



Characterization of extreme weather events during large-scale power outages

Nicole D. Jackson

SRA 2021: Symposium: Resilience modeling of energy systems - Part I

07 December 2021



Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

SAND2021-15381 C

Acknowledgements



**Sandia
National
Laboratories**

- Andrea Staid



**Lawrence Livermore
National Laboratory**

- Jean-Paul Watson



**VANDERBILT
UNIVERSITY**

- Hiba Baroud
- Jin-Zhu Yu
- Paul Johnson



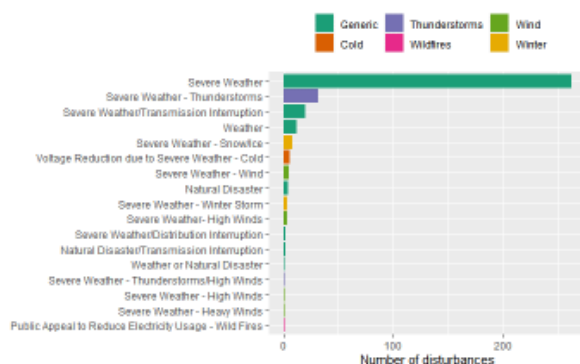
- Ali Ghassemian

This work was funded by the U.S. Department of Energy's Advanced Grid Modeling Research Program.

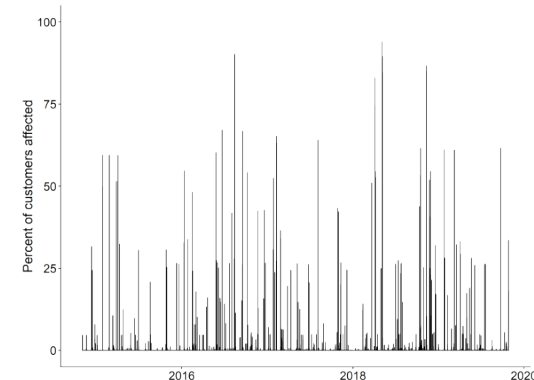
Characterization of extreme weather events during large-scale power outages



Motivation

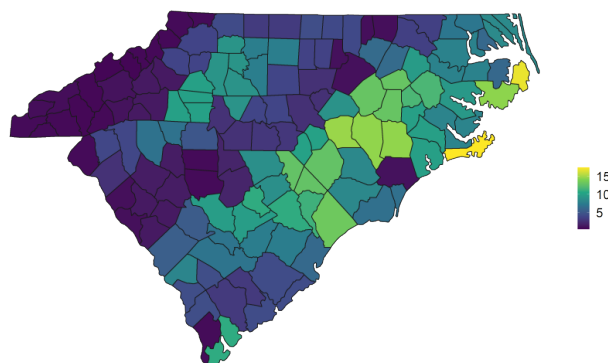


Outages

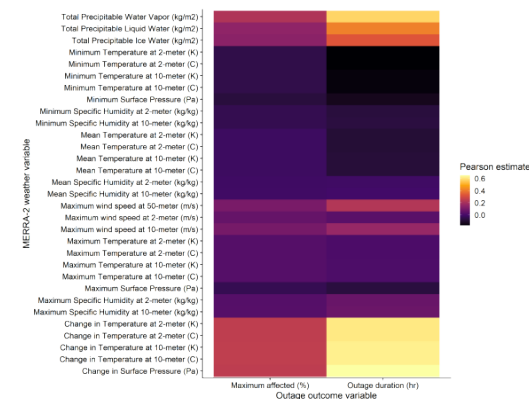


Weather

Maximum wind speed at 2-meter (m/s)



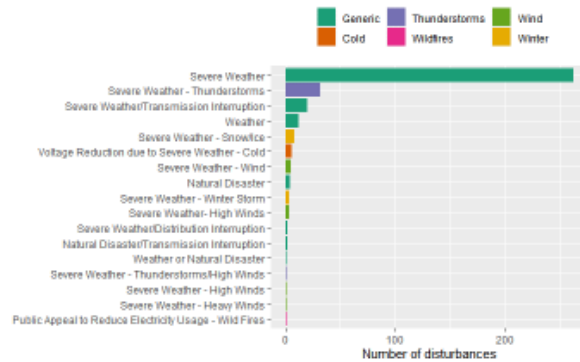
Weather + Outages



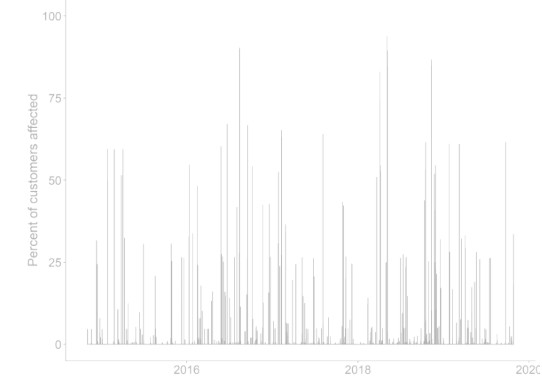
Characterization of extreme weather events during large-scale power outages



Motivation

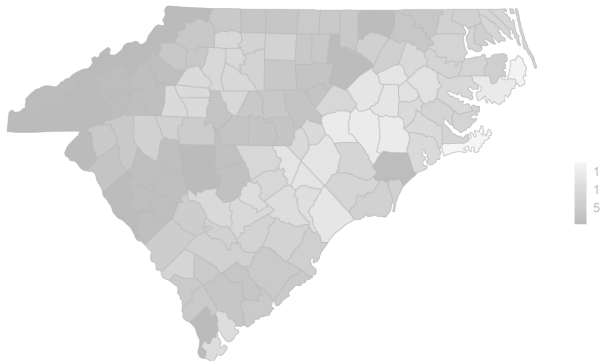


Outages



Weather

Maximum wind speed at 2-meter (m/s)



Weather + Outages



Severe weather events in the United States have co-occurred with large power outages and result in deaths and damage



Newsweek

U.S.

Puerto Rico's Hurricane Maria Power Outage Is Now the World's Second Largest Blackout

BY NICOLE GOODKIND ON 4/12/18 AT 5:40 AM EDT

KVUE News Weather Sports Co

Author: Shawna M Reding
Published: 8:05 AM CDT August 2, 2021
Updated: 10:22 AM CDT August 2, 2021

LOCAL NEWS

Power outages reported across the Austin area amid heavy rain

In the Austin area, more than 20,000 people were reportedly without power for some time Monday morning.

THE TEXAS TRIBUNE

Second Special Legislative Session Watch Texas Legislature COVID-19 Surge Schools and COVID-19 Coronavirus Tracker

WINTER STORM 2021

Massive winter storm prompts disaster declaration and could stress Texas' electric grid

Gov. Greg Abbott urged Texans to stay alert as the National Weather Service issued winter storm warnings or watches for most of the state. Experts fear that electricity demand during the frigid temperatures could cause power outages.

BY MEGAN MENCHACA AND MITCHELL FERMAN FEB. 12, 2021 UPDATED: 7 PM CENTRAL

9NEWS News

Author: Janet Oravetz (9News)
Published: 1:58 PM MST March 11, 2021
Updated: 4:51 PM MST March 11, 2021

WEATHER COLORADO

Be prepared for possible power outages as winter storm approaches

Newsweek

TECH & SCIENCE

Power Outages Affect Millions As Winter Storms Bring Extreme Conditions to U.S.

BY ARISTOS GEORGIOU ON 2/15/21 AT 8:56 AM EST

AP

Blackouts in US Northwest due to heat wave, deaths reported

By NICHOLAS K. GERANIOS and ANDREW SELSKY June 29, 2021

npr

NEWS ARTS & LIFE MUSIC SHOWS & PODCASTS SEARCH

PUBLIC HEALTH

Growing Power Outages Pose Grave Threat To People Who Need Medical Equipment To Live

May 15, 2021 7:01 AM EDT

CHARLOTTE HUFF

FROM **UNDARK**

Bloomenergy Technology Applications Resources Partners Customers Company CONTACT US

AUTHOR
Asim Hussain

October 8, 2019
Microgrids & Resiliency

SEE ALL ARTICLES

A DAY WITHOUT POWER: OUTAGE COSTS FOR BUSINESSES

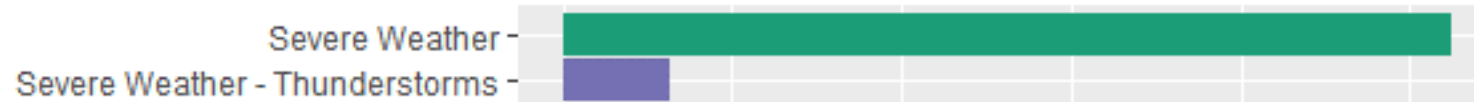
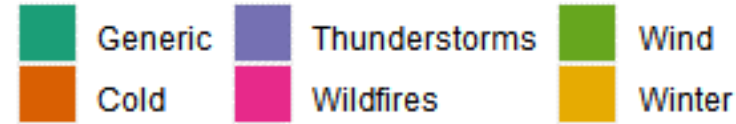
Frequent power outages are becoming an unfortunate norm for U.S. businesses. A [2018 survey](#) found that one in four companies experience a power outage at least once a month. These outages are not mild inconveniences – the costs are quickly rising to be board room-level issues.

