United States county-level exposure to tropical cyclones and associated mortality risks

Colorado School of Public Health Epidemiology Seminar

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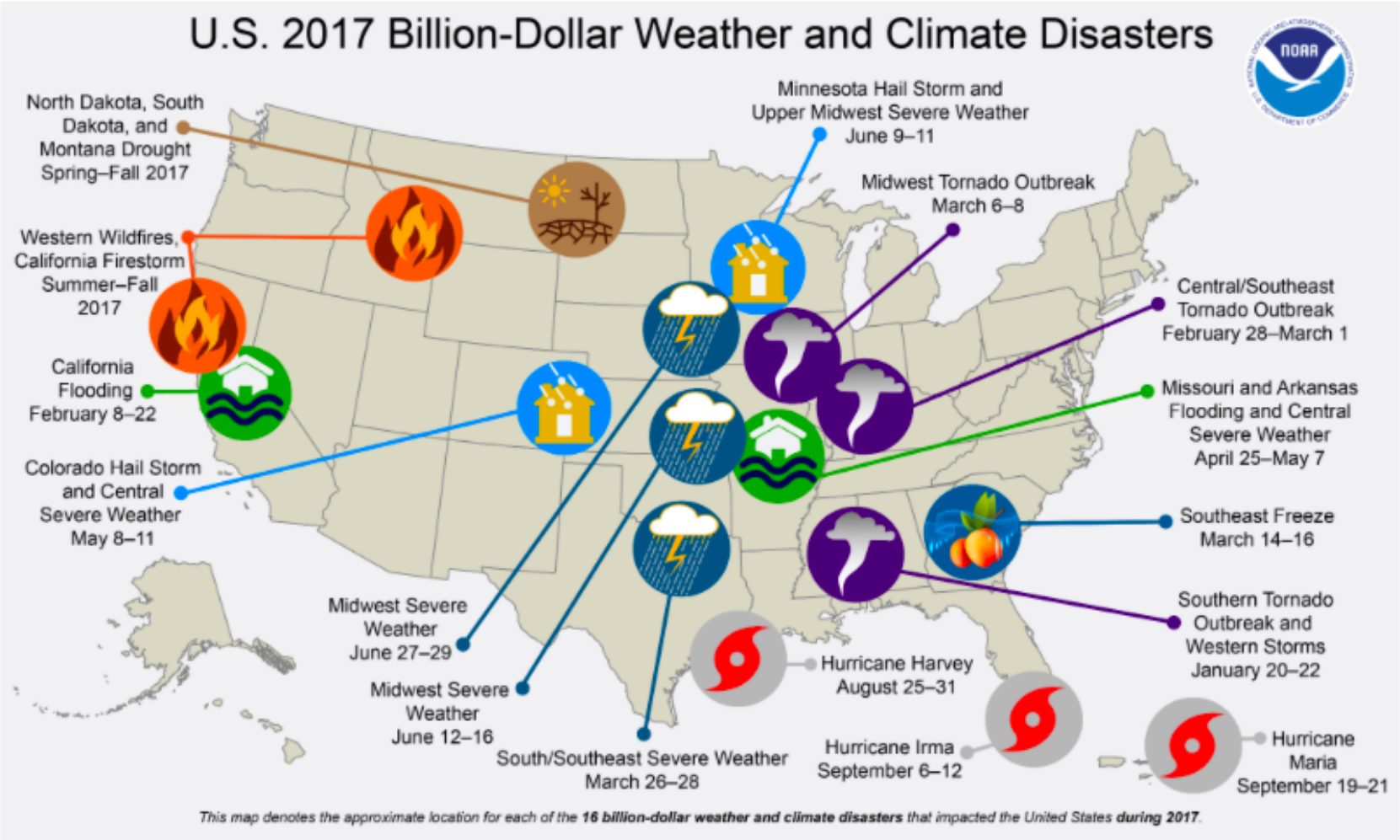
Major U.S. disasters, 2017



Source: https://www.ncdc.noaa.gov/billions/

Hurricane fatality studies

Loss of Life in the United States Associated with Recent Atlantic Tropical Cyclones

Edward N. Rappaport
NOAA/NWS/Tropical Prediction Center/National Hurricane Center, Miami, Florida

Fatalities in the United States from Atlantic Tropical Cyclones

New Data and Interpretation

BY EDWARD N. RAPPAPORT

Nat Hazards (2011) 59:1513–1531
DOI 10.1007/s11069-011-9849-x

ORIGINAL PAPER

An analysis of coastal and inland fatalities in landfalling US hurricanes

Jeffrey Czajkowski · Kevin Simmons · Daniel Sutter

Reporting cause of death

CAUSE OF DEATH (See instructions and examples)

32. **PART I.** Enter the chain of events--diseases, injuries, or complications--that directly caused the death. DO NOT enter terminal events such as cardiac arrest, respiratory arrest, or ventricular fibrillation without showing the etiology. DO NOT ABBREVIATE. Enter only one cause on a line. Add additional lines if necessary.

Approximate interval: Onset to death

IMMEDIATE CAUSE (Final disease or condition ---------> resulting in death)
a. Crushed chest
Due to (or as a consequence of):

Sequentially list conditions, if any, leading to the cause listed on line a. Enter the **UNDERLYING CAUSE** (disease or injury that initiated the events resulting in death) **LAST**
b. Shed collapsed during hurricane
Due to (or as a consequence of):
c.
Due to (or as a consequence of):
d.

PART II. Enter other significant conditions contributing to death but not resulting in the underlying cause given in PART I.

Head trauma

33. WAS AN AUTOPSY PERFORMED? ☐ Yes ■ No

34. WERE AUTOPSY FINDINGS AVAILABLE TO COMPLETE THE CAUSE OF DEATH? ☐ Yes ■ No

35. DID TOBACCO USE CONTRIBUTE TO DEATH?
☐ Yes ☐ Probably
■ No ☐ Unknown

36. IF FEMALE:
☐ Not pregnant within past year
☐ Pregnant at time of death
☐ Not pregnant, but pregnant within 42 days of death
☐ Not pregnant, but pregnant 43 days to 1 year before death
☐ Unknown if pregnant within the past year

37. MANNER OF DEATH
☐ Natural ☐ Homicide
■ Accident ☐ Pending Investigation
☐ Suicide ☐ Could not be determined

Source: https://www.cdc.gov/nchs/data/dvs/hurricane_certification.pdf

Reporting cause of death

CAUSE OF DEATH (See instructions and examples)

32. **PART I.** Enter the chain of events--diseases, injuries, or complications--that directly caused the death. DO NOT enter terminal events such as cardiac arrest, respiratory arrest, or ventricular fibrillation without showing the etiology. DO NOT ABBREVIATE. Enter only one cause on a line. Add additional lines if necessary.

Approximate interval: Onset to death

IMMEDIATE CAUSE (Final disease or condition ---------> resulting in death)

a. Acute respiratory failure — 4 hours
Due to (or as a consequence of):

Sequentially list conditions, if any, leading to the cause listed on line a. Enter the **UNDERLYING CAUSE** (disease or injury that initiated the events resulting in death) **LAST**

b. Severe emphysema
Due to (or as a consequence of):

c. Heat and loss of air conditioner power from hurricane
Due to (or as a consequence of):

d.

PART II. Enter other significant conditions contributing to death but not resulting in the underlying cause given in PART I.

