CLIMATE-DEPENDENT MODELING OF THE COVID-19 PANDEMIC

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Previous Work and Project Goal

- Science article published in early 2020 questions importance of climate in the transmission of pandemic stage SARS-CoV-2 because of significance in the transmission of endemic stage infections such as the flu
  - Results suggested that although climate plays a role, population immunity is a larger driver of infection spread
- Climate data now available for the past year allows for the creation of a model that incorporates real-time specific humidity levels

PROJECT GOAL:
Model the COVID-19 pandemic in relation to 2020 specific humidity and geographic location through changing parameters

SIR Modeling

Model Components

- S = Susceptible, I = Infected, R = Recovered
- N = S+I+R
- At time *t*,

$$\frac{dS}{dt} = -S\beta(t)\frac{I}{N}$$
$$\frac{dI}{dt} = S\beta(t)\frac{I}{N} - \gamma I$$
$$\frac{dR}{dt} = \gamma I$$

Where:
$\beta(t)$ = climate-driven rate of transmission
γ = rate of recovery
N = total population

Model Assumptions

- N is constant and unchanging (no births or deaths)
- Once recovered, individuals become permanently immune

Geographic Climate Data

- NetCDF files from the climate database Copernicus were downloaded from "ERA5 hourly data on pressure levels from 1979 to present" containing daily specific humidity data from 2014-2020 covering the area of the contiguous 48 states
- NetCDF converted to raster stack object with a different layer each day
- Raster::extract used to extract average daily specific humidity for each state using spData package's built in us_states shapefile, transformed to the same CRS as the raster data

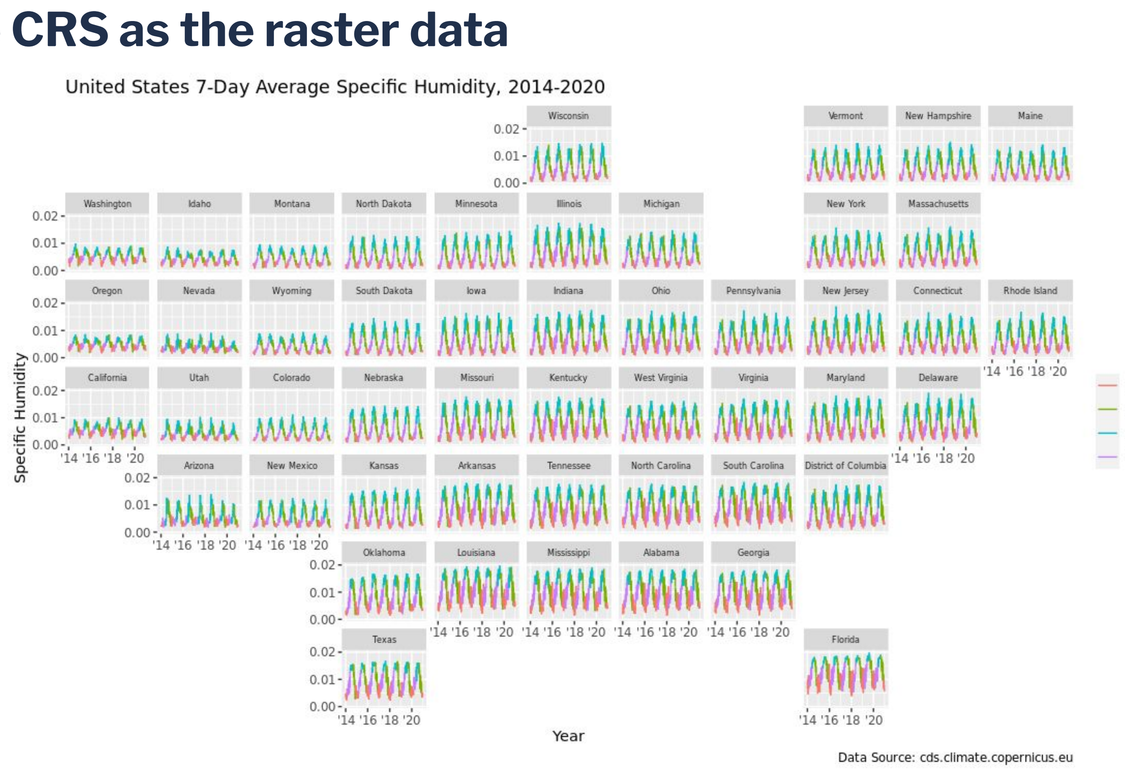

Figure #1: Line graphs of the 7-Day Average Specific Humidity by season in the 48 contiguous states and Washington, D.C.