AP

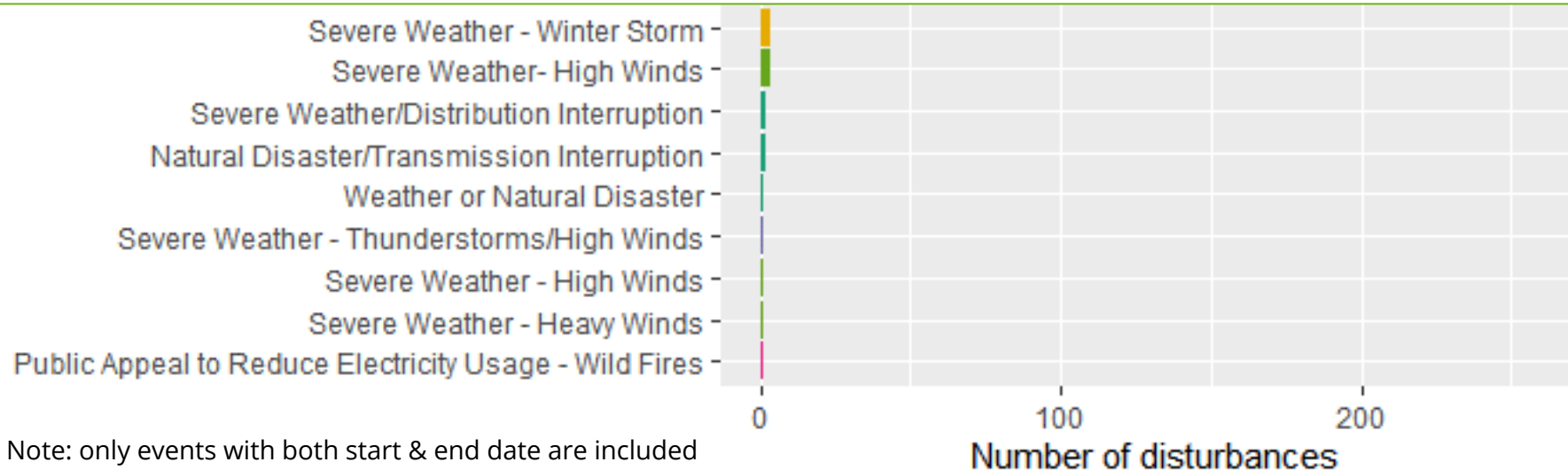
Texas death toll from February storm, outages surpasses 100

By PAUL J. WEBER and JAMIE STENGLE March 25, 2021

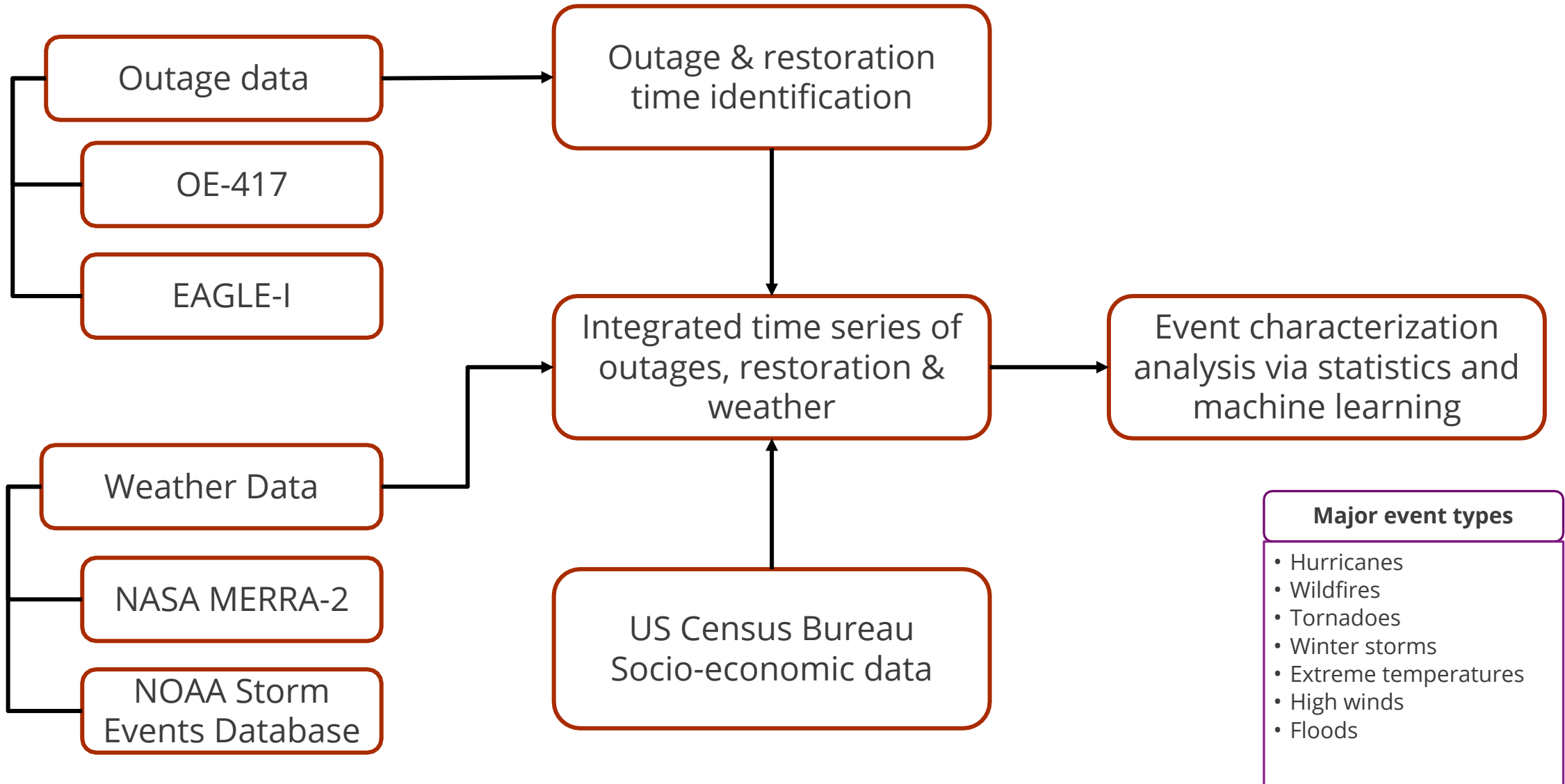
Partial weather information available for large-scale power outages for the period 2014-2019 as identified by OE-417 data



Study Objective: Conduct an integrated assessment of power outages and restoration in the United States considering outage information, weather events, and socio-economic data.



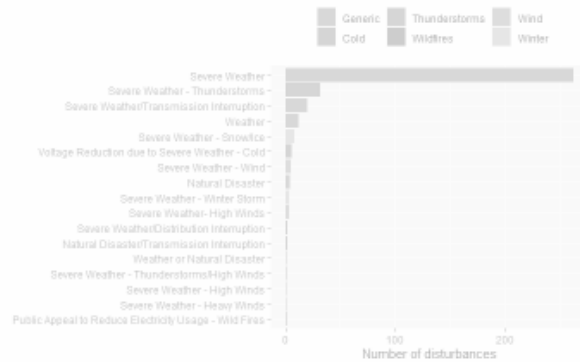
Integrated assessment relies on multiple datasets to characterize weather during outages and restorations



Characterization of extreme weather events during large-scale power outages

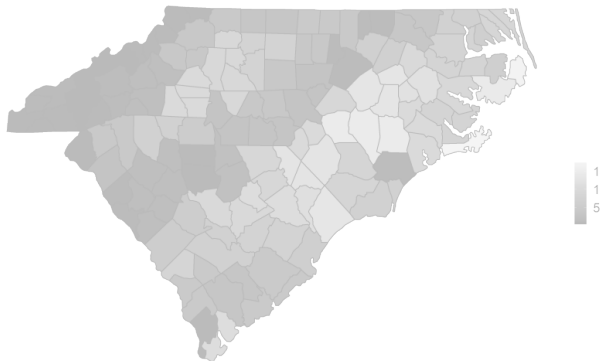


Motivation

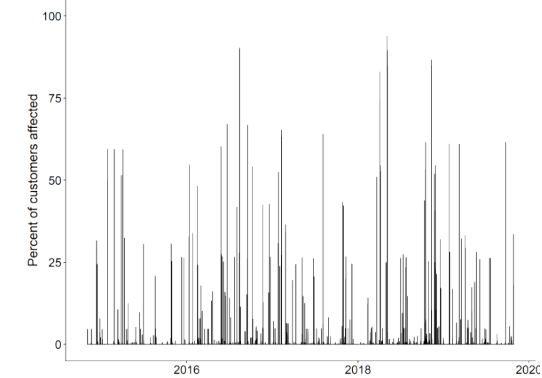


Weather

Maximum wind speed at 2-meter (m/s)



