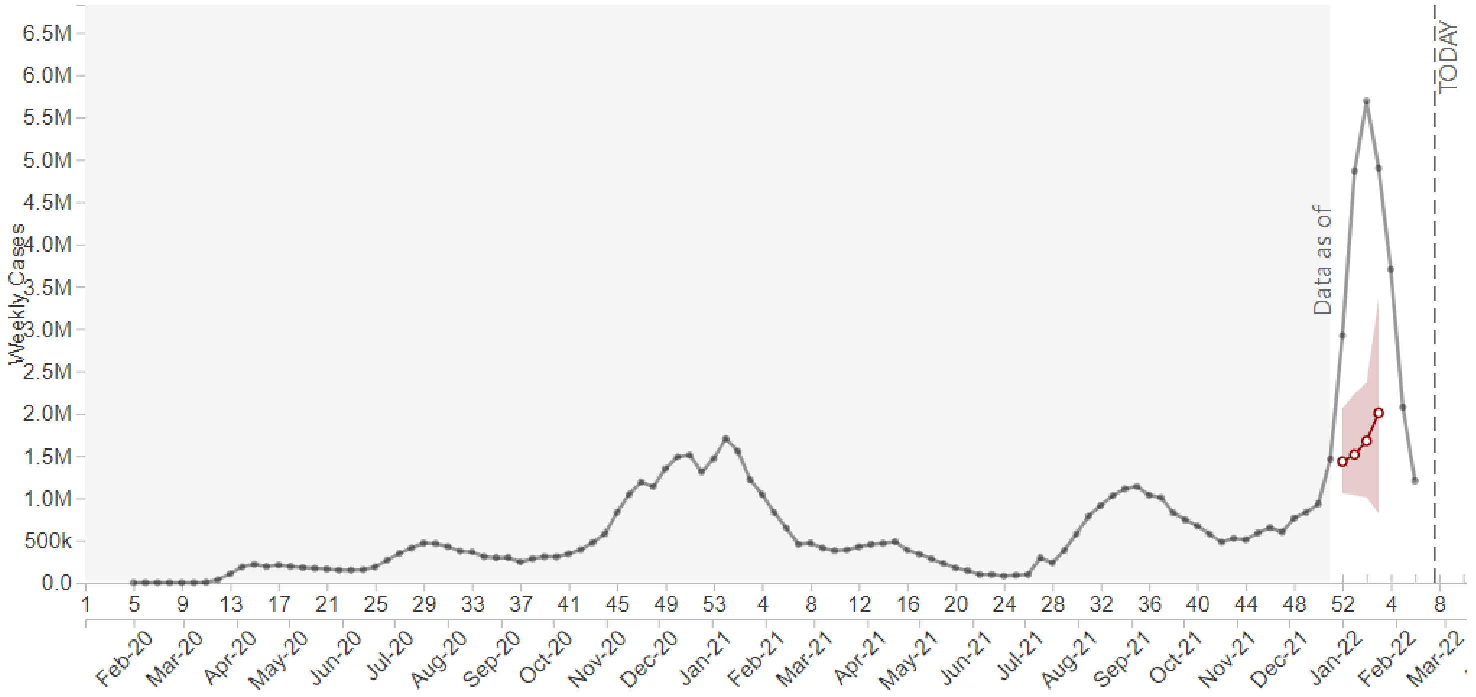
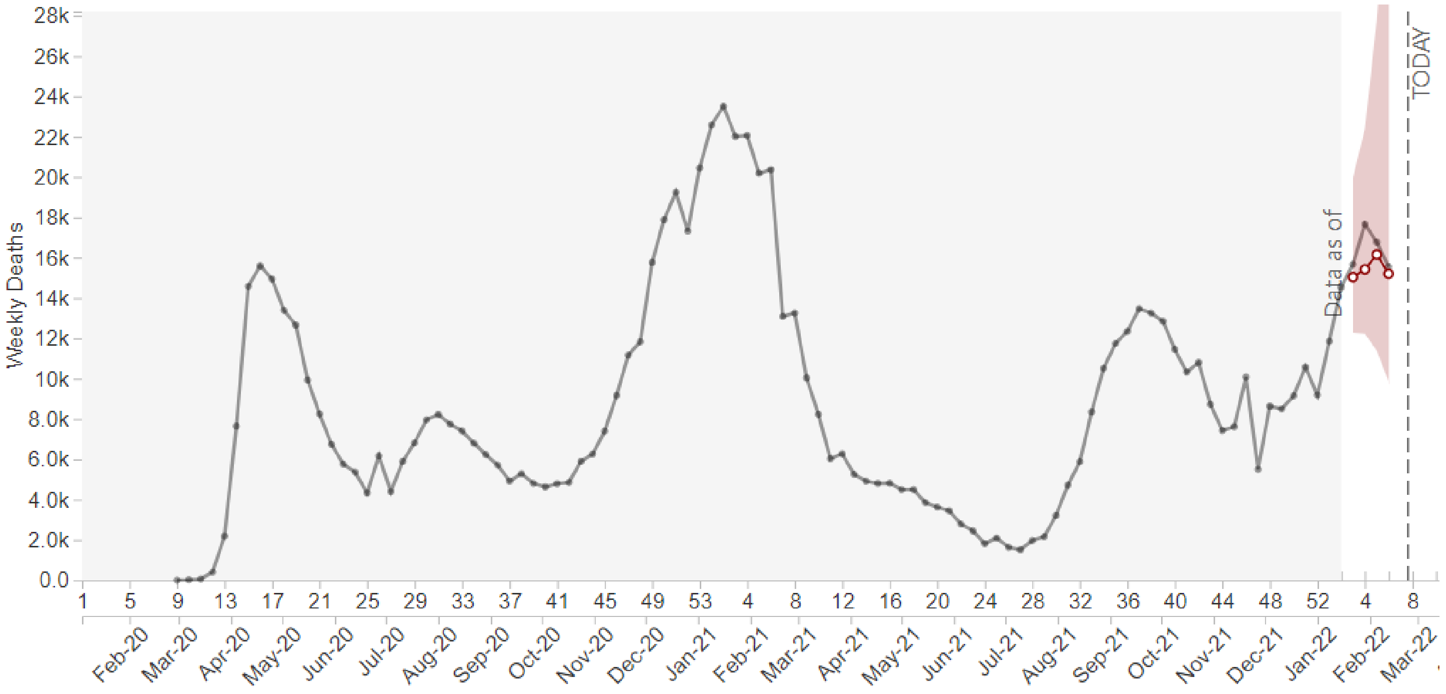
Comparison of case forecasts & reported data



