Spatial Copula Modeling to Examine the Effect of Severe Winter Weather Events on Property Risk in the Great Lakes Region

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Outline

Background: Context

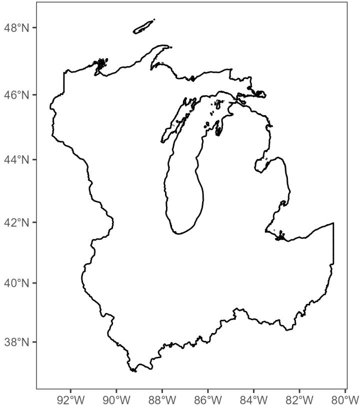
- Winter storm frequency and severity are escalating.
- Profound implications for insurance risk and the ability to calculate reserves.
- Significant impact to the daily lives of individuals.
  - Substantive connection to the resilience of vulnerable communities in the presence of a changing climate.

Background: Previous Work

- Previous work has been done to analyze property losses caused by extreme climate and weather.
- Much older works began to investigate the relationship between property losses and extreme weather events (Changnon et al. 2001; Changnon 2007).
- More recent works have focused on the effects of winter weather on losses in an acturial context.
  - In the United States, the focus has been focused on North Eastern snow and ice storms (Shimkus 2017)
  - In Europe, several studies have taken place, primarily in Switzerland and Germany, centering on wind storms (Karremann et al. 2014; Severino et al. 2023; van Ederen et al. 2024
- Much of the previous work in this area has focused on Max-Stable processes for modeling spatial extremes.

Winter Weather Extremes in the Midwest: Study Region

- This project follows similarly by focusing on winter weather in the Great Lakes Region.
- Five States: Illinois, Indiana, Michigan, Ohio, Wisconsin
- Spatial analysis unit: Census Tracts
- Study Period: 2019-2024



Data Sources: Property Risk

- Insurance risk and loss data is largely proprietary at spatial resolutions smaller than county.
- In place of actual property risk data, I propose a composite index (shown below).
- Parameters $\alpha, \beta, \gamma, \eta$ are loadings from a principal component analysis.
- The data is primarily drawn from two sources: The American Community Survey and U.S. Geological Survey.

$$\begin{aligned} R(s) =& (\alpha \times \text{Demographic}(s)) + (\beta \times \text{Economic}(s)) + \\ & (\gamma \times \text{Housing}(s)) + (\eta \times \text{Physical Environment}(s)) \end{aligned}$$

Data Sources: Winter Weather

- Our predictors are climate and weather data obtained from the Oak Ridge National Laboratory [1]
  - Average Daily Temperature
  - 24H Precipitation
  - Snow Water Equivalent
- Supplemented with data from the NOAA Storm Event Database. [2]

[1] doi.org/10.3334/ORNLDAAC/2129
[2] https://www.ncei.noaa.gov/stormevents/details.jsp

Copula Model

- Our proposed model is a spatial copula model (shown below), where the spatial dependence is encoded through a specification on the dependency in our residuals.
- The covariance structure is specified by a spatial covariance function/kernel (e.g. Matérn).
- Use Karhunen–Loève expansion to represent our function predictors.

$$
\begin{aligned}
R(s) &\sim \beta_0 + \int_{\mathcal{T}} \mathbf{X}(t,s)\beta(t)dt + \epsilon(s) \\
U(s) &= F_\epsilon(\epsilon(s)) \\
U(s_i) &\sim \text{spatial copula } C_\theta(\Sigma_\theta(i,j))
\end{aligned}
$$

Next Steps

- Dig deeper into property insurance premiums to refine $R(s)$.
- Evaluate robustness to lower spatial resolutions (Zip Codes, Counties, etc.).
- Evaluate model on an out-of-sample set of data.
    - Evaluate on 2013-2018 data.
    - Evaluate on New England (MA, CT, VT, ME, NH).
    - Evaluate on DMV.

Thank you!