Outages



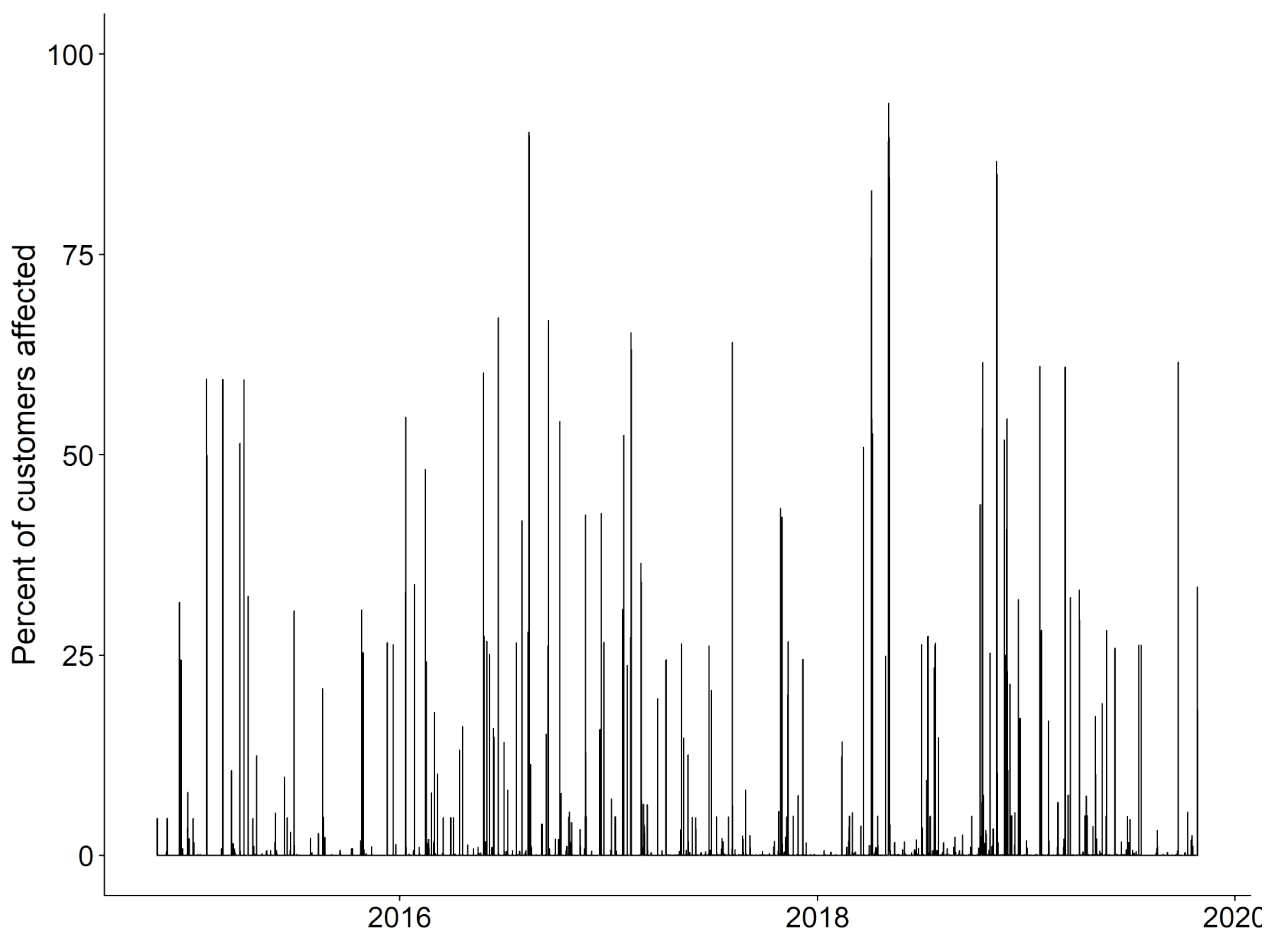
Weather + Outages



County outage data is noisy and impacts ability to define discrete power outage events



Hamilton County, New York



Outage event rules

- Percent affected = $\frac{\text{customers affected}}{\text{2010 county population}}$

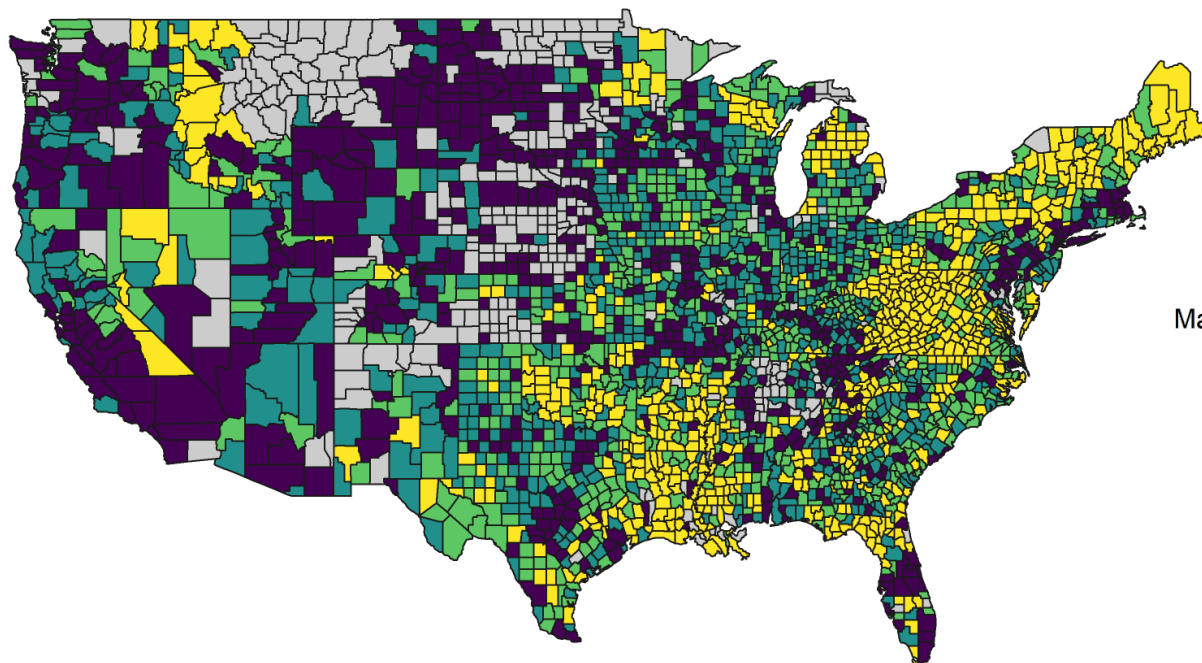
Period	Criteria
Start	Lag(percent affected) > 1%
End	Lead(percent affected) < 1%
During	Any interval [start, end]
None	Customers affected == 0%
Low	0% < customers affected < 1%
Incomplete	Outage event at first, last time interval






- Time between events must be > 2 hours
- Adjacent outages merged together

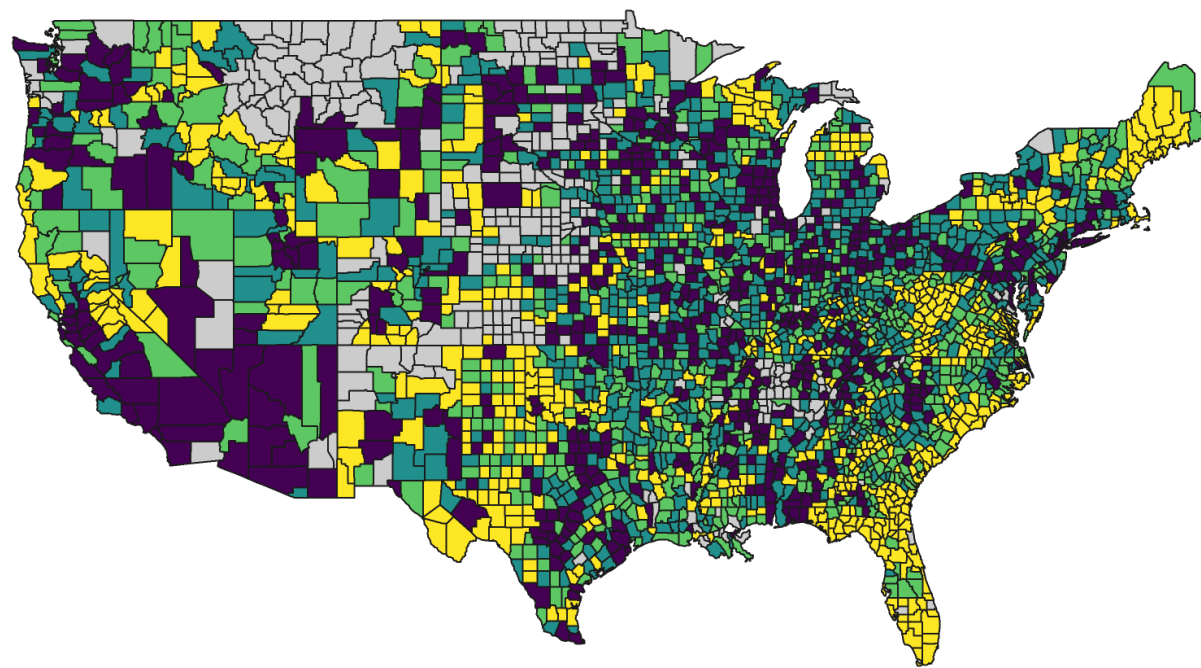
Spatial distribution number of outages and maximum percent affected during 2014-2019 period