https://www.cdc.gov/covid-data-tracker/#forecasting

Comparison of death forecasts & reported data

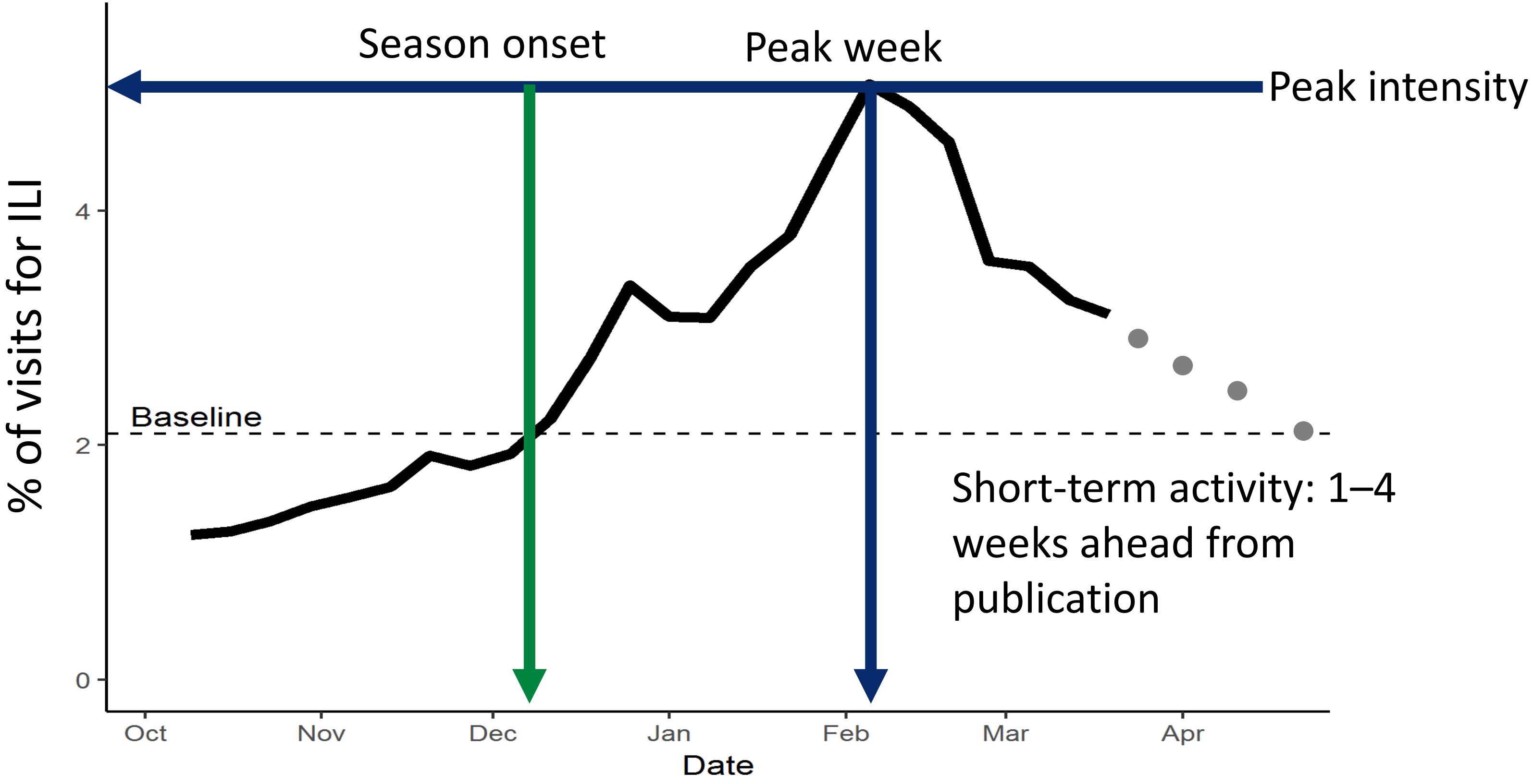


https://www.cdc.gov/covid-data-tracker/#forecasting

Future Plans

What are we doing for the 2022–23 season?

Previous influenza forecasting targets (data: ILINet)



