

Supplementary Materials for
**Monthly excess mortality across counties in the United States during the
COVID-19 pandemic, March 2020 to February 2022**

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The PDF file includes:

Supplementary Text
Figs. S1 to S3
Tables S1 to S3
Data S1

Supplementary Text

Data Extraction from CDC WONDER

The CDC WONDER online database query system found at <https://wonder.cdc.gov/> was used to extract all mortality data used in this project. To obtain death counts for all-cause mortality, we used the Multiple Cause of Death (Final) database from 1999-2020. We obtained two main sets of extracts, one for data at the county-month level and one for data at the county-year level (to investigate suppression). In order to minimize suppression, additional extracts were obtained at the wave level and the pandemic year level (pooling different months) for all figures and tables using these longer time periods. For all-cause mortality extracts, the data request was submitted for the time period of interest using the request form with the following settings:

- Tab 1. Organize table layout: Group results by County and by: Month for monthly data, Year for yearly data, and no additional group for wave and pandemic year data
- Tab 4. Select time period of death: specific period
- Tab 6. Select underlying cause of death: *All* (All Causes of Death)
- Tab 8. Other options: checking Export Results. The request generates a text file.

To extract data for the time periods of March 2020 to February 2022, we used the Multiple Cause of Death (Provisional) database from 2018 – Last Month database. The data requests were submitted for each time period of interest using the request form with the following settings:

- Tab 1. Organize table layout: Group results by County and by: Month for monthly data, Year for yearly data, and no additional group for wave and pandemic year data
- Tab 4. Select time period of death: March 2020 to February 2022
- Tab 6. Select underlying cause of death: *All* (All Causes of Death)

- Tab 8. Other options: checking Export Results. The request generates a text file.

Geographic Classifications

USDA/ERS/NCHS Metropolitan-Nonmetropolitan Categories:

- **Large central metros:** counties in metropolitan statistical areas with a population of 1 million or more that (1) contain the entire population of the largest principal city of the metropolitan statistical area, (2) whose entire population resides in the largest principal city of the metropolitan statistical area, or (3) contain at least 250,000 of the population of any principal city in the metropolitan statistical area
- **Large fringe metros:** counties in metropolitan statistical areas of a population of 1 million or more that do not meet the definition of large central metros
- **Small or medium metros:** counties in metropolitan statistical areas with a population between 50,000 and 999,999.
- **Nonmetro areas:** all other counties.

U.S. Census Divisions:

- **New England:** Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont
- **Middle Atlantic:** New Jersey, New York, Pennsylvania
- **East North Central:** Indiana, Illinois, Michigan, Ohio, Wisconsin
- **West North Central:** Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota
- **South Atlantic:** Delaware, District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia
- **East South Central:** Alabama, Kentucky, Mississippi, Tennessee
- **West South Central:** Arkansas, Louisiana, Oklahoma, Texas
- **Mountain:** Arizona, Colorado, Idaho, New Mexico, Montana, Utah, Nevada, Wyoming
- **Pacific:** Alaska, California, Hawaii, Oregon, and Washington

U.S. Census Regions:

- **Midwest:** Indiana, Illinois, Michigan, Ohio, Wisconsin, Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota
- **Northeast:** Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont, New Jersey, New York, Pennsylvania
- **South:** Delaware, District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia, Alabama, Kentucky, Mississippi, Tennessee, Arkansas, Louisiana, Oklahoma, Texas
- **West:** Arizona, Colorado, Idaho, New Mexico, Montana, Utah, Nevada, Wyoming,

Alaska, California, Hawaii, Oregon, and Washington

Model Definition in INLA

We report here the model definition in INLA. This should help the reader understand the specifics of the model and interpret the supplemental tables and figures, reporting (graphically or in table format) the posterior distribution of the model's parameters and hyperparameters with the exception of the random effects for the counties.

```
# priors
hyper.bym <- list(theta1 = list('PCprior', param=c(1, 0.01)),
                 theta2 = list('PCprior', param=c(0.5, 0.5)))
hyper.iid <- list(theta = list(prior="pc.prec", param=c(1, 0.01)))
hyper.ar1 <- list(theta1 = list(prior="pc.prec", param=c(1, 0.01)))

# model formula
formula <- deaths ~ 1 + offset(log(pop)) + timeID +
           as.factor(month)*as.factor(divisionID) +
           f(FIPSID, model='bym2', hyper=hyper.bym,
             graph=inla.graph, scale.model=T) +
           f(timeID2, model='ar1', hyper=hyper.ar1)
```