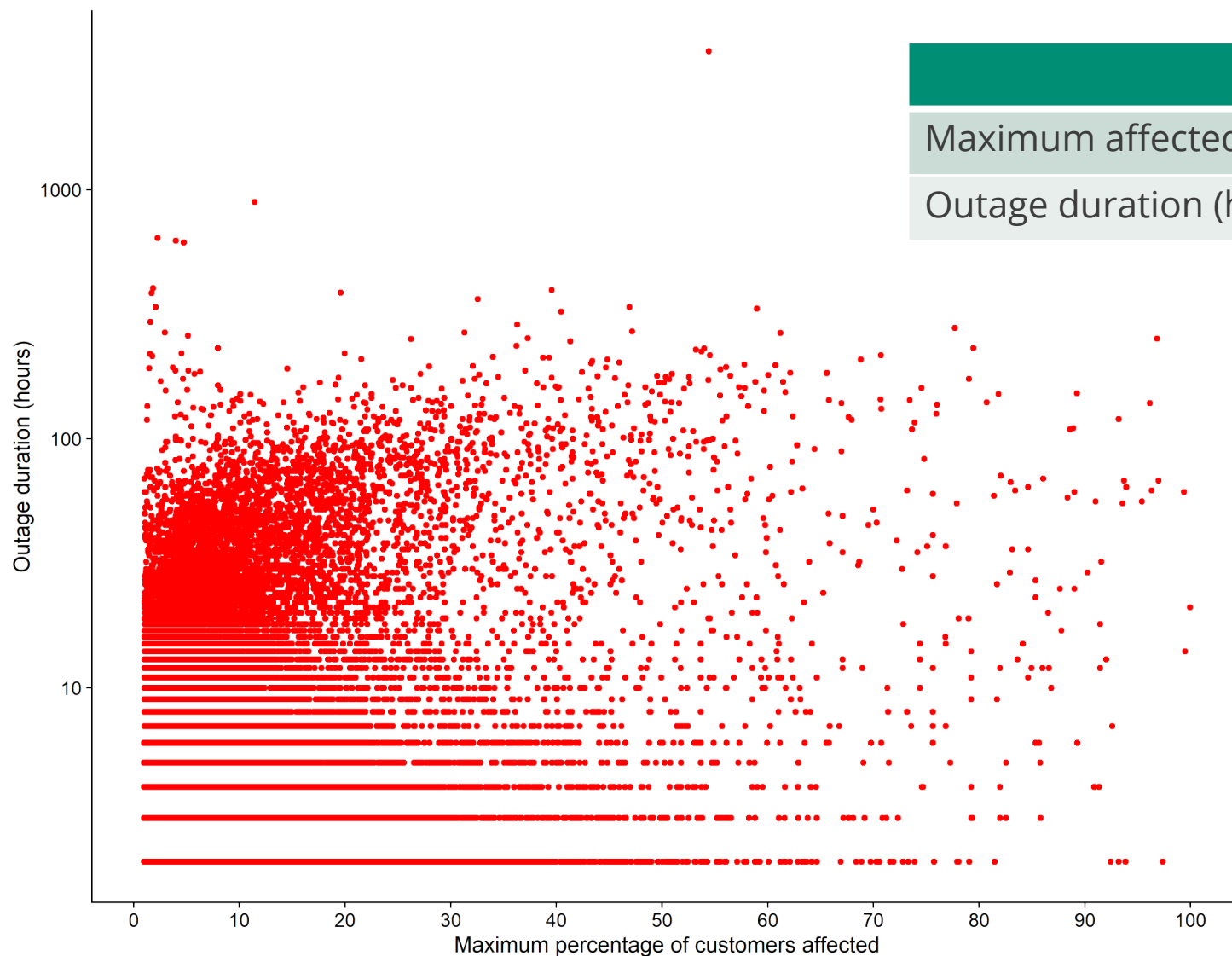
Number of outages:  No data  >1-23  23-45  45-75  >75



Maximum percentage affected:  No data  >1-8  8-16  16-28  >28



Most events affect few customers and have short duration but there many outages that are long duration or affect most people

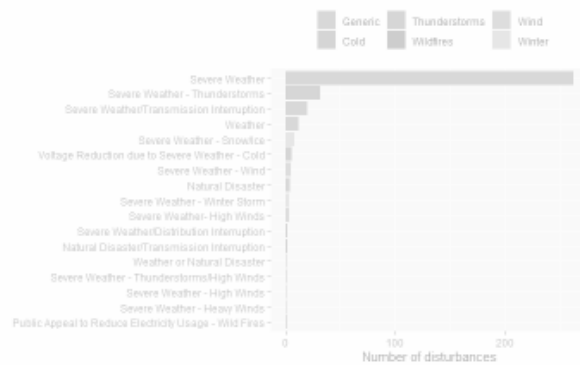


	Median
Maximum affected customers (%)	2.1
Outage duration (hours)	2

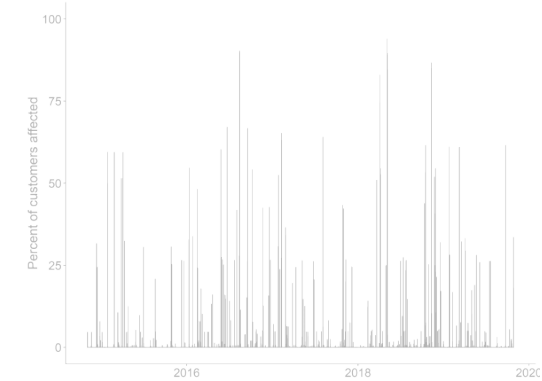
Characterization of extreme weather events during large-scale power outages



Motivation

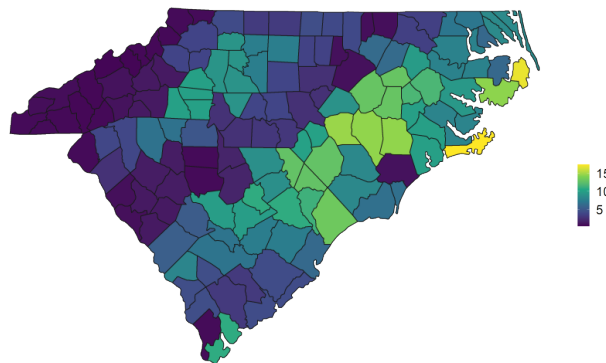


Outages



Weather

Maximum wind speed at 2-meter (m/s)



Weather + Outages



NOAA storm events database event were grouped to simplify identification of weather-related events