Locations: US, 10 regions, and states

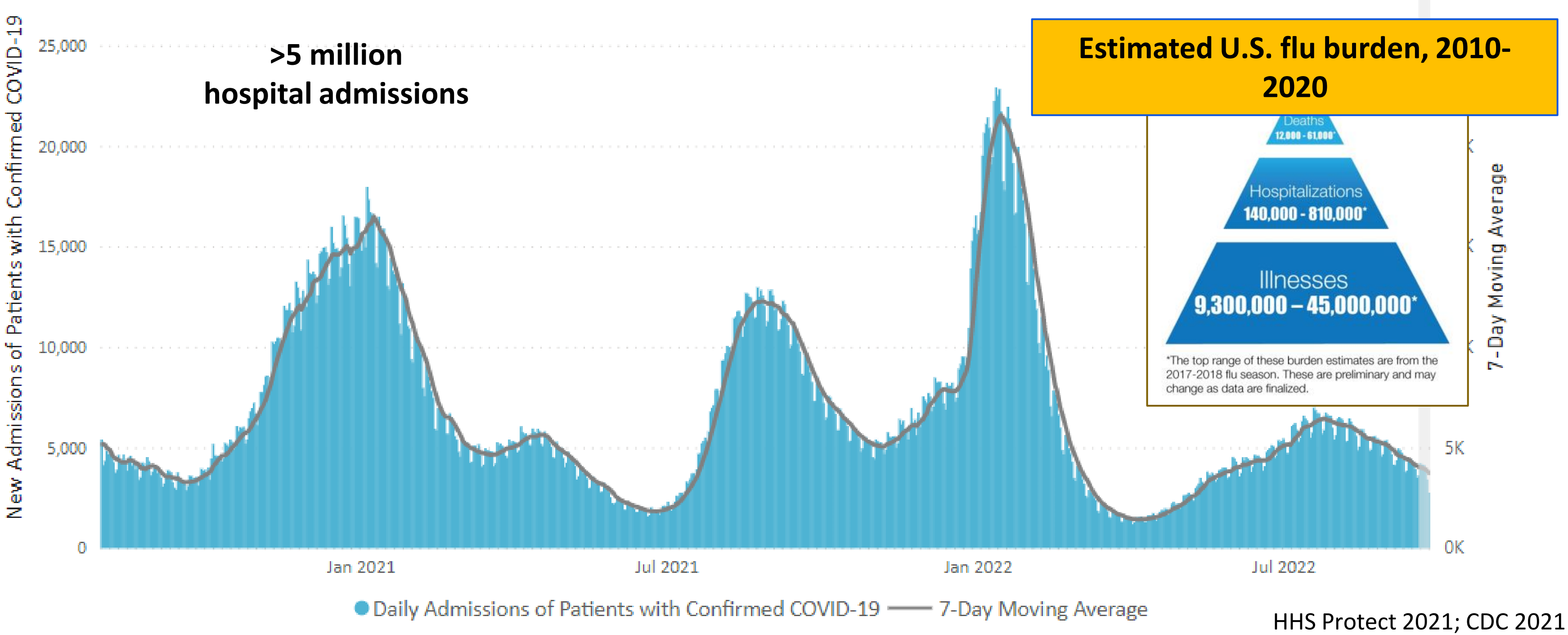
ILI as a flu indicator likely impacted by the pandemic

- ILI not laboratory-confirmed influenza
  - Captures visits due to other respiratory pathogens, such as SARS-CoV-2, that present with similar symptoms
- Healthcare-seeking behaviors have changed dramatically during the COVID-19 pandemic
  - Many people either not accessing the healthcare system or doing it in alternative settings, which may or may not be captured as a part of ILINet

Need to Monitor Hospital Burden Caused by Both COVID-19 and Influenza

In the past year, high number of laboratory-confirmed COVID-19 hospital admissions

HHS Protect Unified Hospital data source, August 2020-September 2022



HHS Protect 2021; CDC 2021

Plans for flu forecasting for the 2022–23 season

- Source: HHS Protect facility-level hospital data
- Main Target: Weekly number of confirmed influenza hospital admissions (same target as COVID hospitalization forecasts)
- Horizon: Up to 4 weeks
- Potential "Experimental" Targets: Increase/decrease or trajectory samples
- Geography: National and state
- Start date: mid-October 2022
- Communication: FluSight webpage
  - https://www.cdc.gov/flu/weekly/flusight/index.html