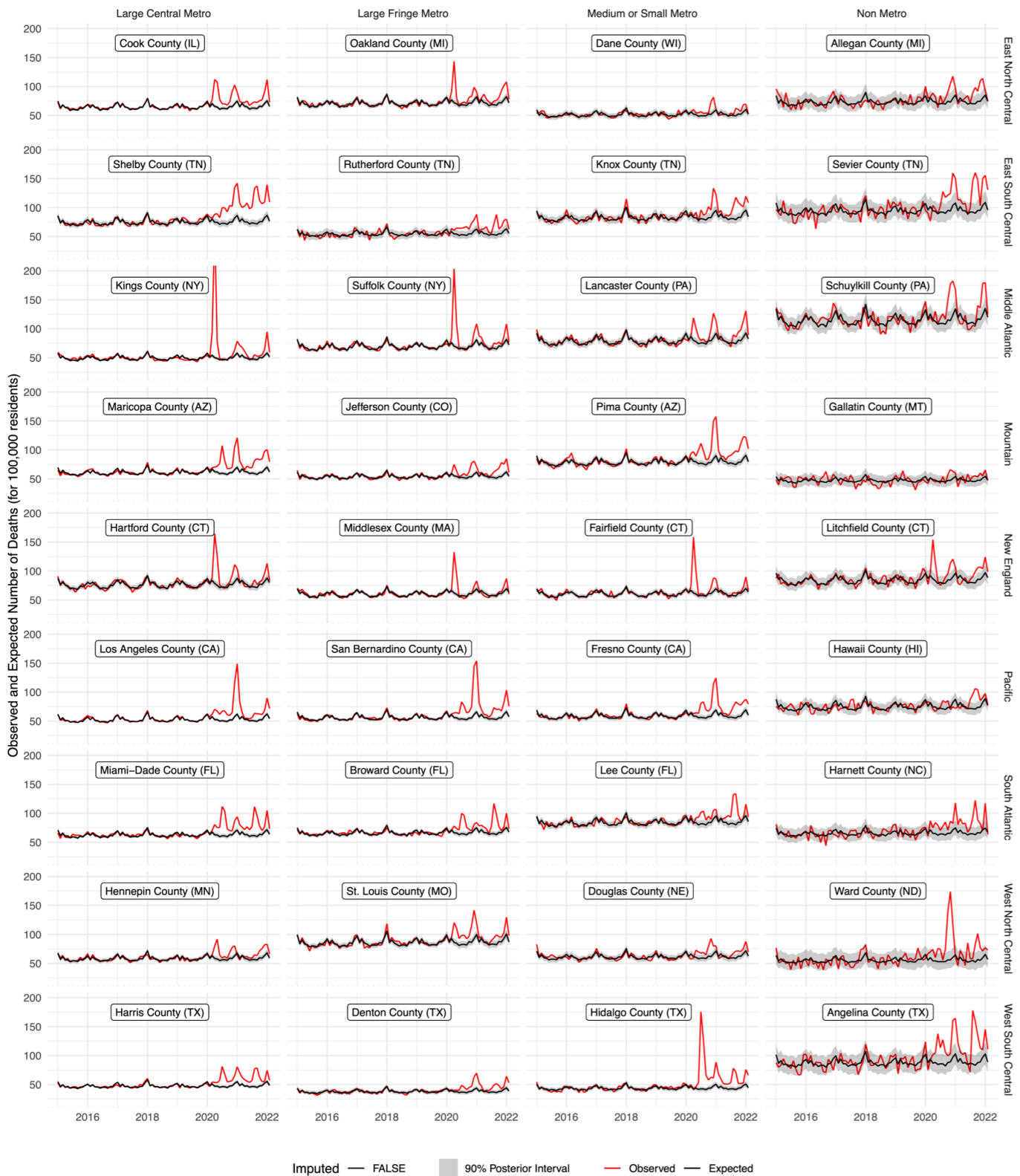


Fig. S1. Sample Model Output for the Largest Counties in each Census Division and Metro-Nonmetro Category. Each facet represents observed (red) versus expected (black) deaths for 100,000 residents. The gray area around the line for expected deaths represents the 90% posterior interval. Counties are aligned on a grid where rows represent Census divisions and columns represent metro-nonmetro categories. The largest county by population for each combination of Census division and metro-nonmetro category was selected for each cell.