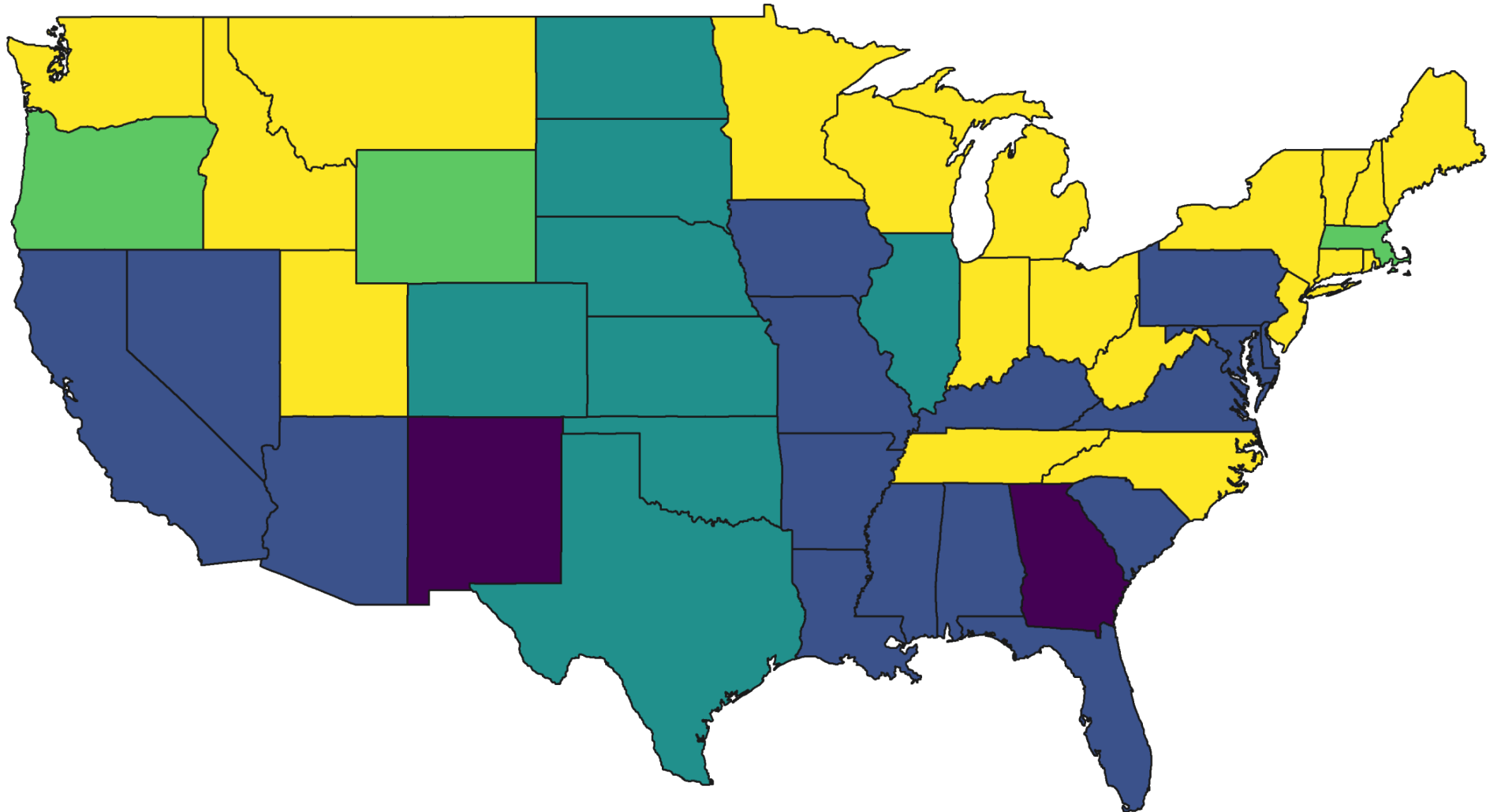


Parent Category	NOAA storm event
Drought	Drought
Extreme Cold	Cold/Wind Chill, Extreme Cold/Wind Chill, Frost/Freeze
Extreme Heat	Excessive Heat, Heat
Floods	Coastal Flood, Flash Flood, Flood, Heavy Rain, Lakeshore Flood
Hail	Hail
High Winds	High Wind, Strong Wind
Hurricanes	Hurricane, Hurricane (Typhoon), Tropical Depression, Tropical Storm
Tornadoes	Funnel Cloud, Tornado
Wildfires	Dense Smoke, Wildfire
Winter Storms	Avalanche, Blizzard, Heavy Snow, Ice Storm, Lake-Effect Snow, Sleet, Winter Storm, Winter Weather

Spatial clustering of dominant NOAA-captured storms based on total number of recorded events



Top event type: ■ Drought ■ Floods ■ Hail ■ High Winds ■ Winter Storms



Multiple climate variables available through MERRA-2 that are translated to the county-scale