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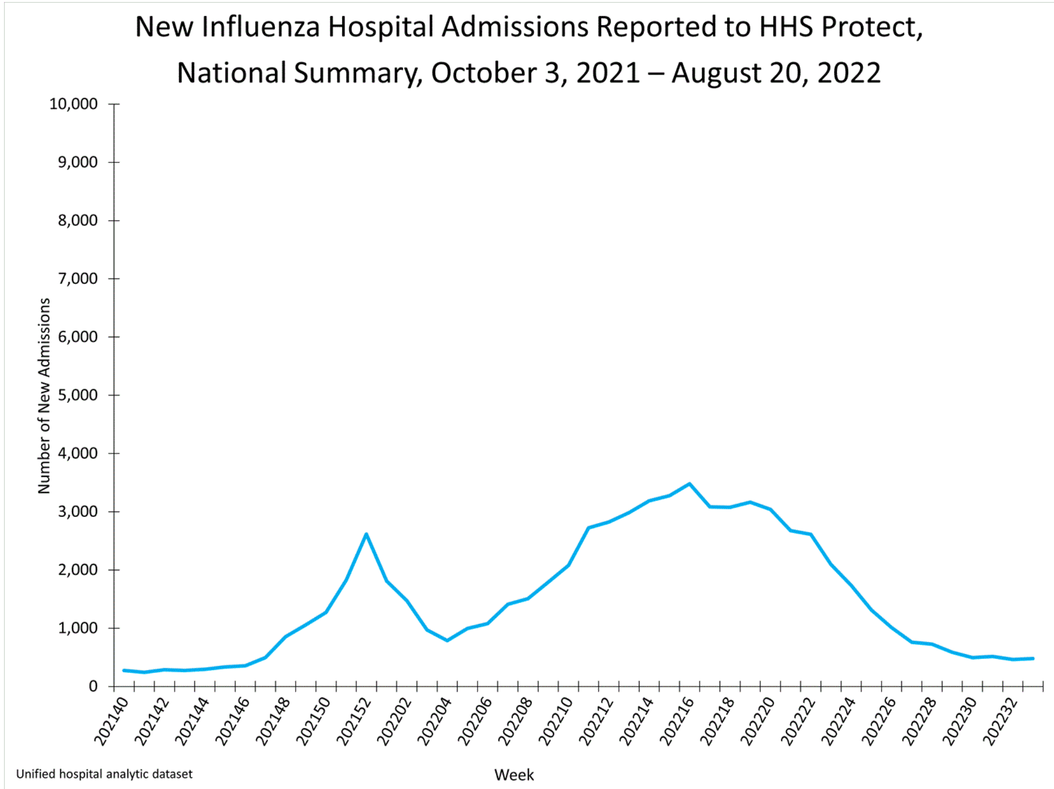
National New Flu Hospital Admissions, October 2021–August 2022

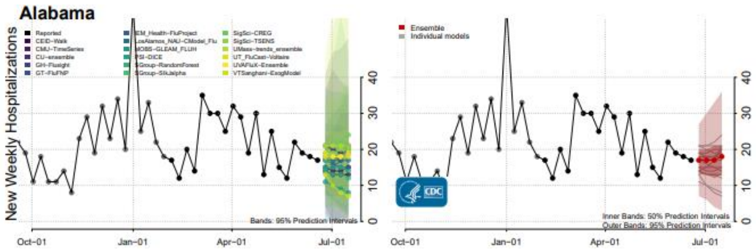


CDC Flu Forecast Communication

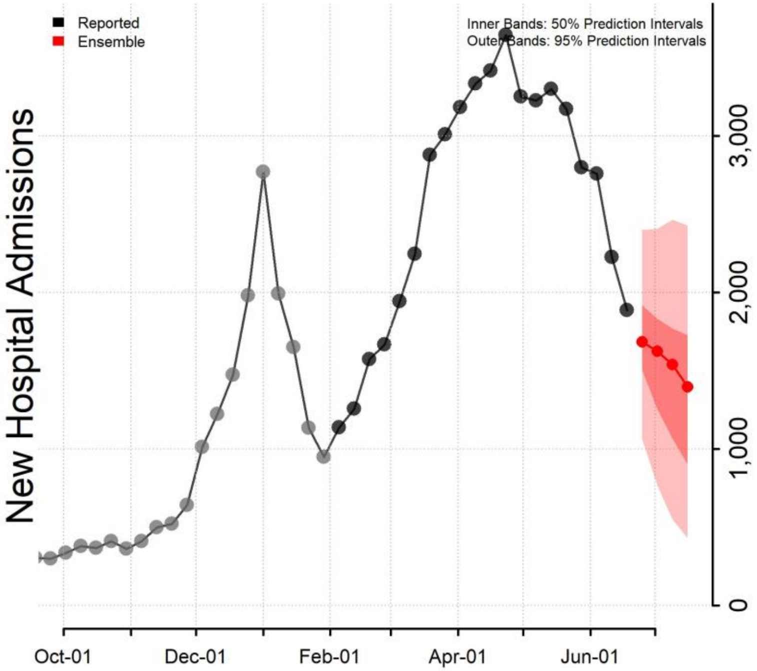
Reported and forecasted new influenza hospitalizations as of June 20, 2022.