33. WAS AN AUTOPSY PERFORMED? ☐ Yes ■ No

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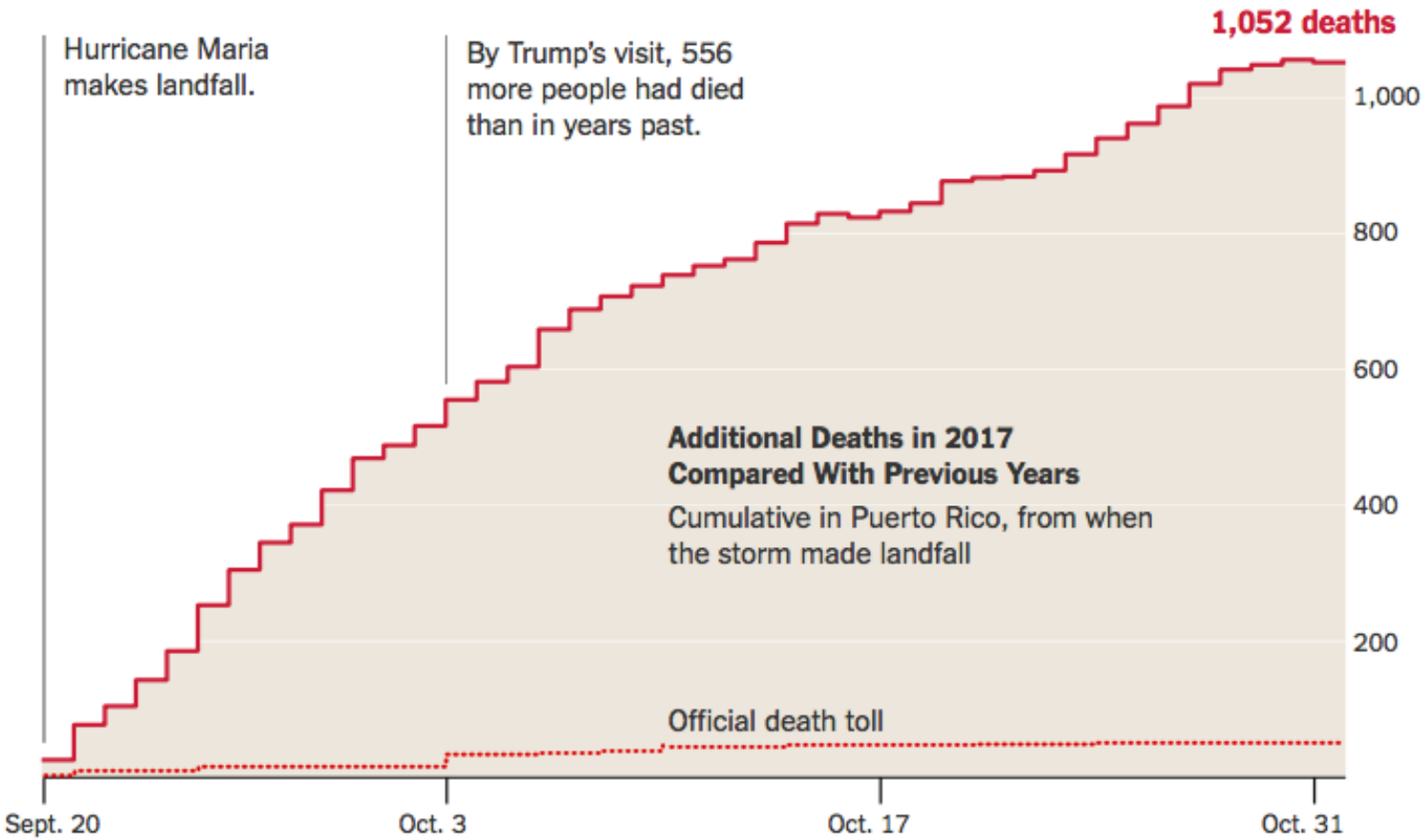
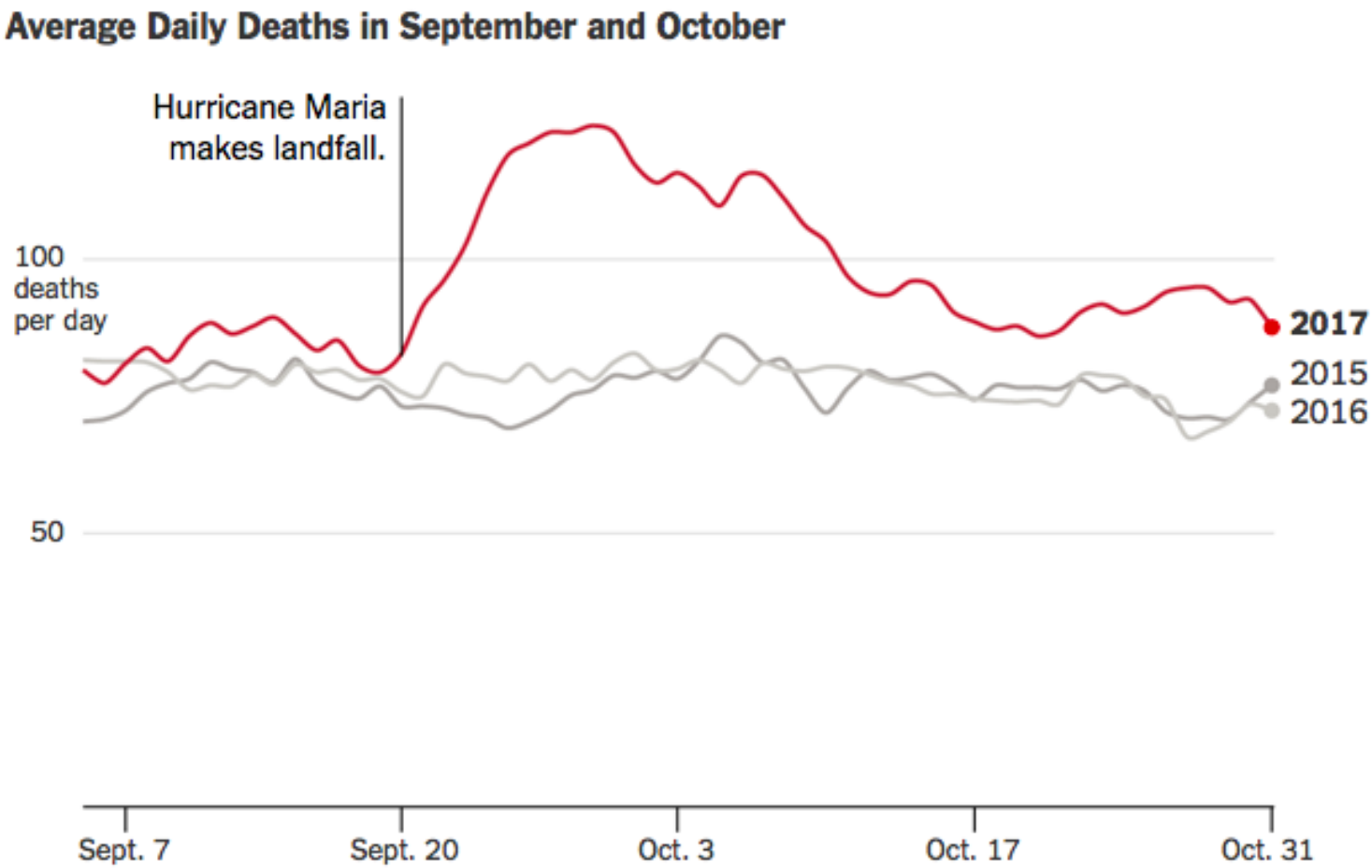
Source: https://www.cdc.gov/nchs/data/dvs/hurricane_certification.pdf

Hurricane Maria example



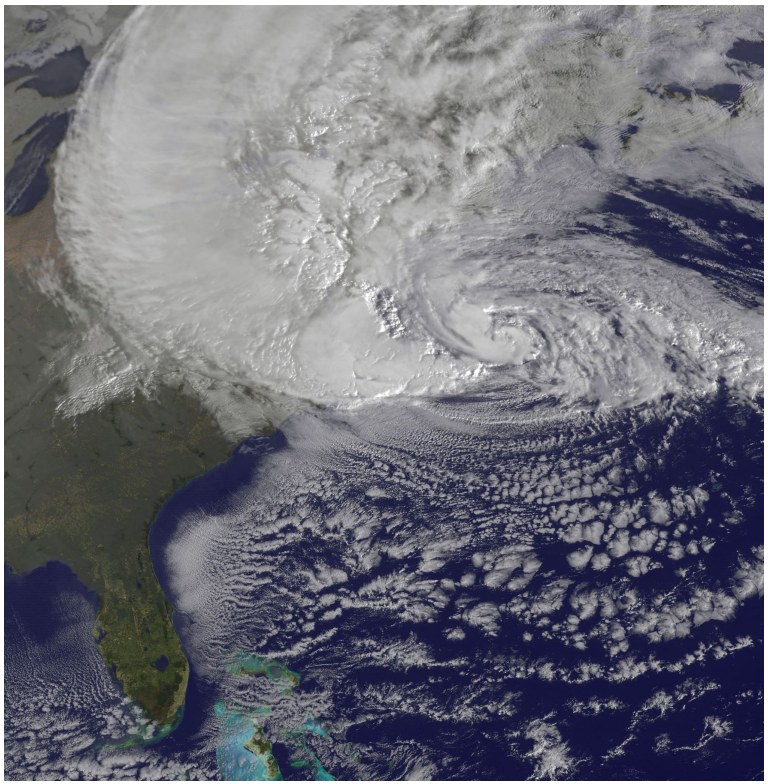
Source: The New York Times

Hurricane Maria example



Source: The New York Times

Health risks associated with Hurricane Sandy (2012)



Source: NOAA / NASA GOES Project

Health risks in storm-affected areas

- Change in patterns of emergency department visits (Kim et al. 2016)
- Increased outpatient cases of food and waterborne disease among elderly (Bloom et al. 2016)
- Increased rate of myocardial infarctions (Swerdel et al. 2014)
- Increased hospitalizations for dehydration (Lee et al. 2016)
- Difficulty obtaining medical care, medications, and medical equipment (Davidow et al. 2016)

Project aims

Project aims

- Assess exposure to tropical storms for all U.S. Atlantic basin tropical storms, 1988–2015, based on reasonable measurements of tropical storm hazards
- Determine agreement between hazard-based classifications for U.S. counties
- Investigate mortality risks associated with tropical storm exposures in U.S. communities
- Make exposure assessments accessible to other researchers for epidemiological and other impact studies