- Similar operations performed at the county level using U.S. Census Bureau shapefiles for geographic outlines
- Datasets then had rolling 7-day and 21-day averages calculated and attached to them, as well as population information and the date of the first reported case in that location

References

Baker, Rachel E., Wenchang Yang, Gabriel A. Vecchi, C. Jessica E. Metcalf, and Bryan T. Grenfell. "Susceptible Supply Limits the Role of Climate in the Early SARS-CoV-2 Pandemic." *Science* 369, no. 6501 (July 17, 2020): 315. https://doi.org/10.1126/science.abc2535.

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"The New York Times. (2021). Coronavirus (Covid-19) Data in the United States. Retrieved July 18, 2021, from https://github.com/nytimes/covid-19-data."

https://www.census.gov/geographies/mapping-files/time-series/geo/carto-boundary-file.html

Relating the Model to Climate Data

Basic Reproductive Number (R0)

- Rate of transmission, $\beta(t)$ = R0*γ
- Relate specific humidity to the rate of transmission through the basic reproductive number, R0

$$R_0 = e^{aH(t)+log(R_{max}-R_{min})} + R_{min}$$

Where:
a = climate dependence parameter, -227.5
H(*t*) = specific humidity at time *t*
R_{max} = maximum R0, 2.5
R_{min} = minimum R0, 1.5

Computational Techniques

- Necessary to calculate a series of different beta values and reinitialize SIR totals during every iteration
  - Basic model traditionally uses constant beta value applied to SIR totals calculated one before the next
- Achieved through two loops:
  - Loop #1:
    - Calculates R0, and subsequently beta values, to store in a list according to daily average specific humidity
  - Loop #2:
    - Establishes beta and gamma parameters for SIR function calculation at time *t*
    - Uses ODE solver to derive change in SIR from times *t* to *t*+1
    - Reinitializes SIR values for next iteration as results from ODE solver at time *t*+1
- Produces duplicates of every time except 1, remove duplicate rows in final

Applying Model to Geographic Regions

Model Calculations

- At both the state and country levels, datasets containing each location were split into a list of dataframes based on location using split()
  - For i in 1:length(list), each location's calculations were performed and stored in a growing list upon completion

First Recorded Cases

- Because COVID-19 transmission has already been documented, the model was able to start on the date of the first reported case by the NYTimes according to location at the state and county level
  - In the loop calculating beta values, R0 and subsequently beta were set to 0 if the date of the first case was later than the date whose beta value was being calculated
  - Initial Infected totals were also set to the number of individuals reported to be infected on the first reported day of cases