Interpretation of National Forecasts of New Hospitalizations

- This week's ensemble predicts that the number of new weekly confirmed influenza hospital admissions will likely decrease nationally, with **400 to 2,400** new confirmed influenza hospital admissions likely reported in the week ending July 16, 2022.
- This week, 15 modeling groups contributed one or more forecasts that were eligible for inclusion in the new hospitalization ensemble forecasts for at least one jurisdiction. Contributing teams are listed below.
- Ensemble forecasts combine diverse independent team forecasts into one forecast. They have been among the most reliable forecasts in performance for previous influenza and COVID-19 forecasts, but even the ensemble forecasts may not reliably predict rapid changes in the trends.
- The figure shows the number of new confirmed influenza hospital admissions reported in the United States each week from September 26 through June 18 and forecasted new influenza hospital admissions per week over the next 4 weeks, through July 16. Effective February 2, 2022, hospitals are required to report laboratory-confirmed influenza hospitalizations to HHS Protect daily. Prior to this update, reporting influenza hospitalizations was optional (noted as grey in the above figure). [See COVID-19 Guidance for Hospital Reporting and FAQs] for additional details on this guidance.



National Forecast



https://www.cdc.gov/flu/weekly/flusight/index.html

Conclusions

- Forecasting lessons from COVID-19:
  - An ensemble is a robust option for public health
  - Forecast performance can degrade near inflection points
- Ensuring that future influenza forecasting efforts improve on and incorporate the lessons learned and best practices identified during COVID-19 activities will improve the utility of future a forecasts
- CDC continues to build on previous efforts to forecast COVID and flu into the future

Acknowledgements

- CDC colleagues; current and previous forecasting teams; data providers; state, tribal, territorial, and local public health officials

Evaluation of individual and ensemble probabilistic forecasts of COVID-19 mortality in the United States