Assessing exposure to tropical storms

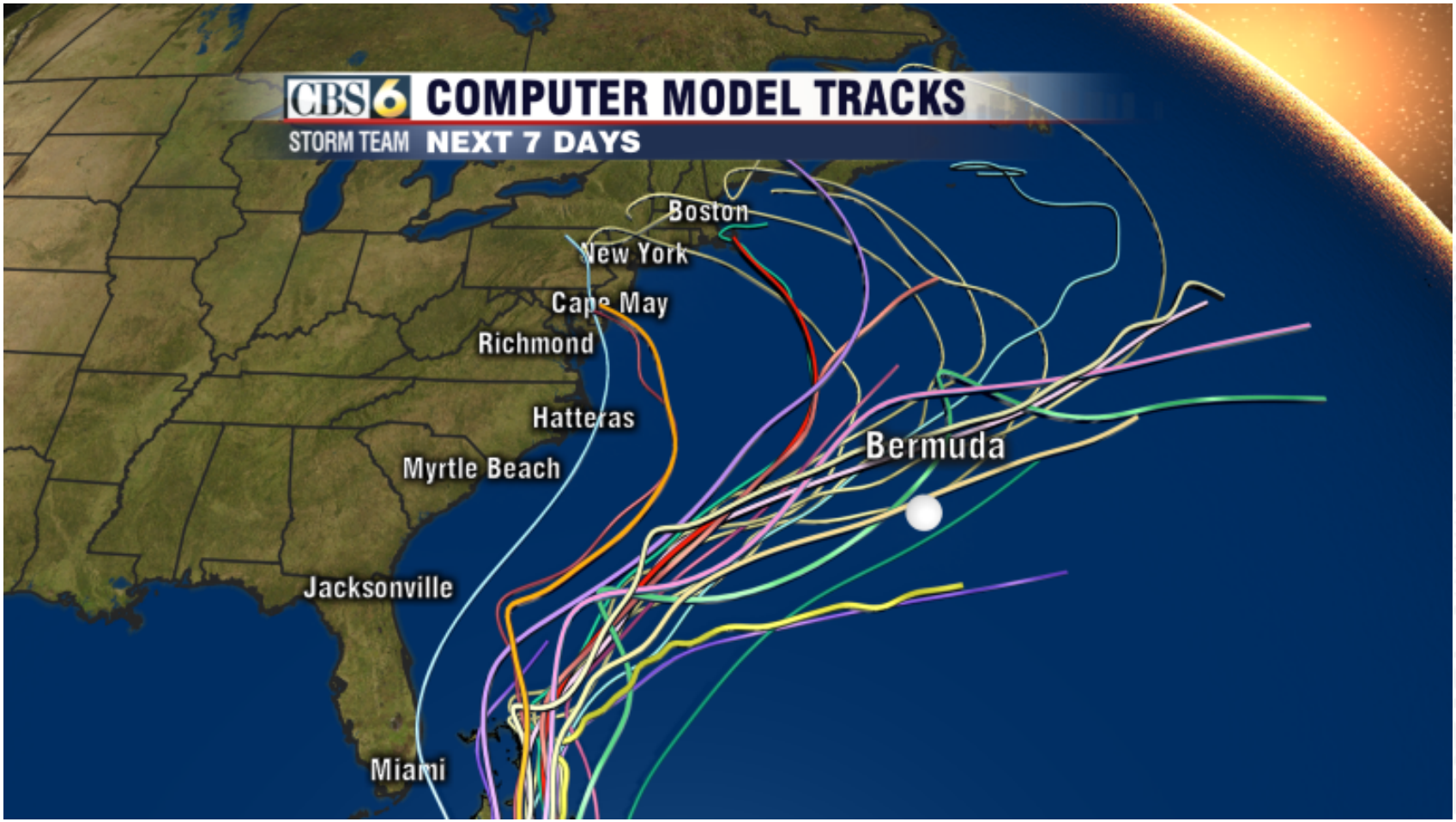
Hurricane hazards and impacts

Source: The New York Times

Hurricane hazards and impacts

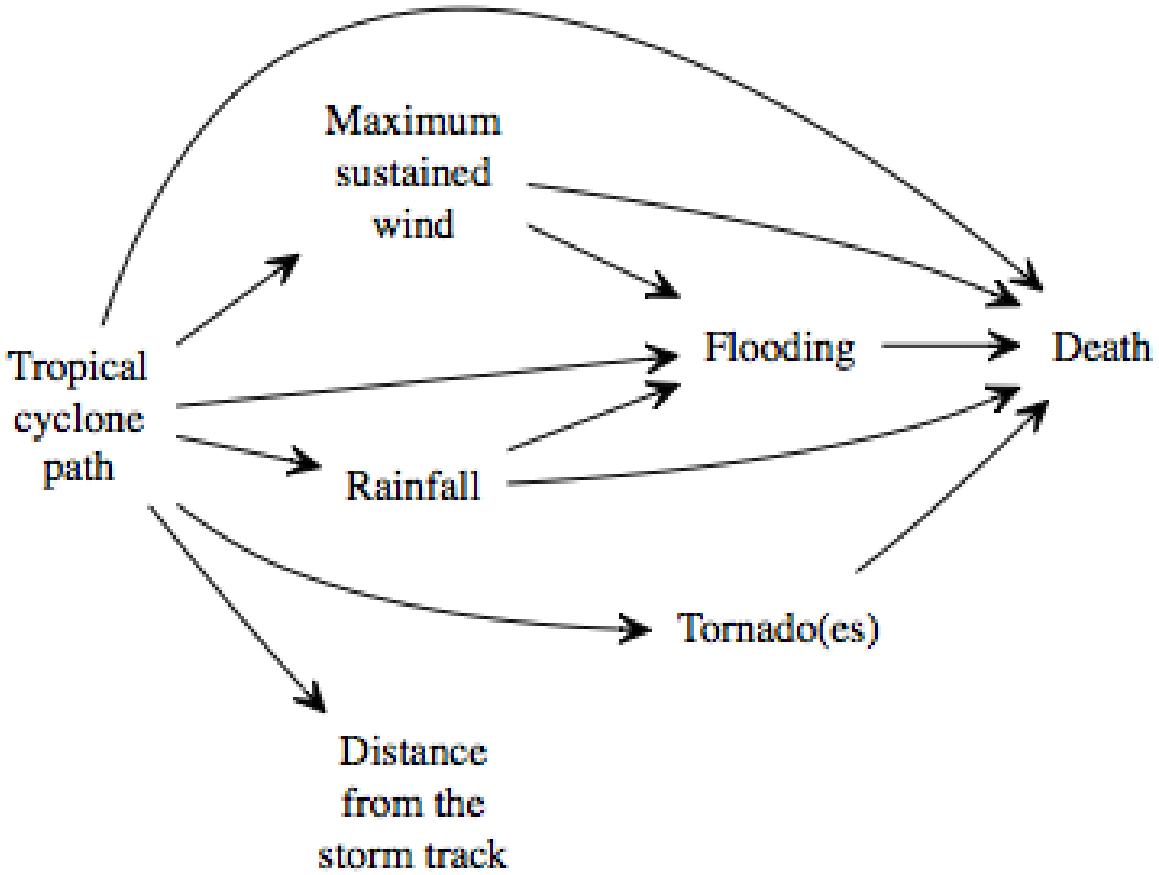
Source: AccuWeather

Forecasts of Hurricane Sandy's track

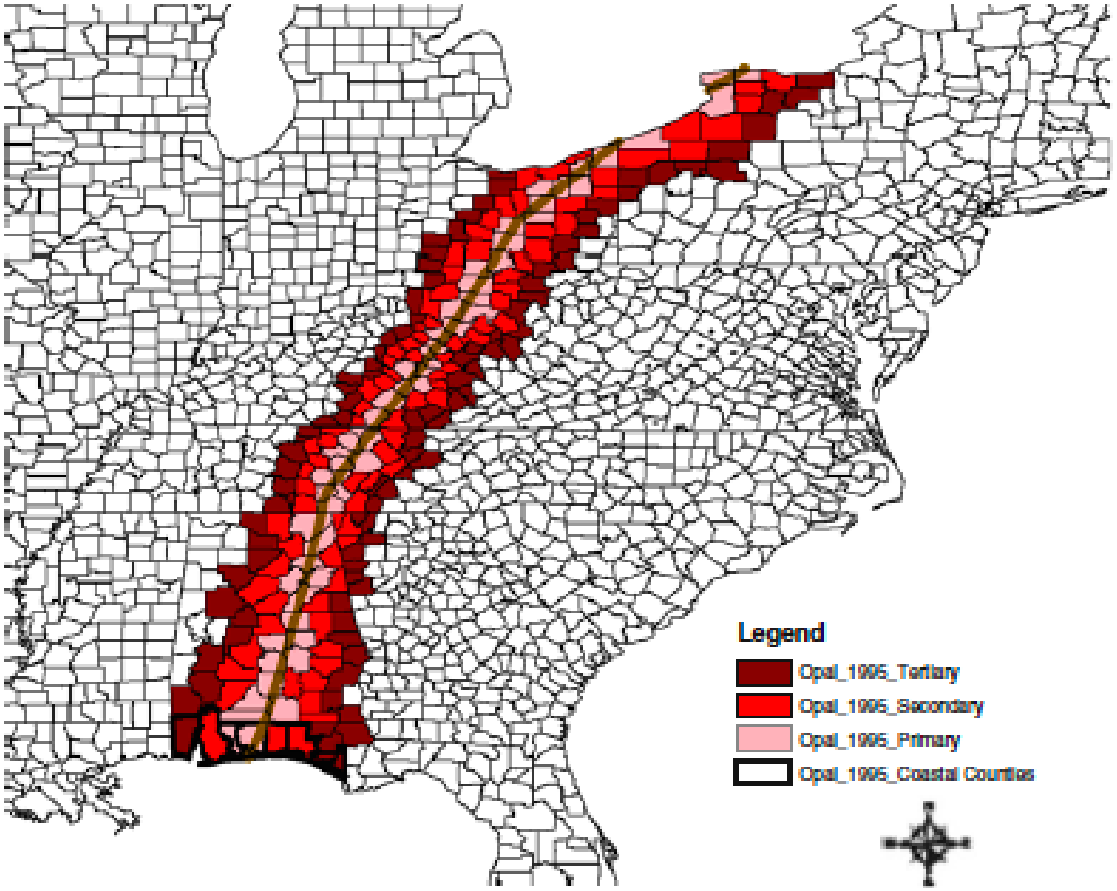


Source: http://wtvr.com/2012/10/24/sandy-becomes-a-hurricane/

Hurricane hazards



Assessing exposure

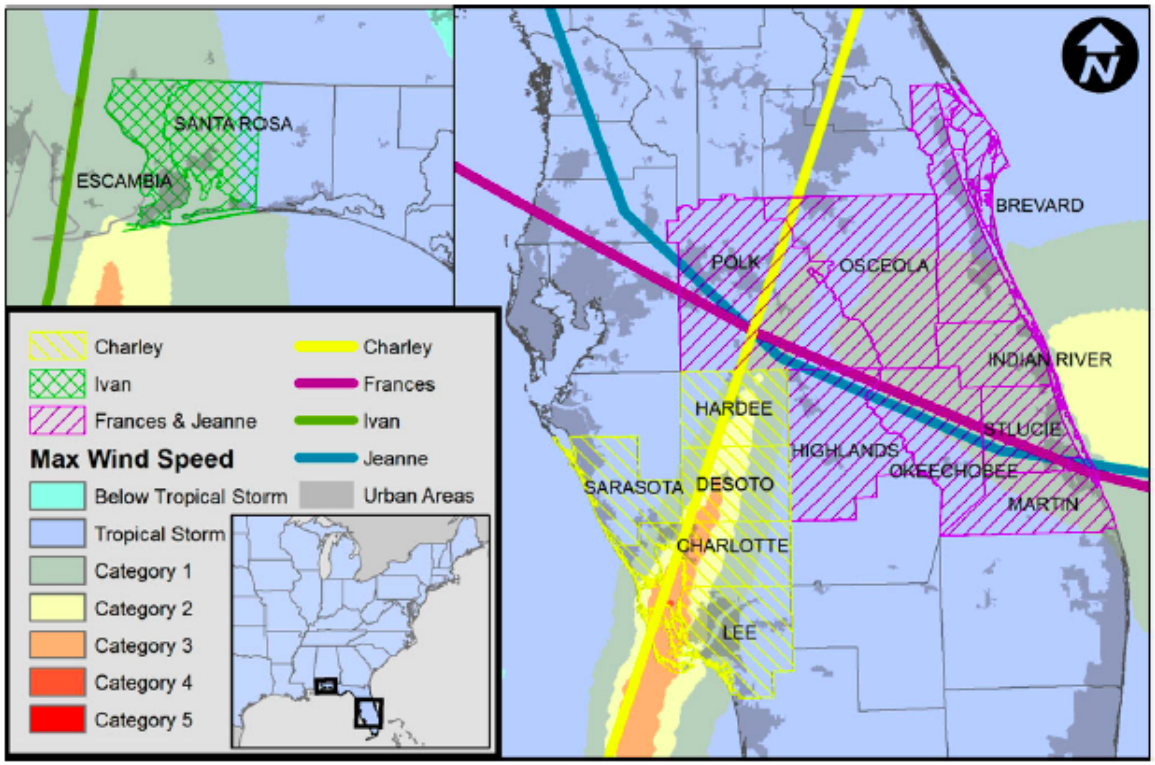


Czajkowski et al. 2011

Example exposure assessment

Czajkowski et al. (2011) classified counties based on distance to storm tracks to study mortality risks.