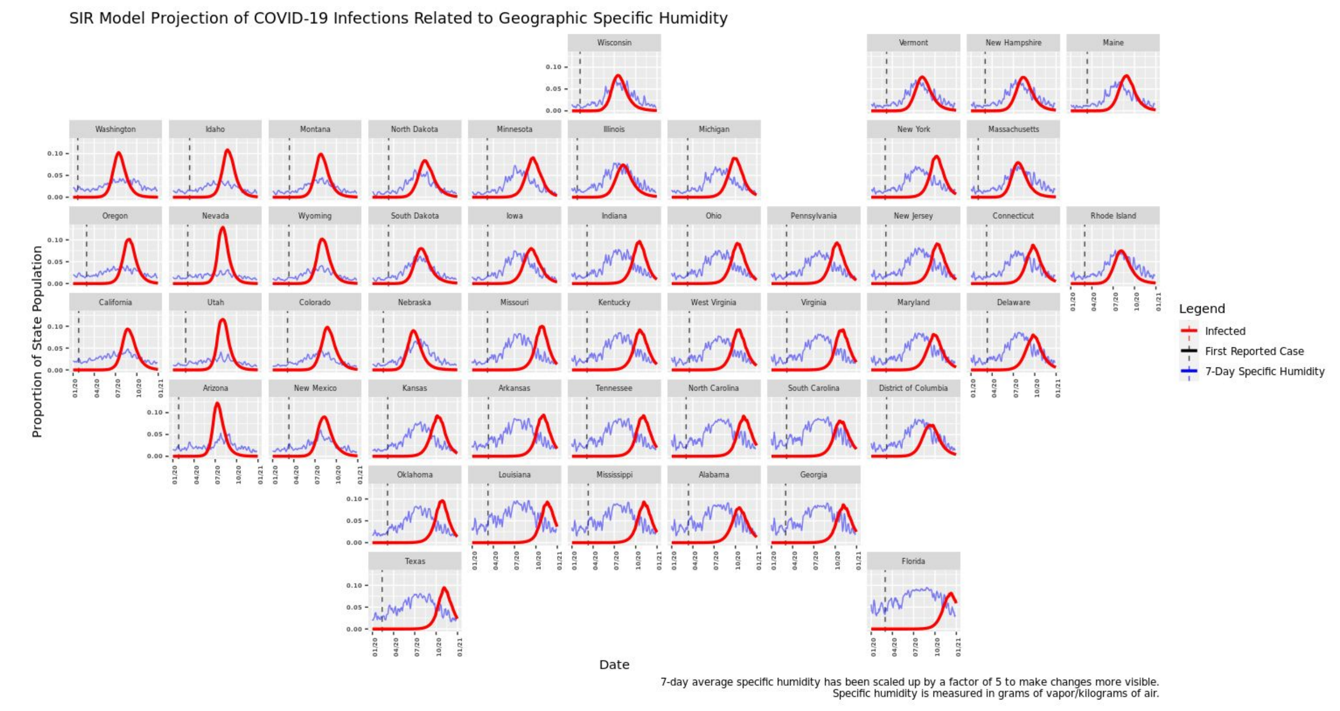

Figure #2: SIR model forecasts and specific humidity by state

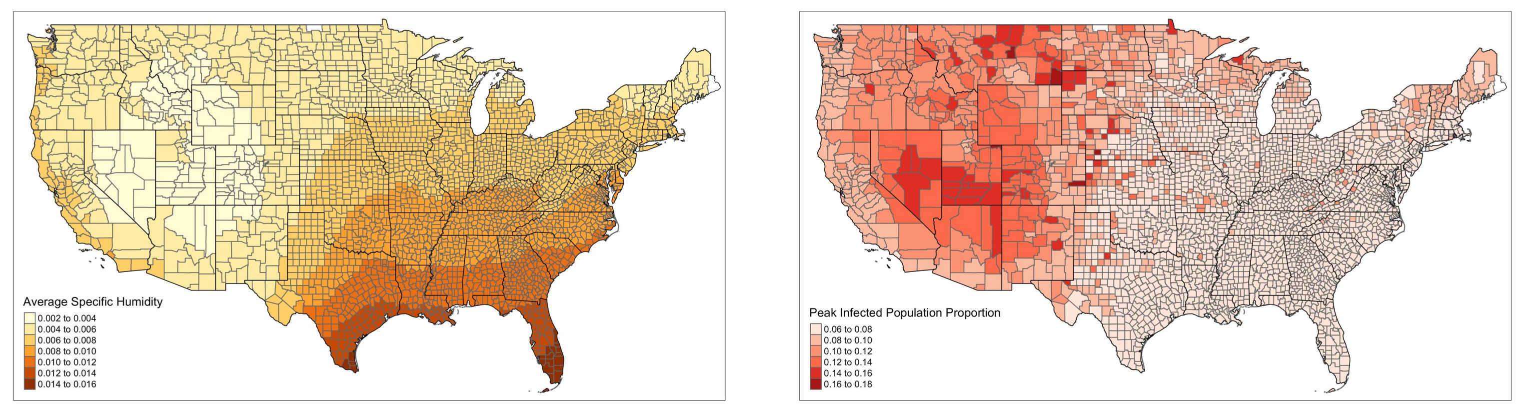

Figure #3: County average specific humidity compared to model-projected peak infected population

Future Work and Applications

- Use more complex models, for example including waning immunity, vaccinations, and multi-variants
- Increase accuracy and specificity of models and visualizations, specifically at the county level
- Run models for more countries and continents

Computing *for* Global Challenges

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