Estee Y Cramer[1], Evan L Ray[1], Velma K Lopez[2], Johannes Bracher[3,4], Andrea Brennen[5], Alvaro J Castro Rivadeneira[1], Aaron Gerding[1], Tilmann Gneiting[4,6], Katie H House[1], Yuxin Huang[1], Dasuni Jayawardena[1], Abdul H Kanji[1], Ayush Khandelwal[1], Khoa Le[1], Anja Mühlemann[7], Jarad Niemi[8], Apurv Shah[1], Ariane Stark[1], Yijin Wang[1], Nutcha Wattanachit[1], Martha W Zorn[1], Youyang Gu[9], Sansiddh Jain[10], Nayana Bannur[10], Ayush Deva[10], Mihir Kulkarni[10], Srujana Merugu[10], Alpan Raval[10], Siddhant Shingi[10], Avtansh Tiwari[10], Jerome White[10], Neil F Abernethy[11], Spencer Woody[12], Maytal Dahan[13], Spencer Fox[12], Kelly Gaither[13], Michael Lachmann[14], Lauren Ancel Meyers[12], James G Scott[15], Mauricio Tec[16], Ajitesh Srivastava[17], Glover E George[18], Jeffrey C Cegan[19], Ian D Dettwiller[18], William P England[18], Matthew W Farthing[18], Robert H Hunter[18], Brandon Lafferty[18], Igor Linkov[19], Michael L Mayo[18], Matthew D Parno[20], Michael A Rowland[18], Benjamin D Trump[19], Yanli Zhang-James[21], Samuel Chen[22], Stephen V Faraone[21], Jonathan Hess[21], Christopher P Morley[23], Asif Salekin[24], Dongliang Wang[23], Sabrina M Corsetti[25], Thomas M Baer[26], Marisa C Eisenberg[27,28,29], Karl Falb[25], Yitao Huang[25], Emily T Martin[29], Ella McCauley[25], Robert L Myers[25], Tom Schwarz[25], Daniel Sheldon[30], Graham Casey Gibson[31], Rose Yu[32,33], Liyao Gao[34], Yian Ma[35], Dongxia Wu[32], Xifeng Yan[36], Xiaoyong Jin[36], Yu-Xiang Wang[36], YangQuan Chen[37], Lihong Guo[38], Yanting Zhao[39], Quanquan Gu[40], Jinghui Chen[40], Lingxiao Wang[40], Pan Xu[40], Weitong Zhang[40], Difan Zou[40], Hannah Biegel[41], Joceline Lega[41], Steve McConnell[42], V P Nagraj[43], Stephanie L Guertin[43], Christopher Hulme-Lowe[44], Stephen D Turner[43], Yunfeng Shi[45], Xuegang Ban[46], Robert Walraven[47], Qi-Jun Hong[48,49], Stanley Kong[50], Axel van de Walle[49], James A Turtle[51], Michal Ben-Nun[51], Steven Riley[52], Pete Riley[51], Ugur Koyluoglu[53], David DesRoches[54], Pedro Forli[55], Bruce Hamory[56], Christina Kyriakides[57], Helen Leis[58], John Milliken[53], Michael Moloney[53], James Morgan[53], Ninad Nirgudkar[59], Gokce Ozcan[53], Noah Piwonka[58], Matt Ravi[59], Chris Schrader[58], Elizabeth Shakhnovich[58], Daniel Siegel[53], Ryan Spatz[59], Chris Stiefeling[60], Barrie Wilkinson[61], Alexander Wong[57], Sean Cavany[62], Guido