Assessing exposure

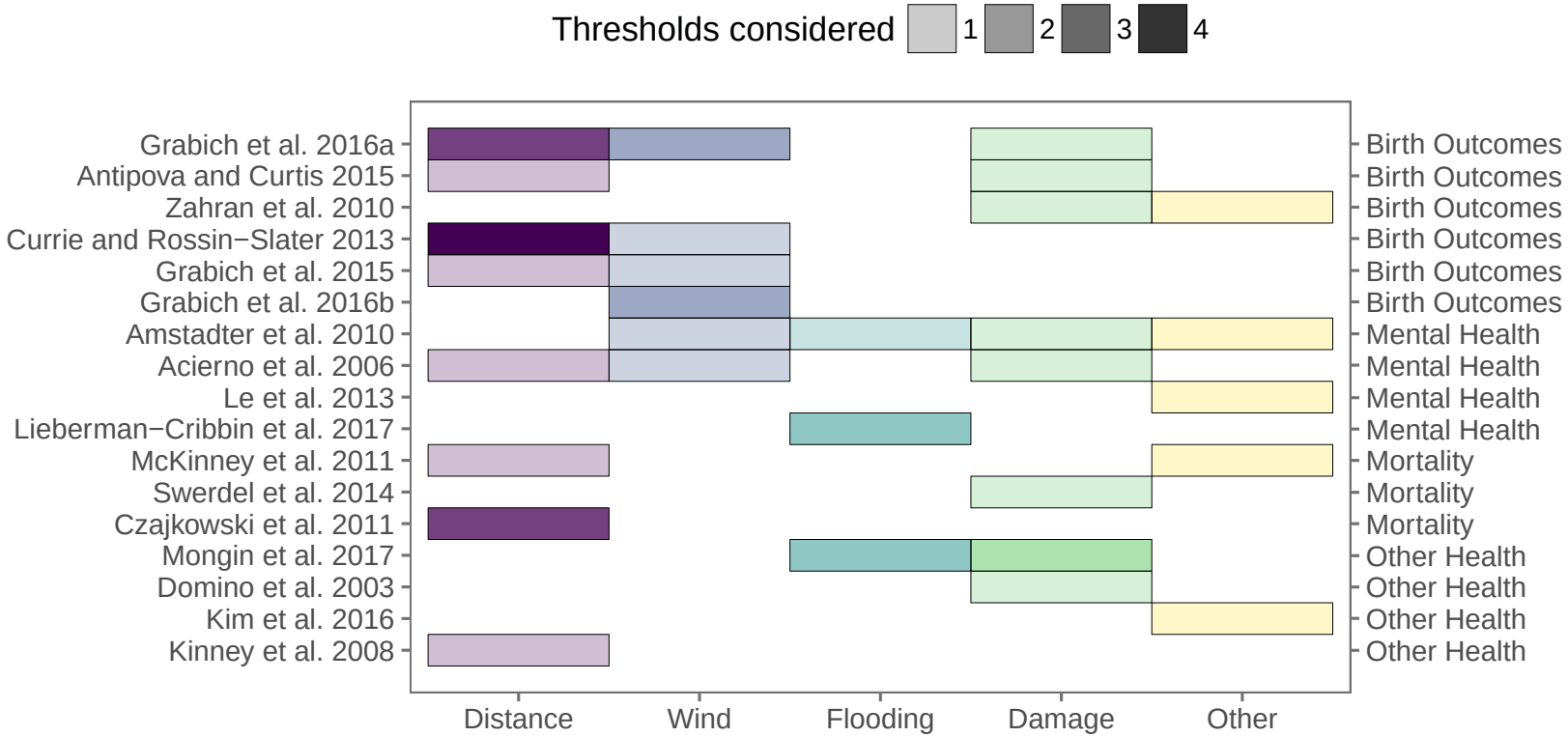


McKinney et al. 2011

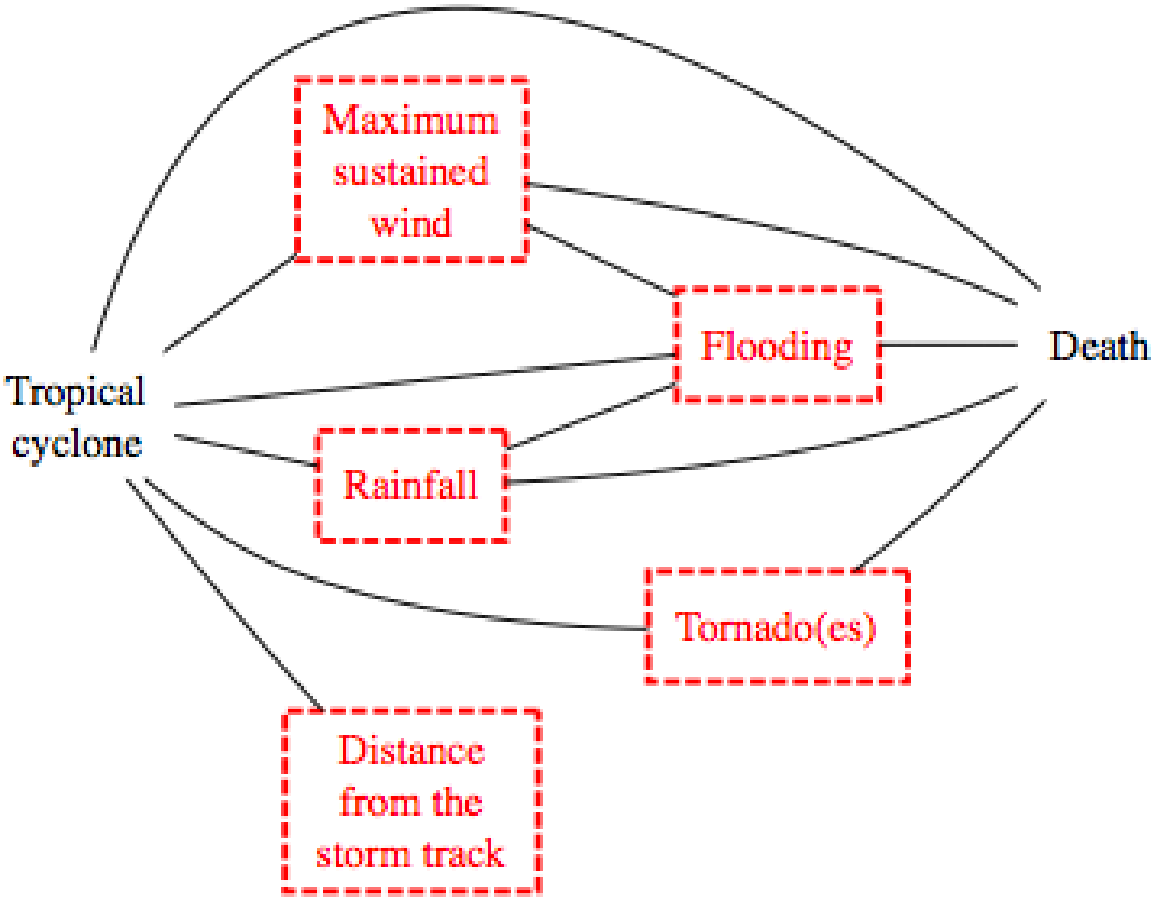
Example exposure assessment

McKinney et al. (2011) classified counties based on distance to storm tracks, evacuations, and wind to study mortality risk.

Previous metrics of tropical cyclone exposure

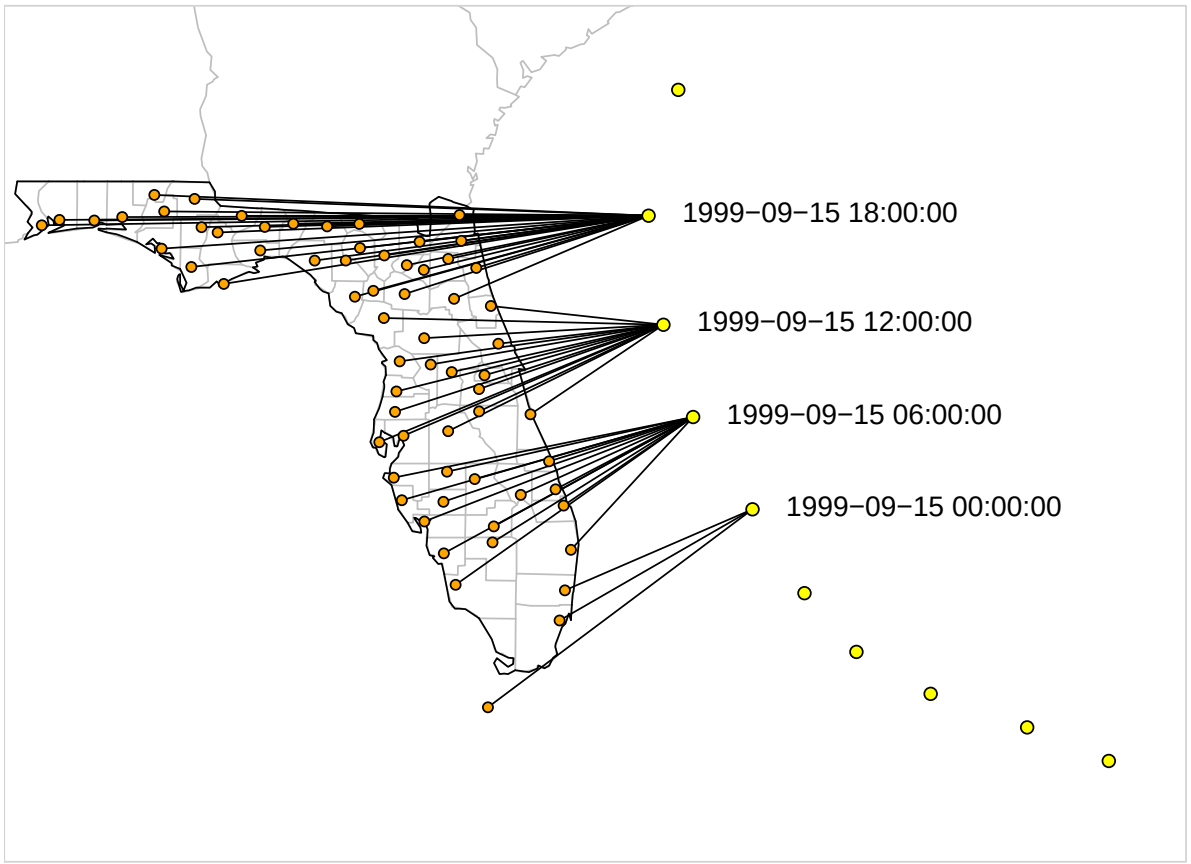


Exposure metrics



Distance from storm

Tropical storm "Best Track" data



Distance metric

We matched storm tracks to county population mean centers to determine the closest approach and date of closest approach of each storm to each county.