Select MERRA-2 variables

Specific Humidity

- 10-meter specific humidity
- 2-meter specific humidity

Temperature

- 10-meter air temperature
- 2-meter air temperature
- Surface skin temperature

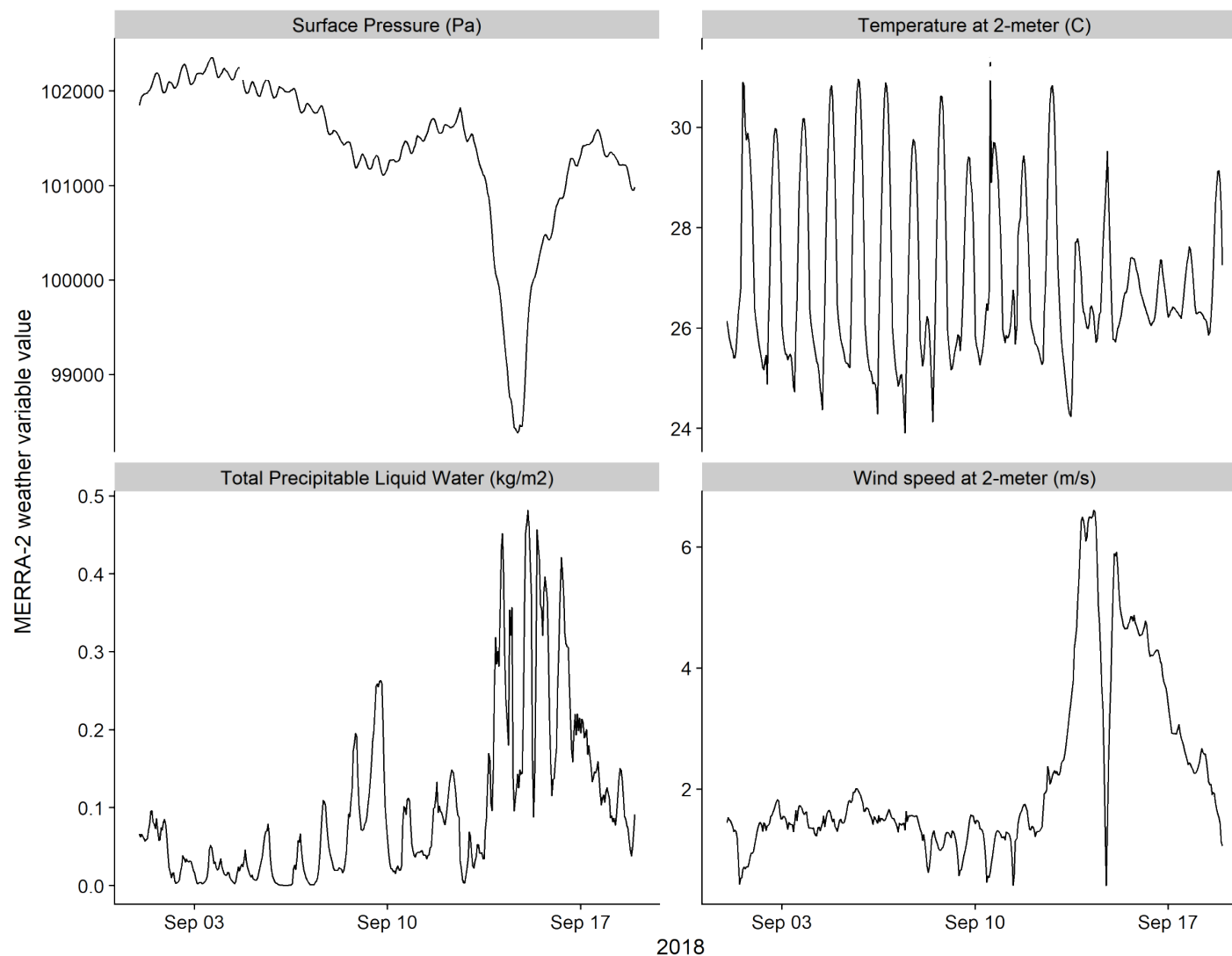
Wind Speed

- 2-meter wind
- 10-meter wind
- 50-meter wind

Pressure

- Surface pressure
- Sea-level pressure

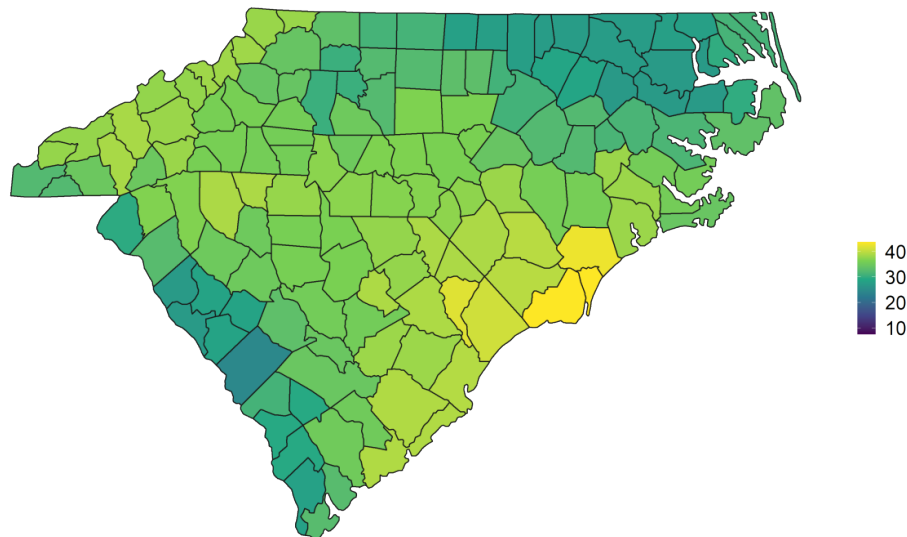
Brunswick County, North Carolina



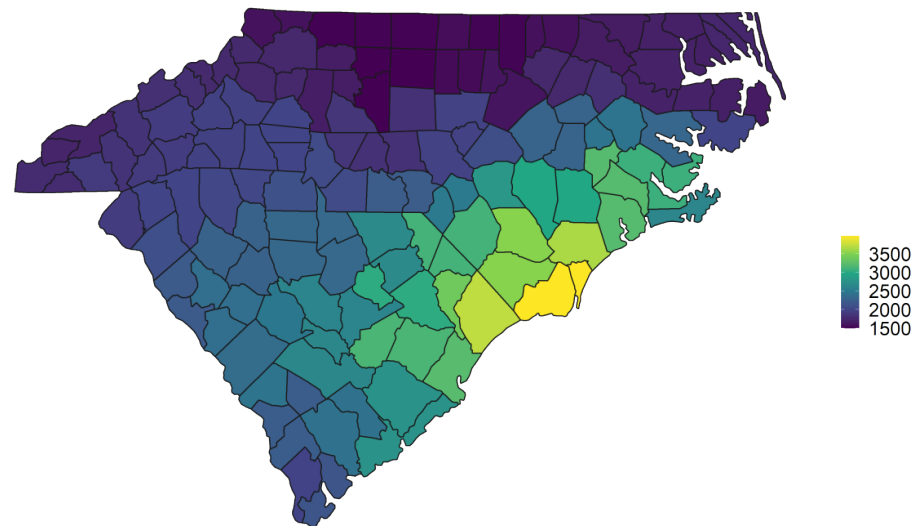
Sample summary weather variables from MERRA-2 during Hurricane Florence (2018) for North and South Carolina



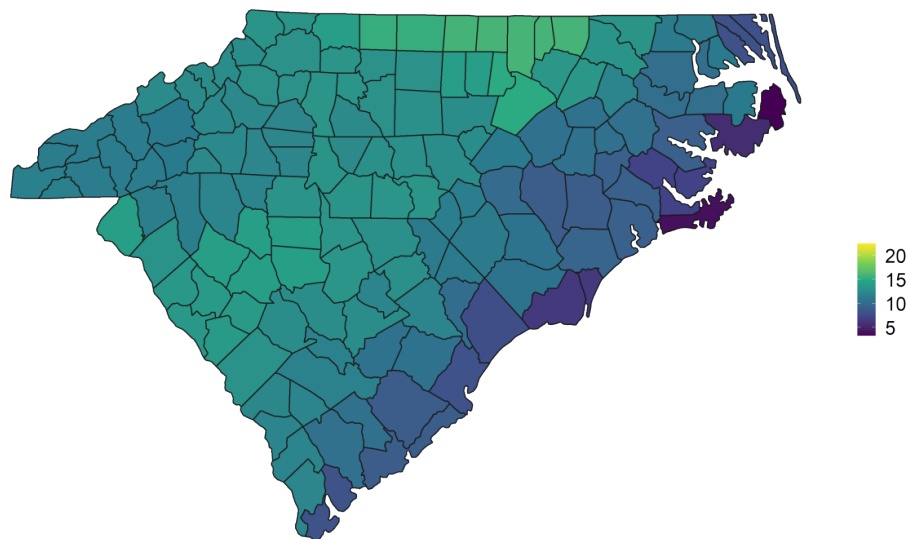
Total Precipitable Liquid Water (kg/m²)



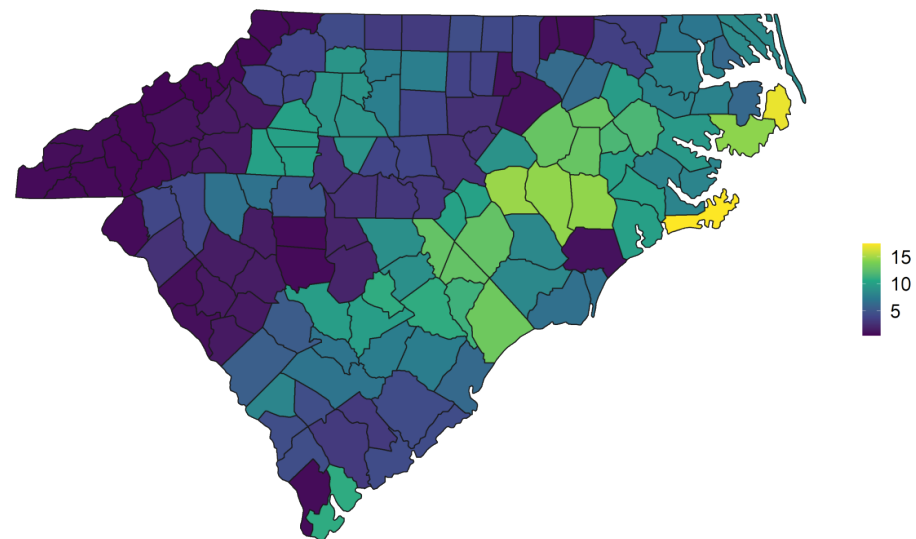
Change in Surface Pressure (Pa)



Change in Temperature at 2-meter (C)



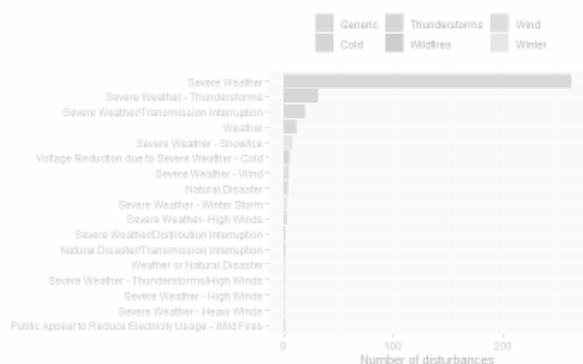
Maximum wind speed at 2-meter (m/s)



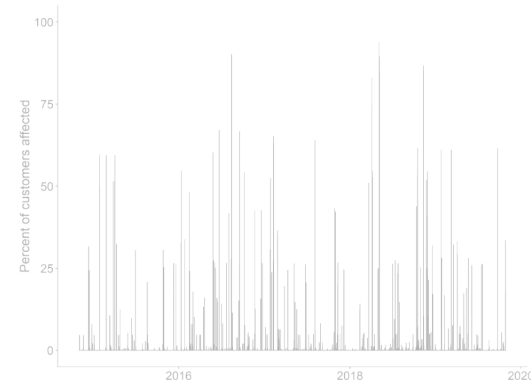
Characterization of extreme weather events during large-scale power outages



Motivation

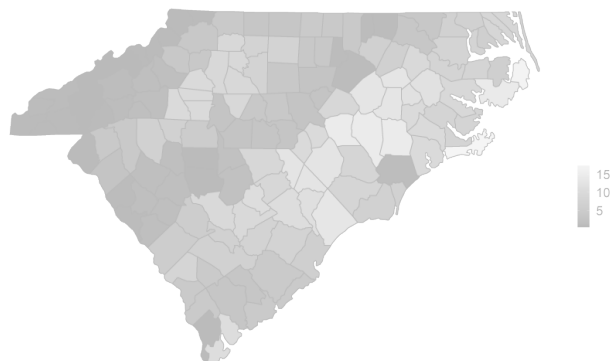


Outages

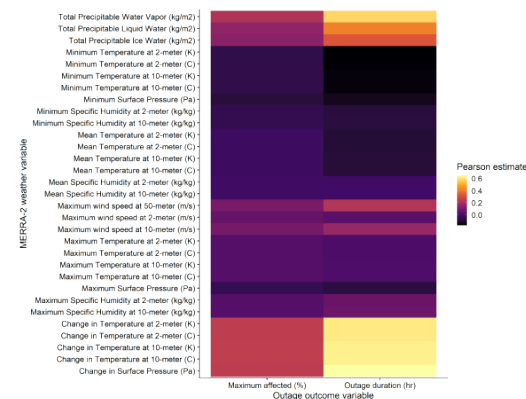


Weather

Maximum wind speed at 2-meter (m/s)