España[62], Sean Moore[62], Rachel Oidtman[62,63], Alex Perkins[62], David Kraus[64], Andrea Kraus[64], Zhifeng Gao[65], Jiang Bian[65], Wei Cao[65], Juan Lavista Ferres[65], Chaozhuo Li[65], Tie-Yan Liu[65], Xing Xie[65], Shun Zhang[65], Shun Zheng[65], Alessandro Vespignani[66,67], Matteo Chinazzi[67], Jessica T Davis[67], Kunpeng Mu[67], Ana Pastore Y Piontti[67], Xinyue Xiong[67], Andrew Zheng[68], Jackie Baek[68], Vivek Farias[69], Andreea Georgescu[68], Retsef Levi[69], Deeksha Sinha[68], Joshua Wilde[68], Georgia Perakis[70], Mohammed Amine Bennouna[70], David Nze-Ndong[70], Divya Singhvi[71], Ioannis Spantidakis[70], Leann Thayaparan[70], Asterios Tsiourvas[70], Arnab Sarker[72], Ali Jadbabaie[72], Devavrat Shah[72], Nicolas Della Penna[73], Leo A Celi[73], Saketh Sundar[74], Russ Wolfinger[75], Dave Osthus[76], Lauren Castro[77], Geoffrey Fairchild[77], Isaac Michaud[76], Dean Karlen[78,79], Matt Kinsey[80], Luke C Mullany[80], Kaitlin Rainwater-Lovett[80], Lauren Shin[80], Katharine Tallaksen[80], Shelby Wilson[80], Elizabeth C Lee[81], Juan Dent[81], Kyra H Grantz[81], Alison L Hill[82], Joshua Kaminsky[81], Kathryn Kaminsky[83], Lindsay T Keegan[84], Stephen A Lauer[81], Joseph C Lemaitre[85], Justin Lessler[81], Hannah R Meredith[81], Javier Perez-Saez[81], Sam Shah[86], Claire P Smith[81], Shaun A Truelove[81,87,88], Josh Wills[86], Maximilian Marshall[89], Lauren Gardner[89], Kristen Nixon[89], John C Burant[90], Lily Wang[8], Lei Gao[91], Zhiling Gu[8], Myungjin Kim[8], Xinyi Li[92], Guannan Wang[93], Yueying 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Saksham Soni[68], Hamza Tazi Bouardi[68], Turgay Ayer[101,109], Madeline Adee[110], Jagpreet Chhatwal[110], Ozden O Dalgic[111], Mary A Ladd[110], Benjamin P Linas[112], Peter Mueller[110], Jade Xiao[101], Yuanjia Wang[113,114], Qinxia Wang[113], Shanghong Xie[113], Donglin Zeng[115], Alden Green[116], Jacob Bien[117], Logan Brooks[116], Addison J Hu[116], Maria Jahja[116], Daniel McDonald[118], Balasubramanian Narasimhan[119,120], Collin Politsch[121], Samyak Rajanala[120], Aaron Rumack[121], Noah Simon[122], Ryan J Tibshirani[116], Rob Tibshirani[120], Valerie Ventura[116], Larry Wasserman[116], Eamon B O'Dea[123], John M Drake[123], Robert Pagano[124], Quoc T Tran[125], Lam Si Tung Ho[126], Huong Huynh[127], Jo W Walker[2], Rachel B Slayton[2], Michael A Johansson[2], Matthew Biggerstaff[2], Nicholas G Reich[1]