Rain exposure

Rain during Tropical Storm Lee

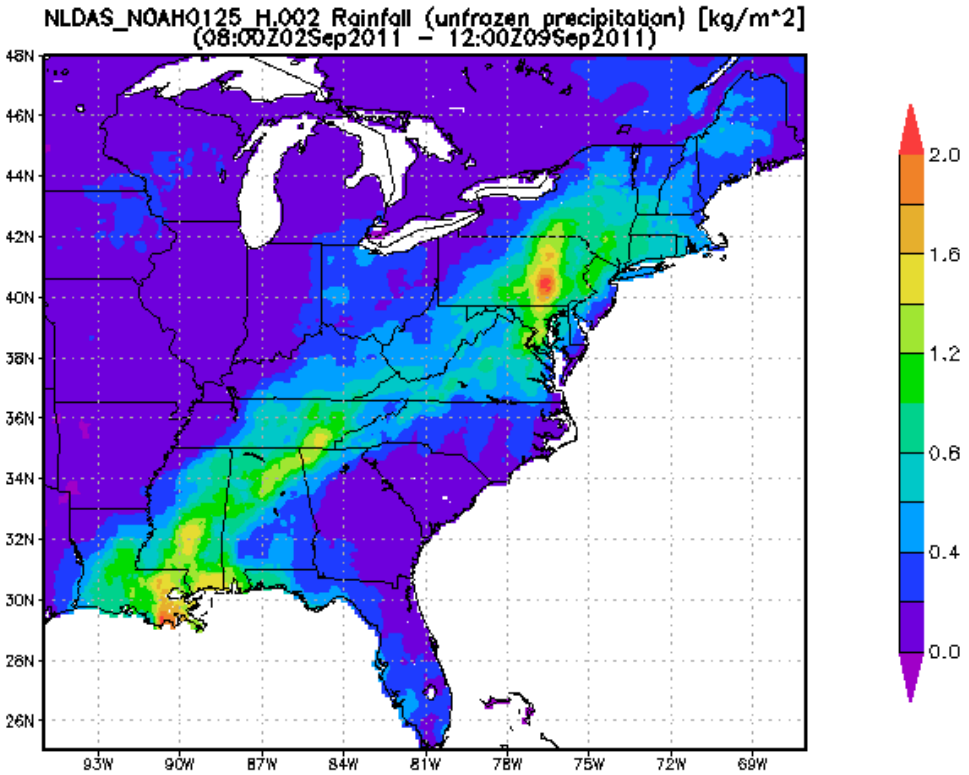
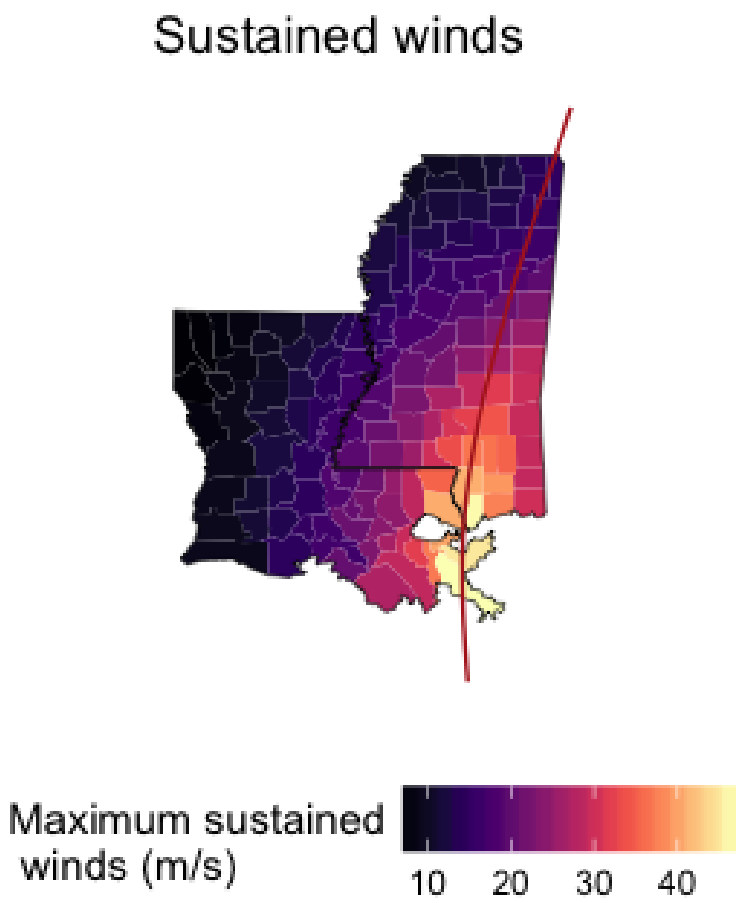


Image source: Goddard Earth Sciences DISC

Rain metric

We used NLDAS-2 precipitation data to assess county rainfall. We summed rain from two days before to one day after the storm. We include a distance threshold for the rain metric.

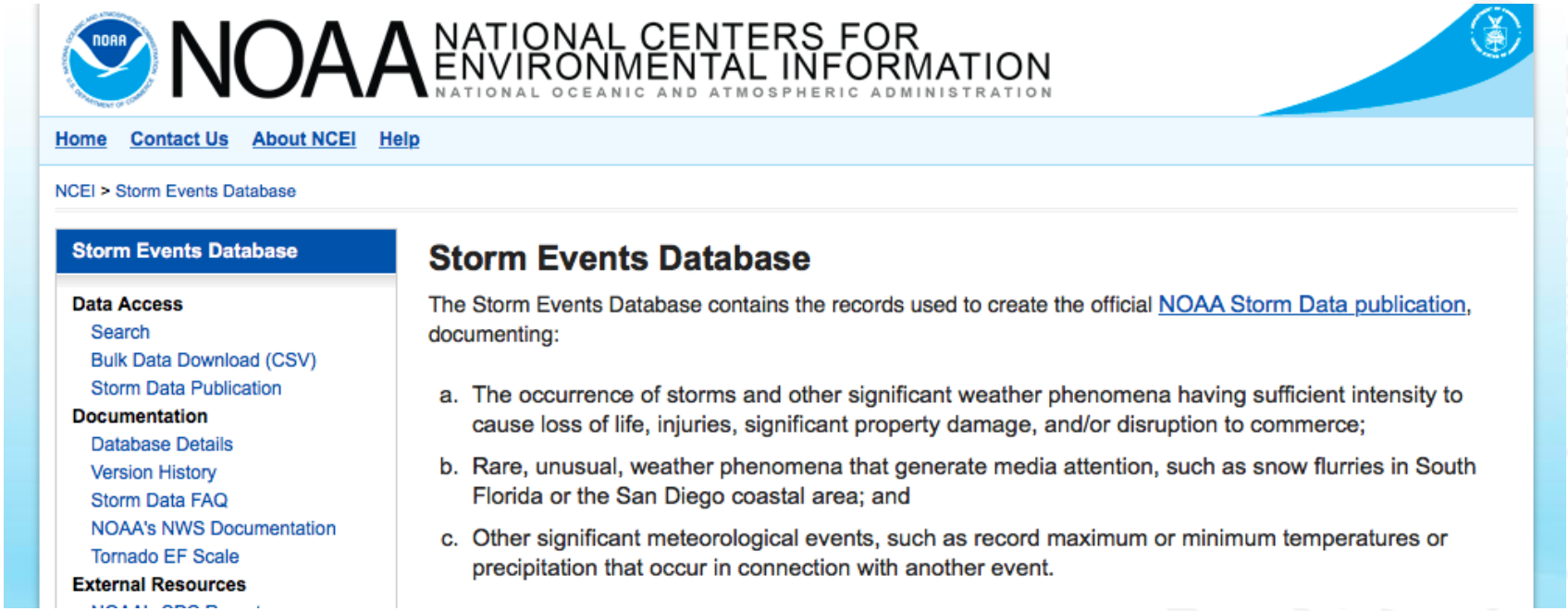
Wind exposure



Wind metric

We modeled county winds with a wind model based on a Willoughby et al. paper. This model inputs storm location and maximum wind from best tracks data.

Flood and tornado events



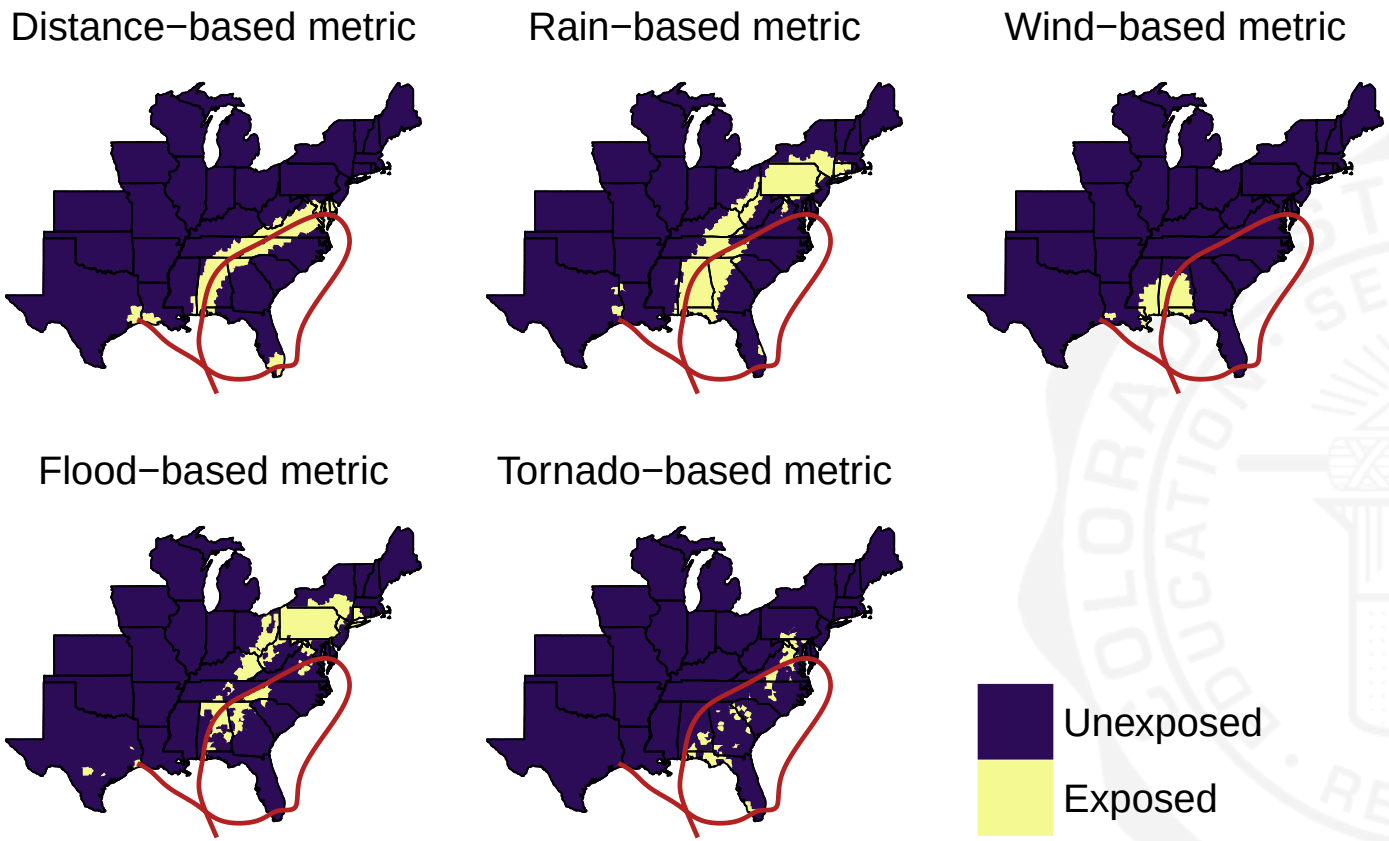
Website: https://www.ncdc.noaa.gov/stormevents/

Storm exposure

Exposure metric	Criterial for exposure
Distance	County population mean center within 100 km of storm track
Rain	County received 75 mm or more rain over the period from two days before to one day after the storm's closest approach and the storm passed within 500 km of the county
Wind	Modeled wind speed at county's population mean center met or exceeded 15 m / s during the storm
Flood	Flood event listed with a start date within two days of the storm's closest approach and county within 500 km of storm track
Tornado	Tornado event listed with a start date within two days of the storm's closest approach and county within 500 km of storm track

Agreement between exposure metrics

County-level exposure to Hurricane Ivan (2004)



Criteria for exposure classifications: **Distance:** Within 100 kms of storm track. **Rain:** $\geq$ 75 mm of rain total for two days before to one day after storm. **Wind:** Modeled wind of $\geq$ 15 m/s. **Flood, Tornado:** Listed event in NOAA Storm Events database.