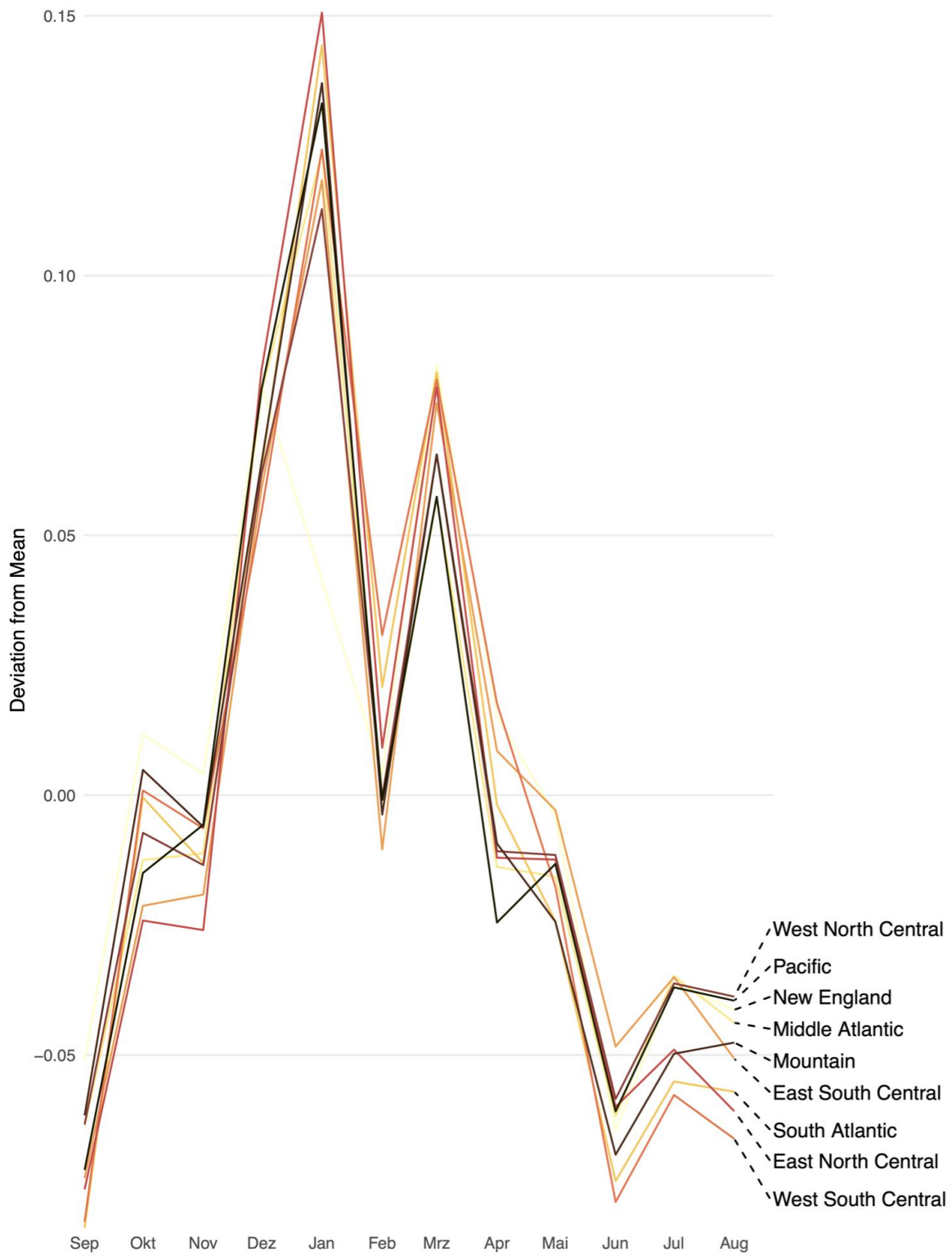


Fig. S2. Month Seasonal Effects by Census Division.