An open challenge to advance probabilistic forecasting for dengue epidemics

Michael A Johansson[1,2], Karyn M Apfeldorf[3], Scott Dobson[3], Jason Devita[3], Anna L Buczak[4], Benjamin Baugher[4], Linda J Moniz[4], Thomas Bagley[4], Steven M Babin[4], Erhan Guven[4], Teresa K Yamana[5], Jeffrey Shaman[5], Terry Moschou[6], Nick Lothian[6], Aaron Lane[6], Grant Osborne[6], Gao Jiang[7], Logan C Brooks[8], David C Farrow[8], Sangwon Hyun[9], Ryan J Tibshirani[8,9], Roni Rosenfeld[8], Justin Lessler[10], Nicholas G Reich[11], Derek A T Cummings[12,13], Stephen A Lauer[11], Sean M Moore[14,15], Hannah E Clapham[16], Rachel Lowe[17,18], Trevor C Bailey[19], Markel García-Díez[20], Marilia Sá Carvalho[21], Xavier Rodó[18,22], Tridip Sardar[22], Richard Paul[23,24], Evan L Ray[25], Krzysztof Sakrejda[11], Alexandria C Brown[11], Xi Meng[11], Osonde Osoba[26], Raffaele Vardavas[26], David Manheim[27], Melinda Moore[26], Dhananjai M Rao[28], Travis C Porco[29], Sarah Ackley[29], Fengchen Liu[29], Lee Worden[29], Matteo Convertino[30], Yang Liu[31], Abraham Reddy[31], Eloy Ortiz[32], Jorge Rivero[32], Humberto Brito[32,33], Alicia Juarrero[32,34], Leah R Johnson[35], Robert B Gramacy[36], Jeremy M Cohen[36], Erin A Mordecai[37], Courtney C Murdock[38,39], Jason R Rohr[14,15], Sadie J Ryan[13,40,41], Anna M Stewart-Ibarra[42], Daniel P Weikel[43], Antarpreet Jutla[44], Rakibul Khan[44], Marissa Poultney[44], Rita R Colwell[45], Brenda Rivera-García[46], Christopher M Barker[47], Jesse E Bell[48], Matthew Biggerstaff[49], David Swerdlow[49], Luis Mier-Y-Teran-Romero[50,10], Brett M Forshey[51], Juli Trtanj[52], Jason Asher[53], Matt Clay[53], Harold S Margolis[50], Andrew M Hebbeler[54,55], Dylan George[55,56], Jean-Paul Chretien[55,57]

Applying infectious disease forecasting to public health: a path forward using influenza forecasting examples

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