County-level agreement in storm exposure

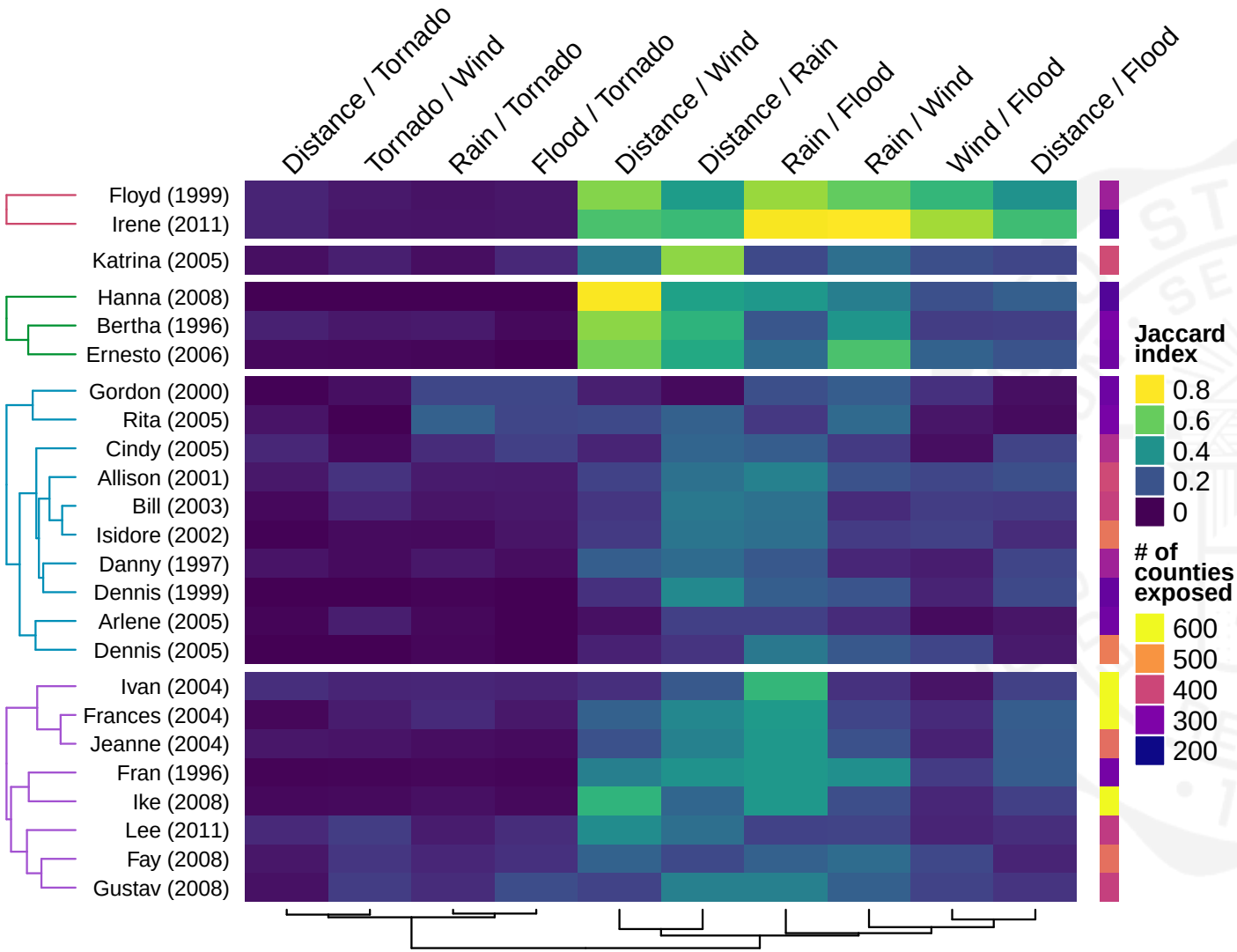
Assessing agreement in county classifications

For each storm and each pair of metrics, we measured the *Jaccard index* as a measure of county-level agreement in exposure classification for a storm:

$$J = \frac{X_1 \cap X_2}{X_1 \cup X_2}$$

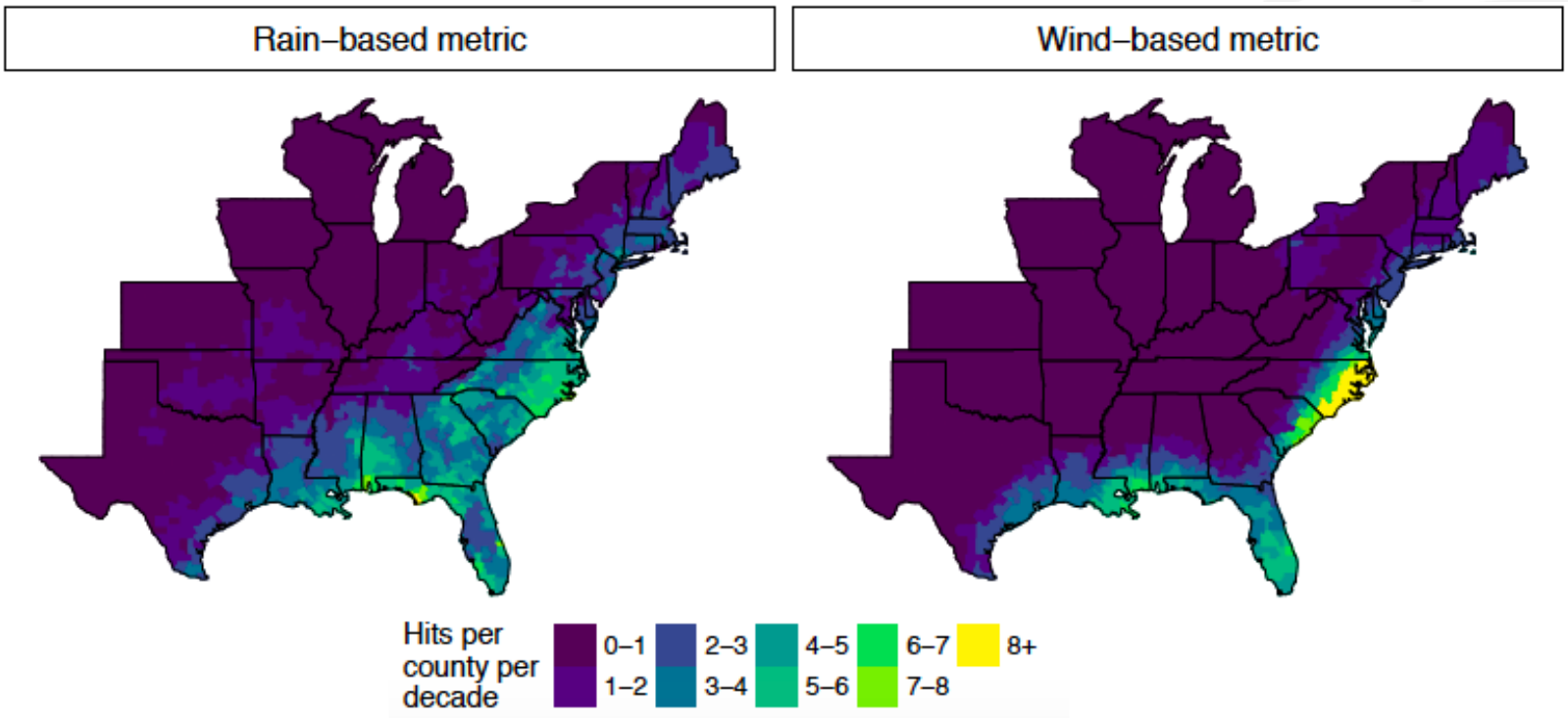
where X_1 is the set of counties exposed to a storm based on the first metric and X_2 is the set of counties exposed to the storm based on the second metric.

County-level agreement in storm exposure



Tropical storm exposure in U.S. counties

Storm hits per county per decade based on rain (left) and wind (right) exposure metrics.



Criteria for exposure classifications: **Rain:** $\geq$ 75 mm of rain total for two days before to one day after storm. **Wind:** Modeled wind of $\geq$ 15 m/s.

Distance as a measure of tropical cyclone exposure

Increase in West Nile Neuroinvasive Disease after Hurricane Katrina

Kevin A. Caillouët,* Sarah R. Michaels,* Xu Xiong,* Ivo Foppa,* and Dawn M. Wesson*

After Hurricane Katrina, the number of reported cases of West Nile neuroinvasive disease (WNND) sharply increased in the hurricane-affected regions of Louisiana and Mississippi. In 2006, a >2-fold increase in WNND incidence was observed in the hurricane-affected areas than in previous years.