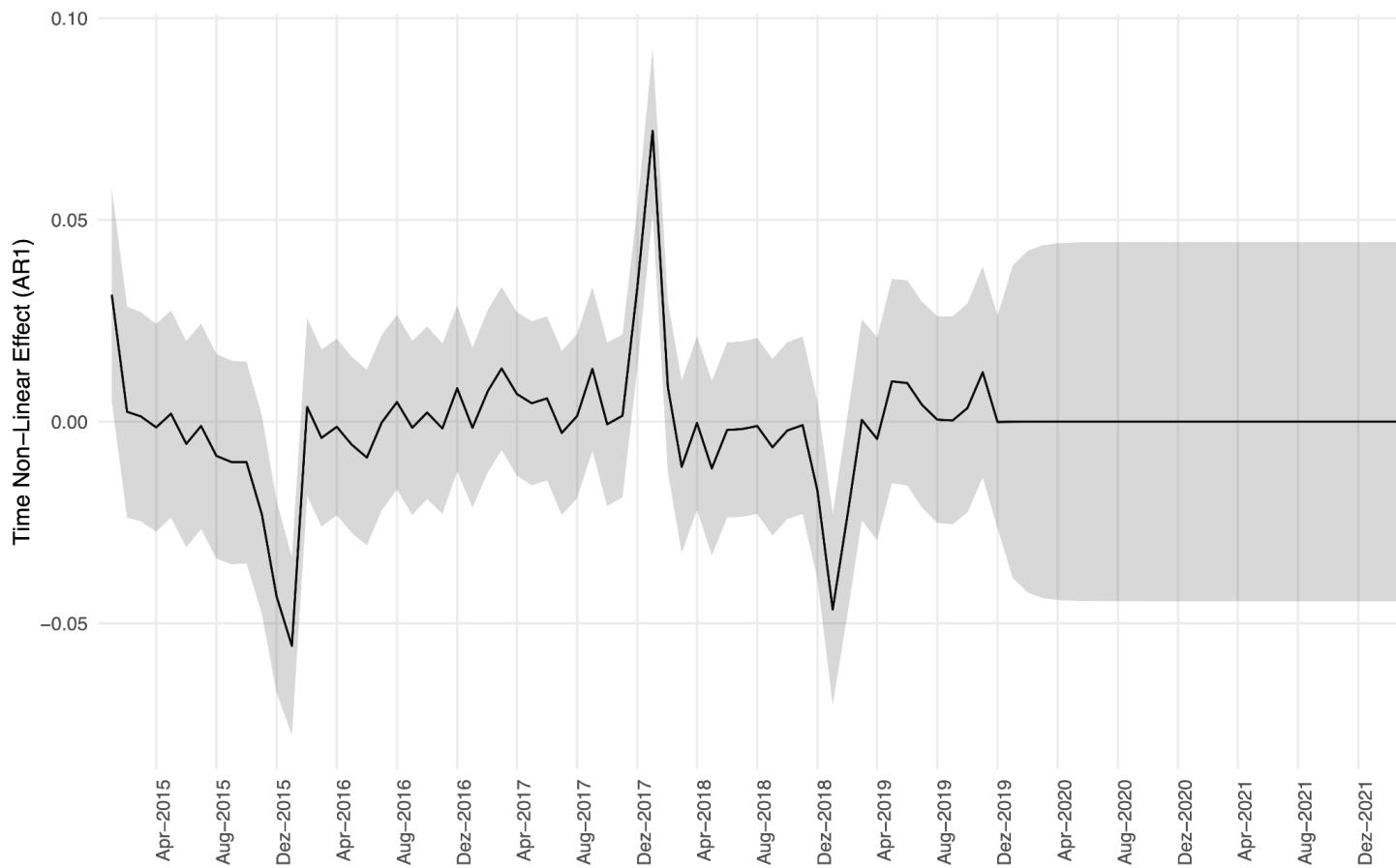


Fig. S3. Non-Linear Effect of Time (AR1 Component) with 95% Posterior Interval.

Metro Status	Midwest		Northeast		South		West	
	Correlation	Coverage	Correlation	Coverage	Correlation	Coverage	Correlation	Coverage
Large Central Metro	0.999	0.894	0.993	0.869	0.997	0.894	0.999	0.867
Large Fringe Metro	0.997	0.924	0.997	0.915	0.997	0.921	0.998	0.922
Medium or Small Metro	0.994	0.933	0.995	0.923	0.995	0.927	0.995	0.922
Non Metro	0.972	0.953	0.973	0.931	0.967	0.942	0.981	0.953

Table S1. Cross-Validation Results for the Model for Monthly Death Counts: Correlation between Predicted and Observed Number of Deaths, and 90% Coverage Probability across the Different Metro-Nonmetro Categories and Census Regions.

	Mean	S.D.	Percentile		
			2.5th	50th	97.5th
Precision for FIPSID	11.2881	0.4625	10.4528	11.2611	12.2724
Phi for FIPSID	0.8492	0.0217	0.8023	0.8507	0.8875
Precision for timelD2	2,467.7001	778.4966	1,415.9661	2,307.7988	4,413.0162
Rho for timelD2	0.5661	0.0690	0.4179	0.5707	0.6886
timelD	0.0005	0.0003	-0.0002	0.0005	0.0011

Table S2. Summary of the Posterior Distribution for the Model's Hyperparameters and for the Linear Time Trend.

Metro Status	Midwest		Northeast		South		West	
	Correlation	Coverage	Correlation	Coverage	Correlation	Coverage	Correlation	Coverage
Large Central Metro	0.999	0.899	0.994	0.875	0.997	0.897	0.999	0.869
Large Fringe Metro	0.997	0.924	0.997	0.916	0.997	0.923	0.998	0.923
Medium or Small Metro	0.994	0.934	0.995	0.923	0.995	0.927	0.995	0.923
Non Metro	0.972	0.953	0.973	0.930	0.967	0.942	0.981	0.953

Table S3. Cross-Validation Results for an Alternative Non-Spatial Model for Monthly Death Counts: Correlation between Predicted and Observed Number of Deaths, and 90% Coverage Probability across the Different Metro-Nonmetro Categories and Census Regions.

https://mu0brt-zhenwei-zhou.shinyapps.io/county_ex_app/

Data S1. RShiny App Presenting an Interactive Map of Monthly Excess Mortality Estimates for 3,127 U.S. Counties, March 2020 - February 2022