Weather + Outages



Key variables extracted from EAGLE-I and NASA MERRA-2



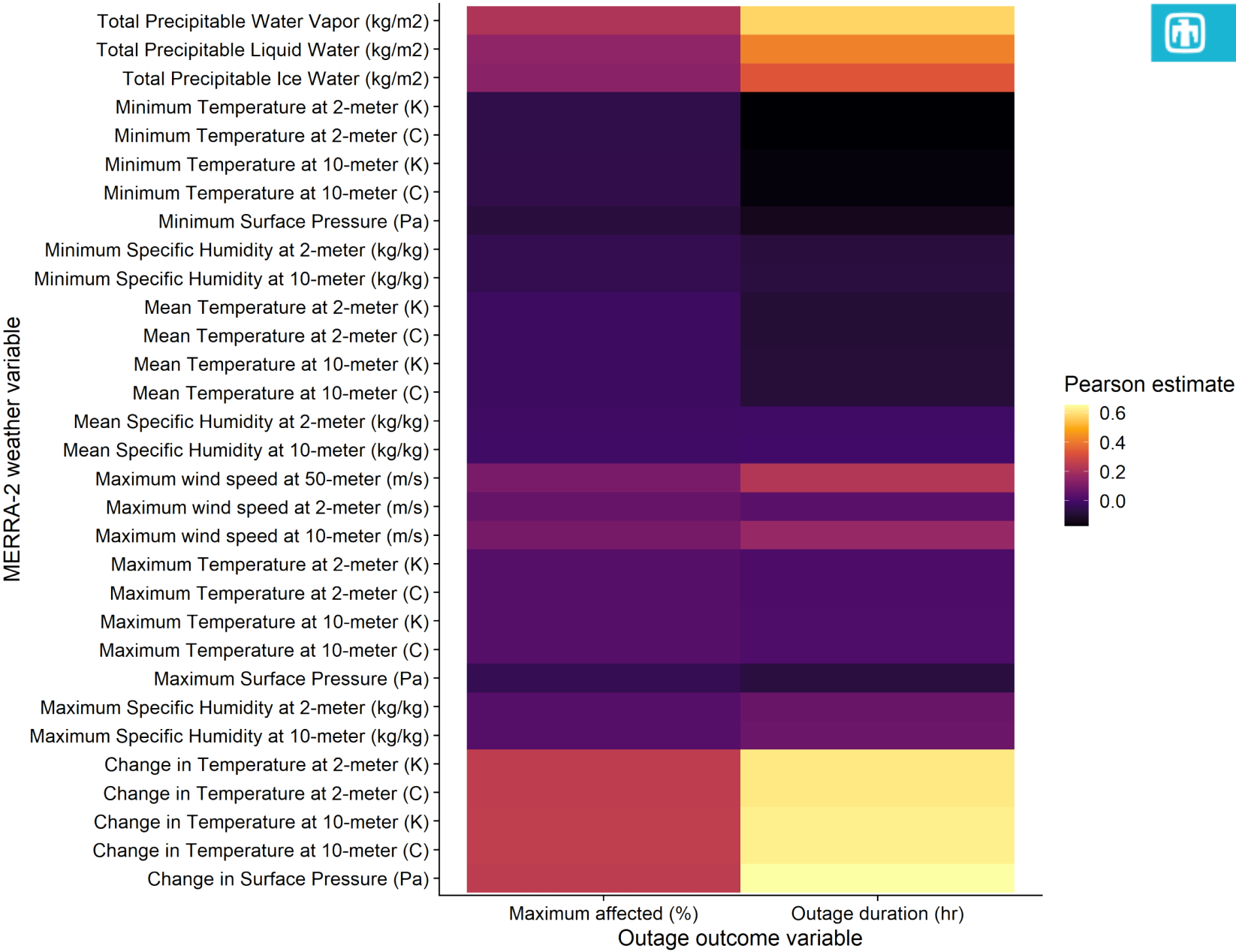
EAGLE-I outages by event

- Maximum percent affected
- Total duration
- Time from maximum affected to full recovery (below 1% affected)

MERRA-2 (pre- and during)

- Wind speed
 - Peak value
 - Duration above threshold
- Pressure
 - Minimum
 - Delta = max – min
 - Time over which delta occurs
- Precipitation (total)
- Specific humidity
 - Maximum, minimum, mean
- Temperature
 - Maximum, minimum, mean
 - Delta = max – min
 - Time over which delta occurs

Strong correlation between outage duration and precipitation and change in temperature observed across all outages in study



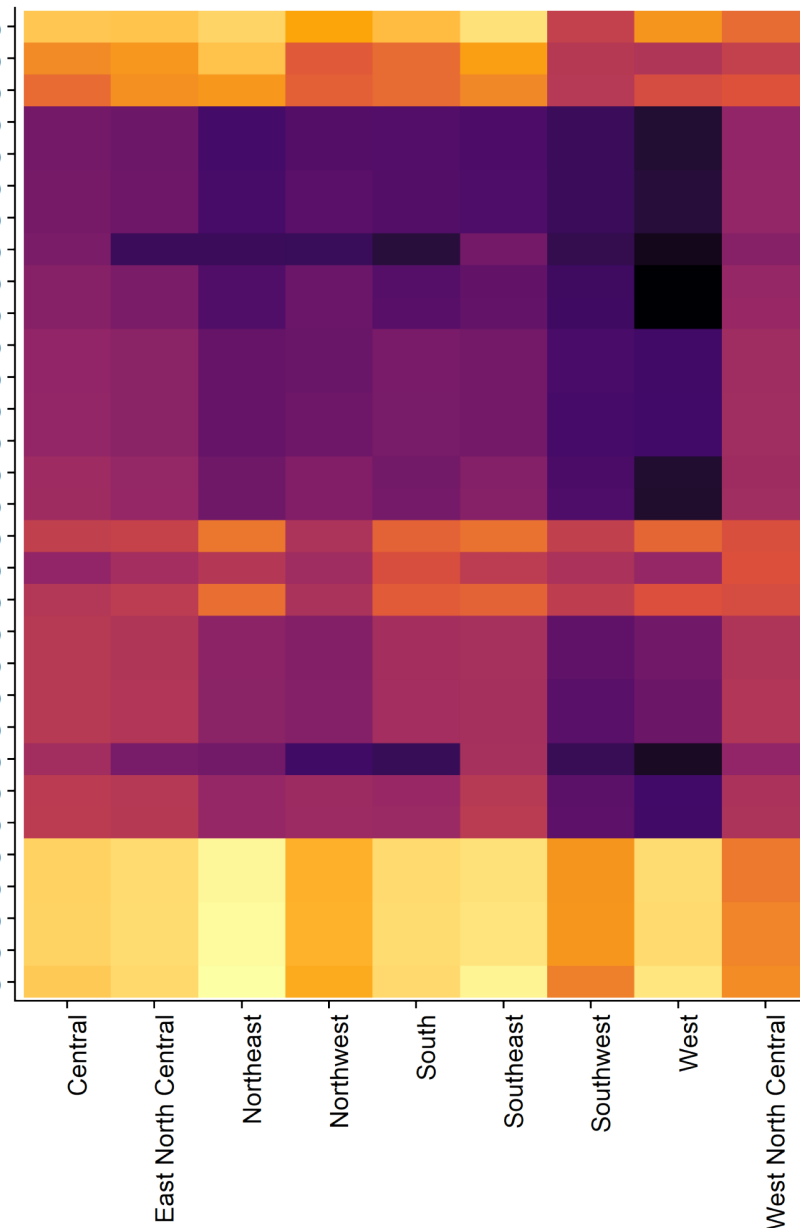
Strongest correlations between maximum percent affected and weather variables precipitation and change in temperature

NOAA Climate Zones



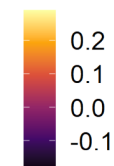
MERRA-2 weather variable

Total Precipitable Water Vapor (kg/m²)
 Total Precipitable Liquid Water (kg/m²)
 Total Precipitable Ice Water (kg/m²)
 Minimum Temperature at 2-meter (K)
 Minimum Temperature at 2-meter (C)
 Minimum Temperature at 10-meter (K)
 Minimum Temperature at 10-meter (C)
 Minimum Surface Pressure (Pa)
 Minimum Specific Humidity at 2-meter (kg/kg)
 Minimum Specific Humidity at 10-meter (kg/kg)
 Mean Temperature at 2-meter (K)
 Mean Temperature at 2-meter (C)
 Mean Temperature at 10-meter (K)
 Mean Temperature at 10-meter (C)
 Mean Specific Humidity at 2-meter (kg/kg)
 Mean Specific Humidity at 10-meter (kg/kg)
 Maximum wind speed at 50-meter (m/s)
 Maximum wind speed at 2-meter (m/s)
 Maximum wind speed at 10-meter (m/s)
 Maximum Temperature at 2-meter (K)
 Maximum Temperature at 2-meter (C)
 Maximum Temperature at 10-meter (K)
 Maximum Temperature at 10-meter (C)
 Maximum Surface Pressure (Pa)
 Maximum Specific Humidity at 2-meter (kg/kg)
 Maximum Specific Humidity at 10-meter (kg/kg)
 Change in Temperature at 2-meter (K)
 Change in Temperature at 2-meter (C)
 Change in Temperature at 10-meter (K)
 Change in Temperature at 10-meter (C)
 Change in Surface Pressure (Pa)