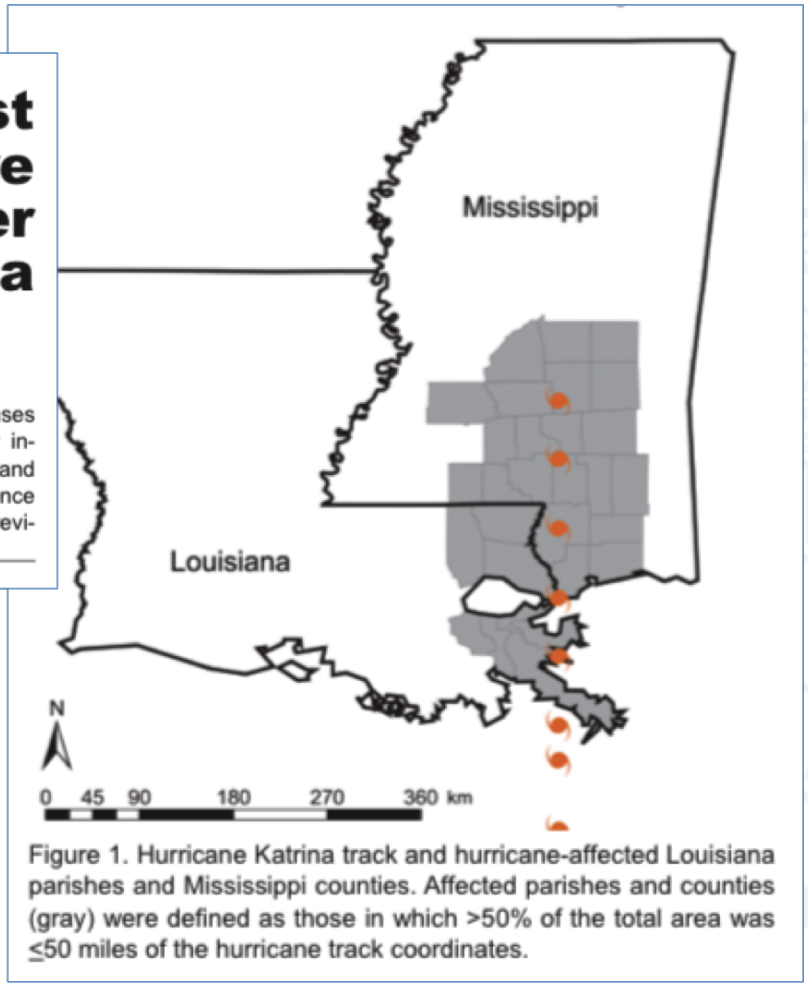
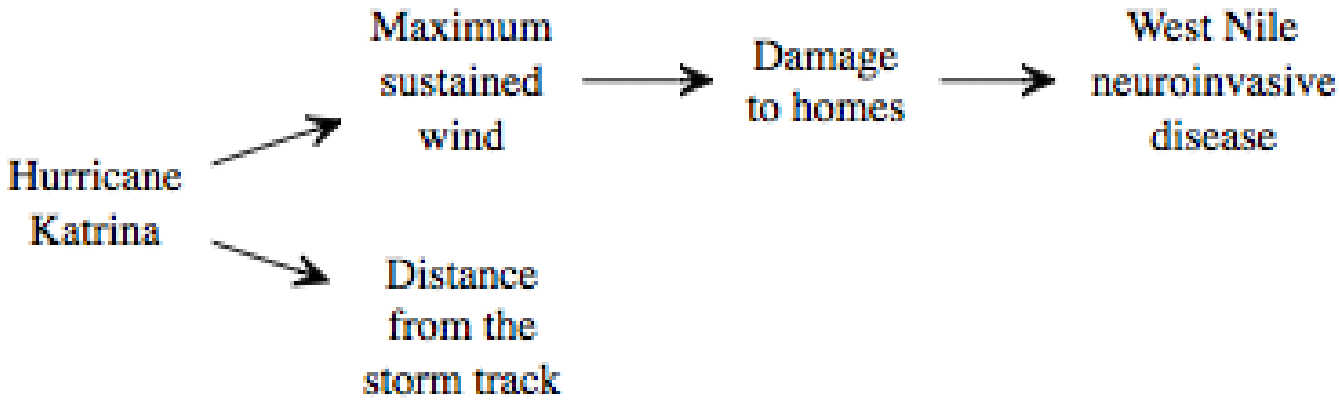
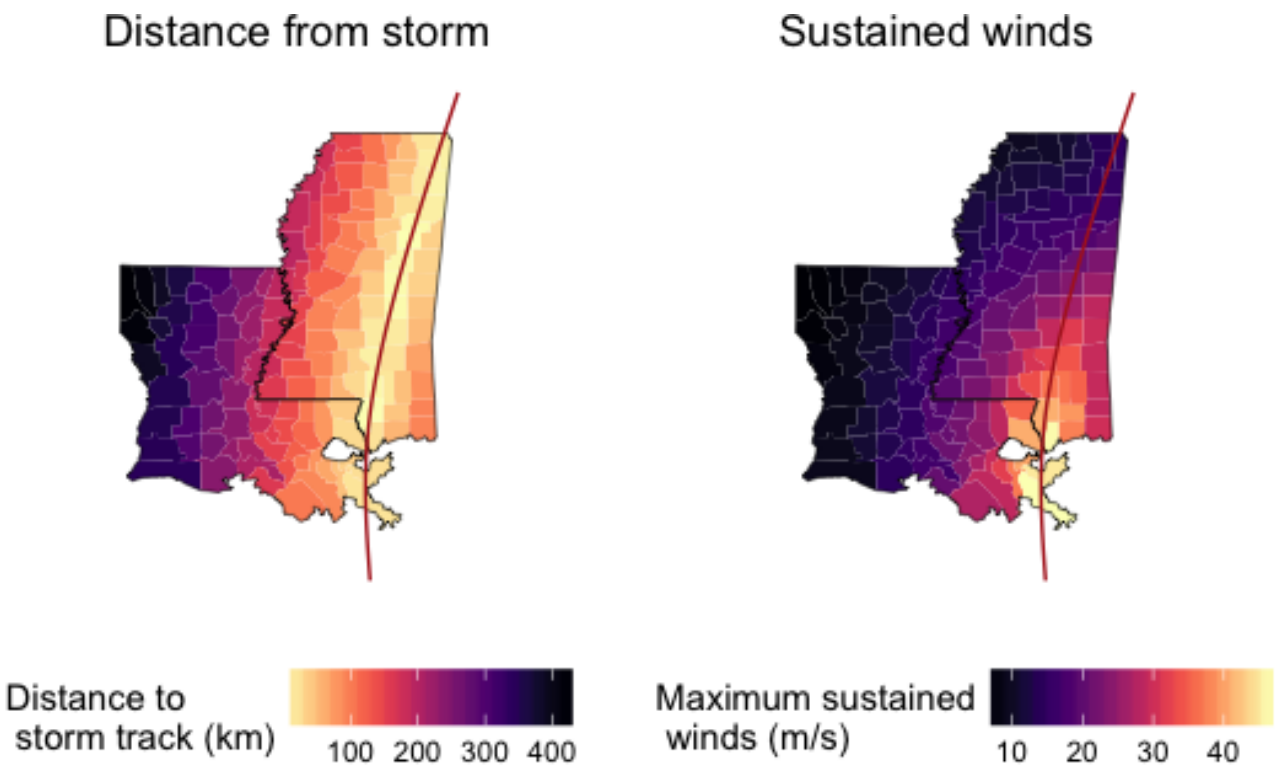


Figure 1. Hurricane Katrina track and hurricane-affected Louisiana parishes and Mississippi counties. Affected parishes and counties (gray) were defined as those in which >50% of the total area was ≤50 miles of the hurricane track coordinates.

Potential pathway for effects of Katrina on West Nile risk

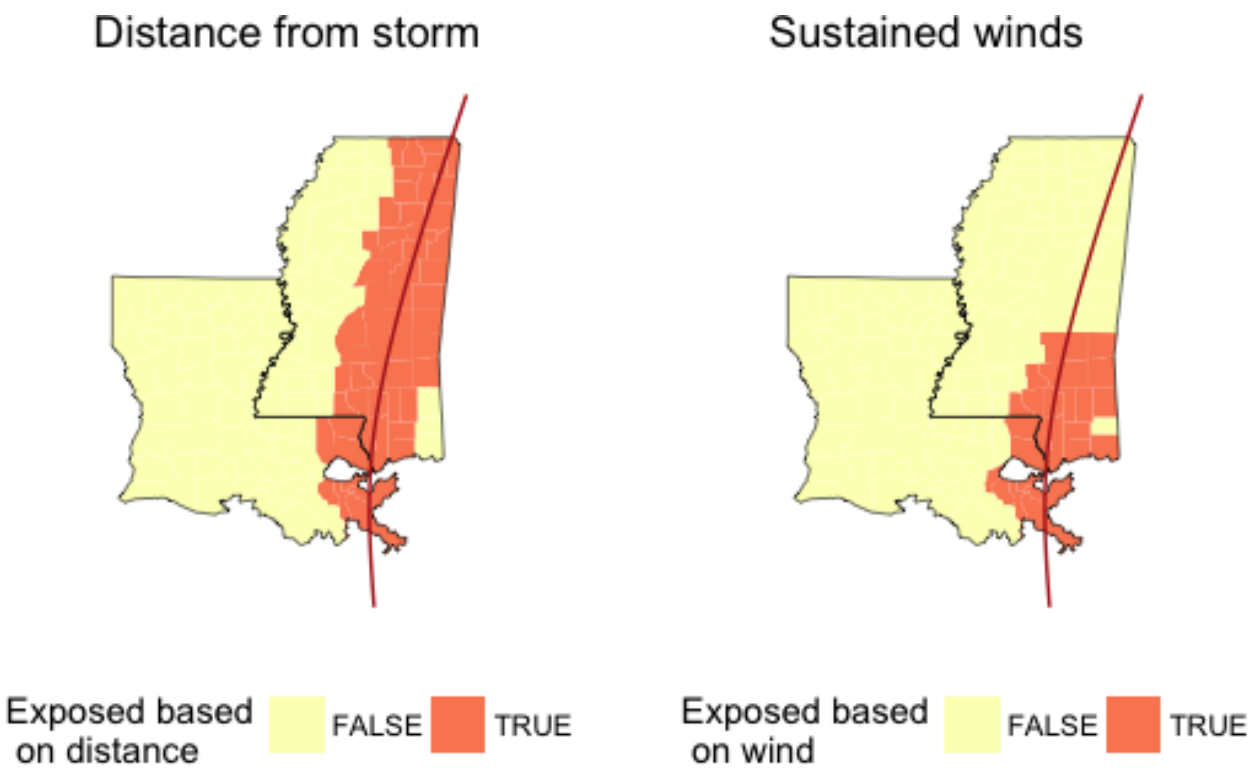


Katrina wind exposure vs. distance from storm track



For each county in Louisiana and Mississippi, we measured the distance of the county's population mean center from the storm track (left) and modeled the maximum sustained windspeed associated with the storm (right).