NOAA climate zone

Pearson estimate



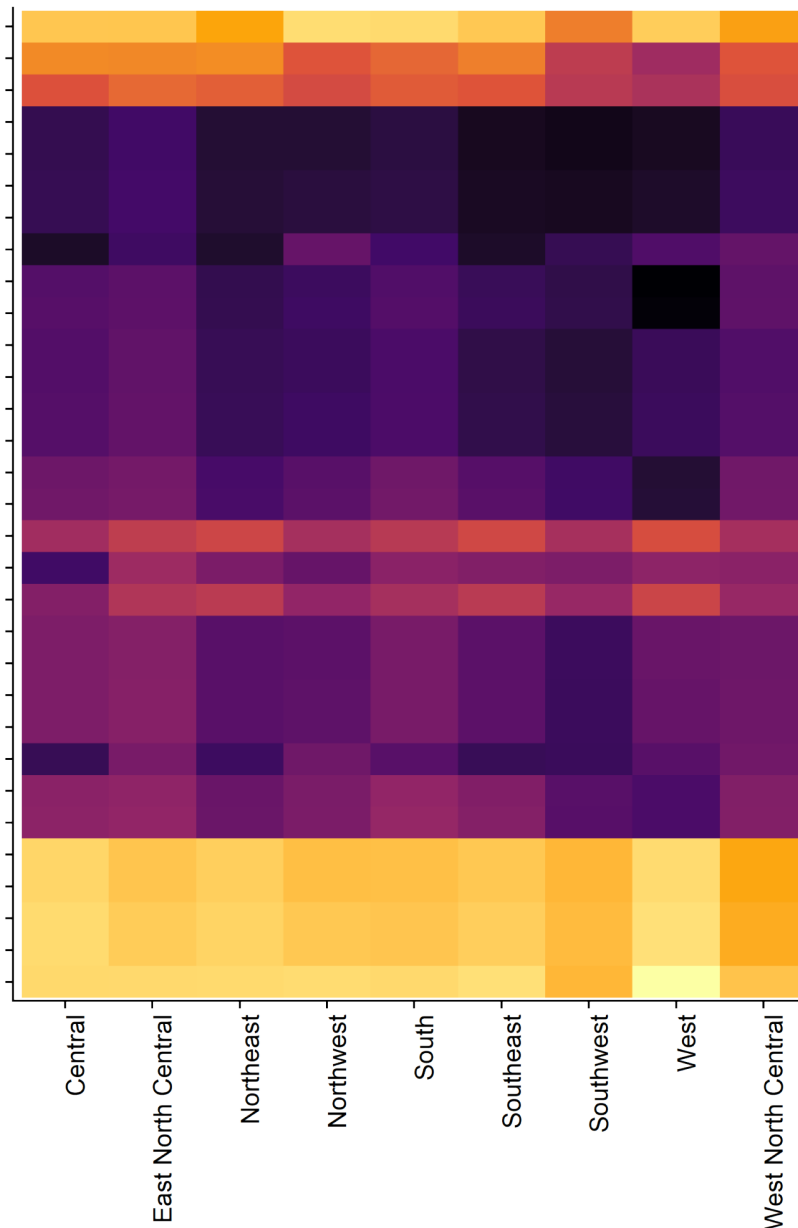
Strongest correlations between outage duration and weather variables precipitation and change in temperature

NOAA Climate Zones



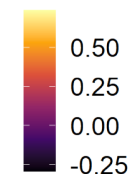
MERRA-2 weather variable

Total Precipitable Water Vapor (kg/m²)
 Total Precipitable Liquid Water (kg/m²)
 Total Precipitable Ice Water (kg/m²)
 Minimum Temperature at 2-meter (K)
 Minimum Temperature at 2-meter (C)
 Minimum Temperature at 10-meter (K)
 Minimum Temperature at 10-meter (C)
 Minimum Surface Pressure (Pa)
 Minimum Specific Humidity at 2-meter (kg/kg)
 Minimum Specific Humidity at 10-meter (kg/kg)
 Mean Temperature at 2-meter (K)
 Mean Temperature at 2-meter (C)
 Mean Temperature at 10-meter (K)
 Mean Temperature at 10-meter (C)
 Mean Specific Humidity at 2-meter (kg/kg)
 Mean Specific Humidity at 10-meter (kg/kg)
 Maximum wind speed at 50-meter (m/s)
 Maximum wind speed at 2-meter (m/s)
 Maximum wind speed at 10-meter (m/s)
 Maximum Temperature at 2-meter (K)
 Maximum Temperature at 2-meter (C)
 Maximum Temperature at 10-meter (K)
 Maximum Temperature at 10-meter (C)
 Maximum Surface Pressure (Pa)
 Maximum Specific Humidity at 2-meter (kg/kg)
 Maximum Specific Humidity at 10-meter (kg/kg)
 Change in Temperature at 2-meter (K)
 Change in Temperature at 2-meter (C)
 Change in Temperature at 10-meter (K)
 Change in Temperature at 10-meter (C)
 Change in Surface Pressure (Pa)



NOAA climate zone

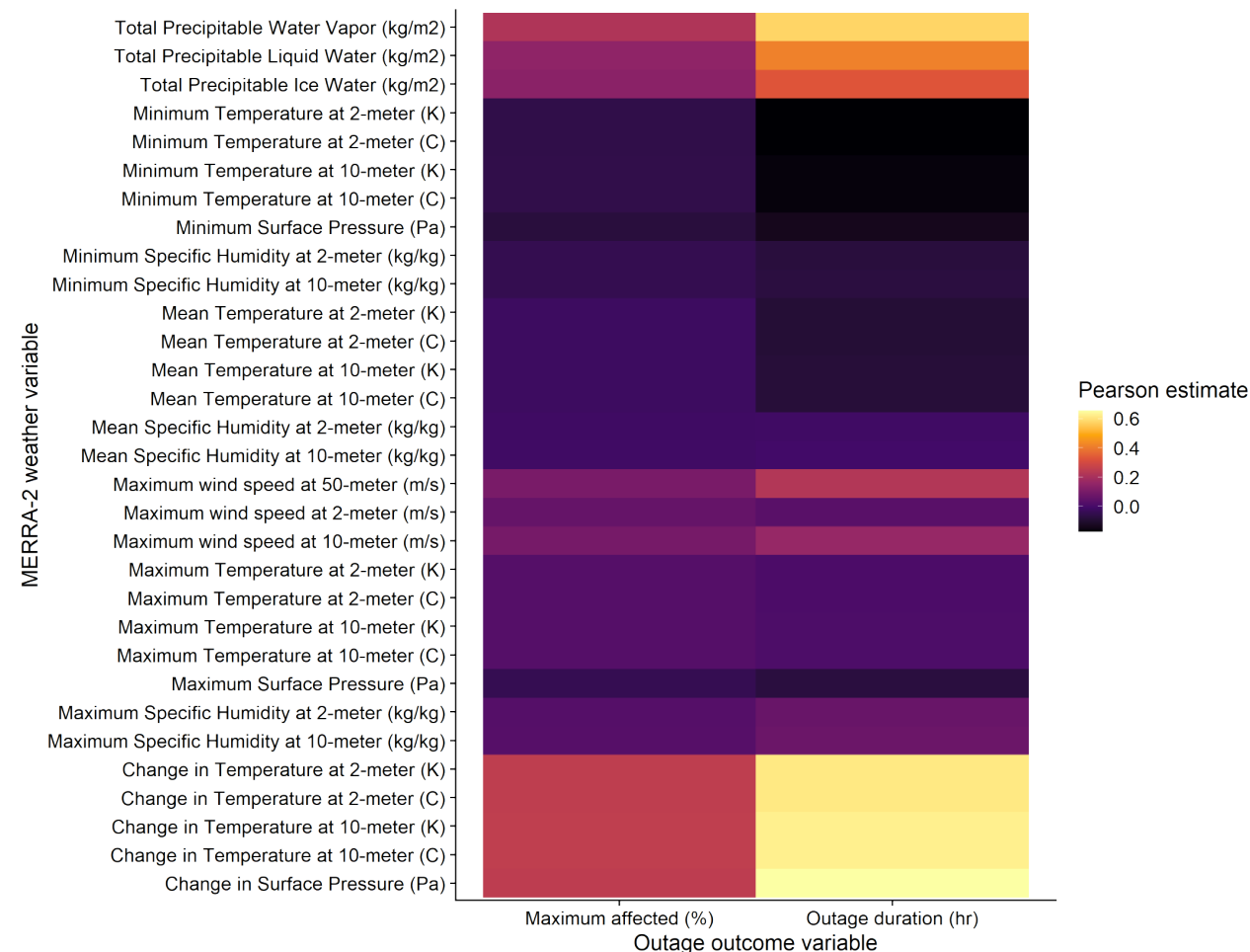
Pearson estimate



In conclusion, strong correlations between outages and precipitation and change in temperature in U.S. during 2014-2019



- Coupled county-level outage data and hourly weather data
- Observed differences in national and climate region trends
- Future work directions
 - Ground truthing outages and weather
 - Machine learning for outage and restoration prediction
 - Incorporation of socio-economic variables



Nicole Jackson (njacks@sandia.gov)

Andrea Staid (astaid@sandia.gov) • Hiba Baroud (hiba.baroud@vanderbilt.edu)