Katrina wind exposure vs. distance from storm

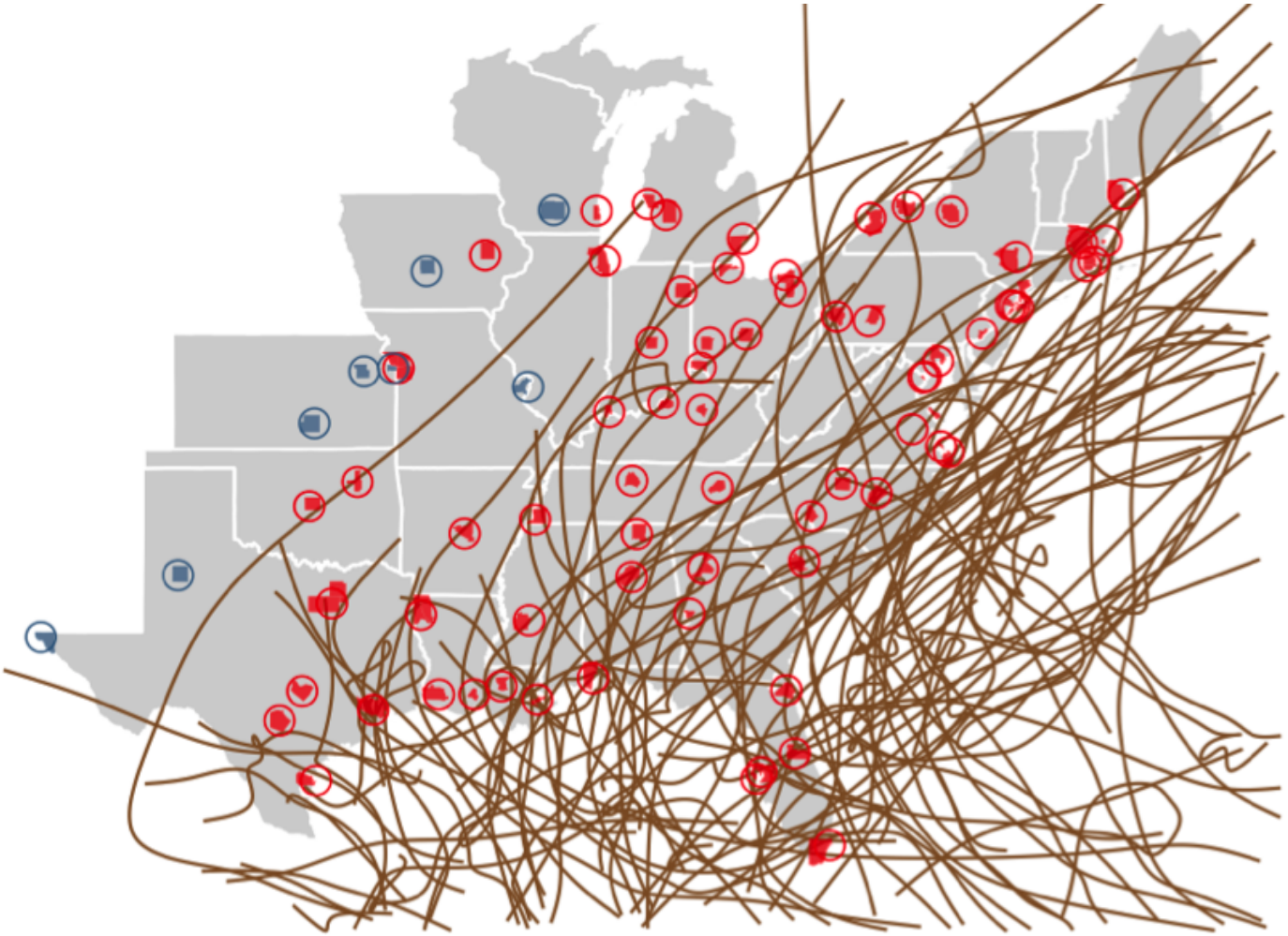


Binary storm exposure classifications based on distance from the storm track (left) and maximum sustained wind (right) for Hurricane Katrina.

Tropical storms and mortality risks

Study storms and communities

Storms and communities considered, 1988–2005



Relative risk of mortality associated with storm exposure

Relative risk of mortality associated with storm exposure

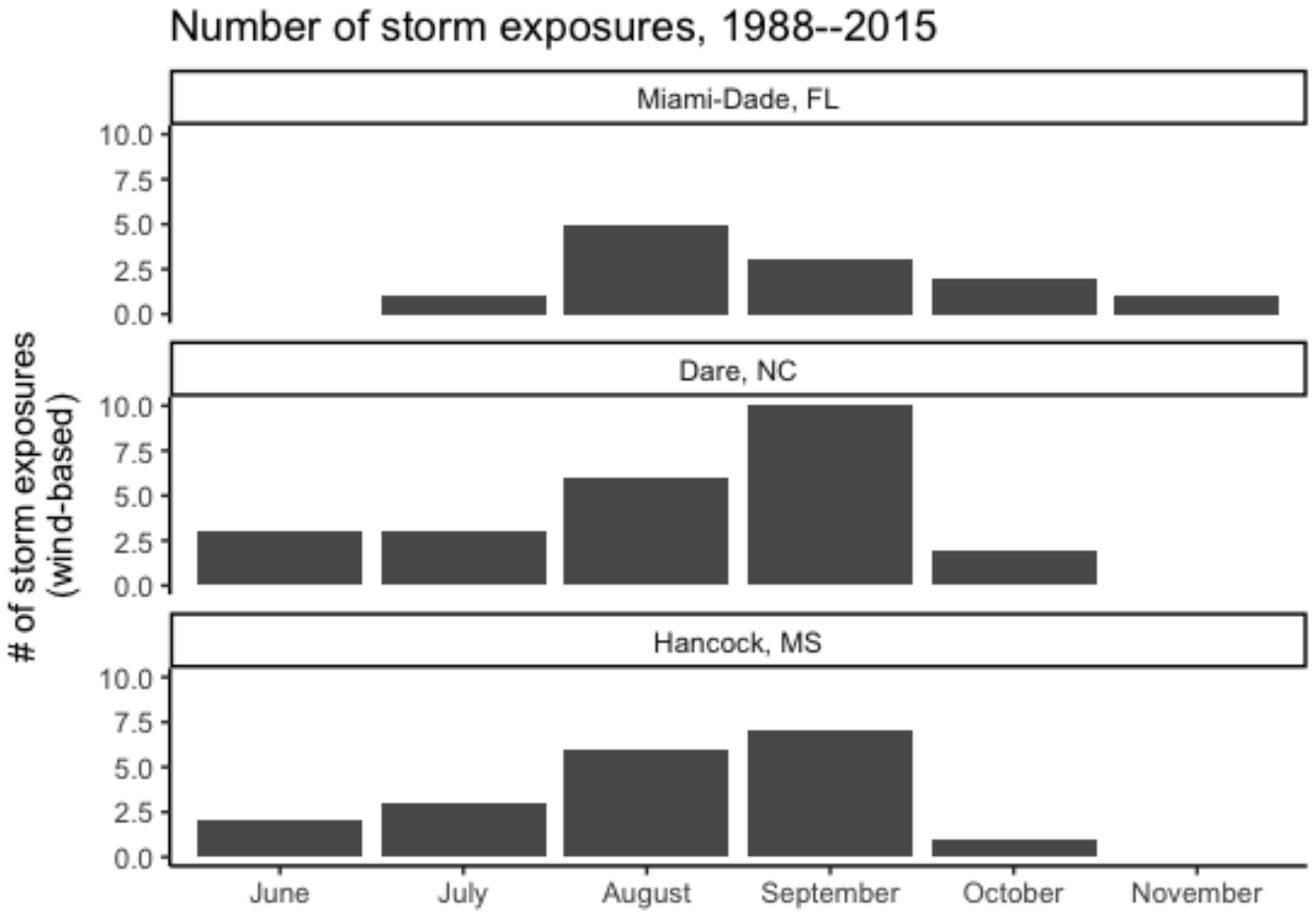
We aimed to measure the *relative risk (RR)* of mortality during the storm compared to what would have been expected the same days if there had not been a storm:

$$RR = \frac{\text{Rate of deaths during storm}}{\text{Expected rate of deaths without storm}}$$

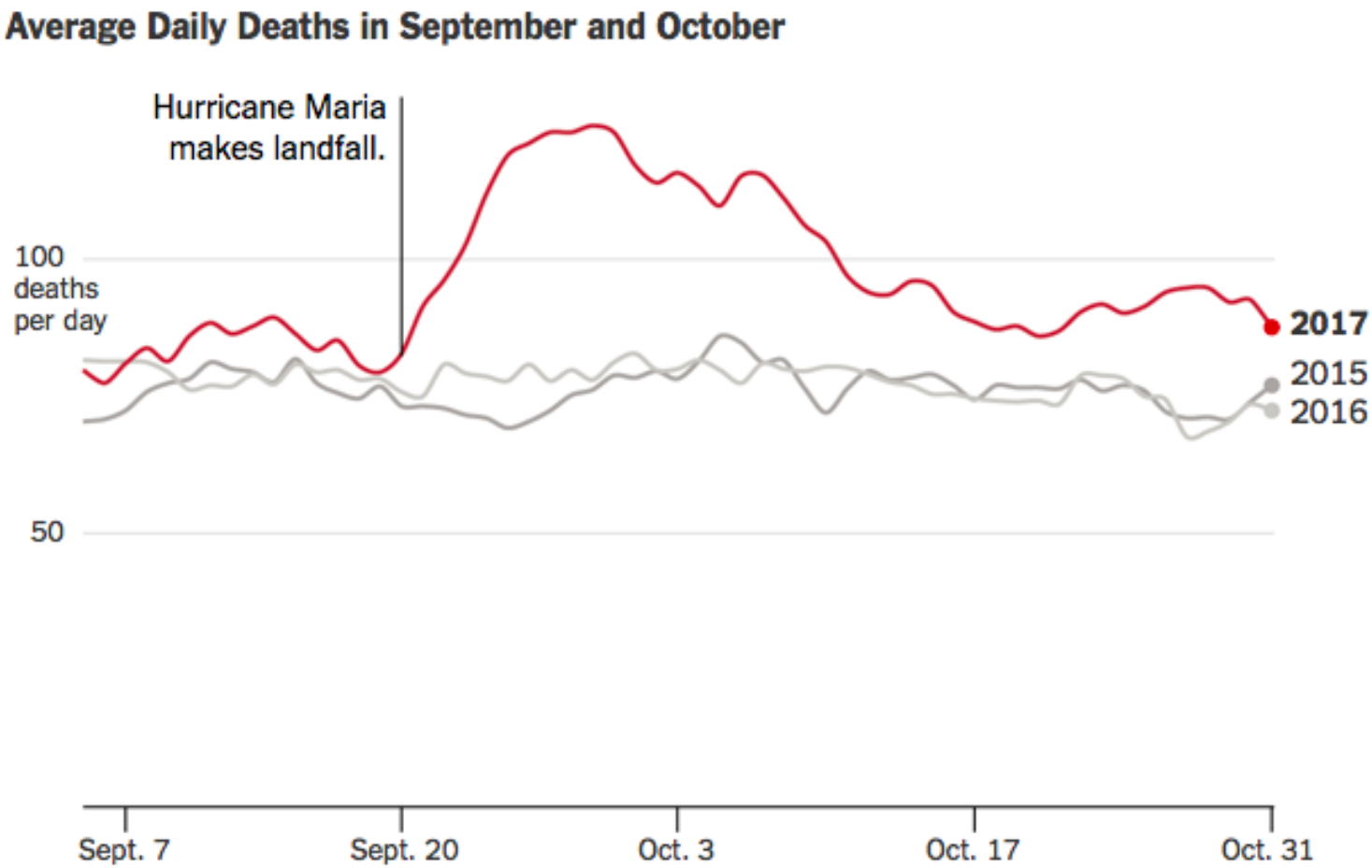
We assessed this relative rate for (1) specific days during the storm period (two days before to seven days after storm's closest approach) and (2) the total storm period.

Seasonality in tropical cyclones

Storm occurrence by month for three high-risk US counties.

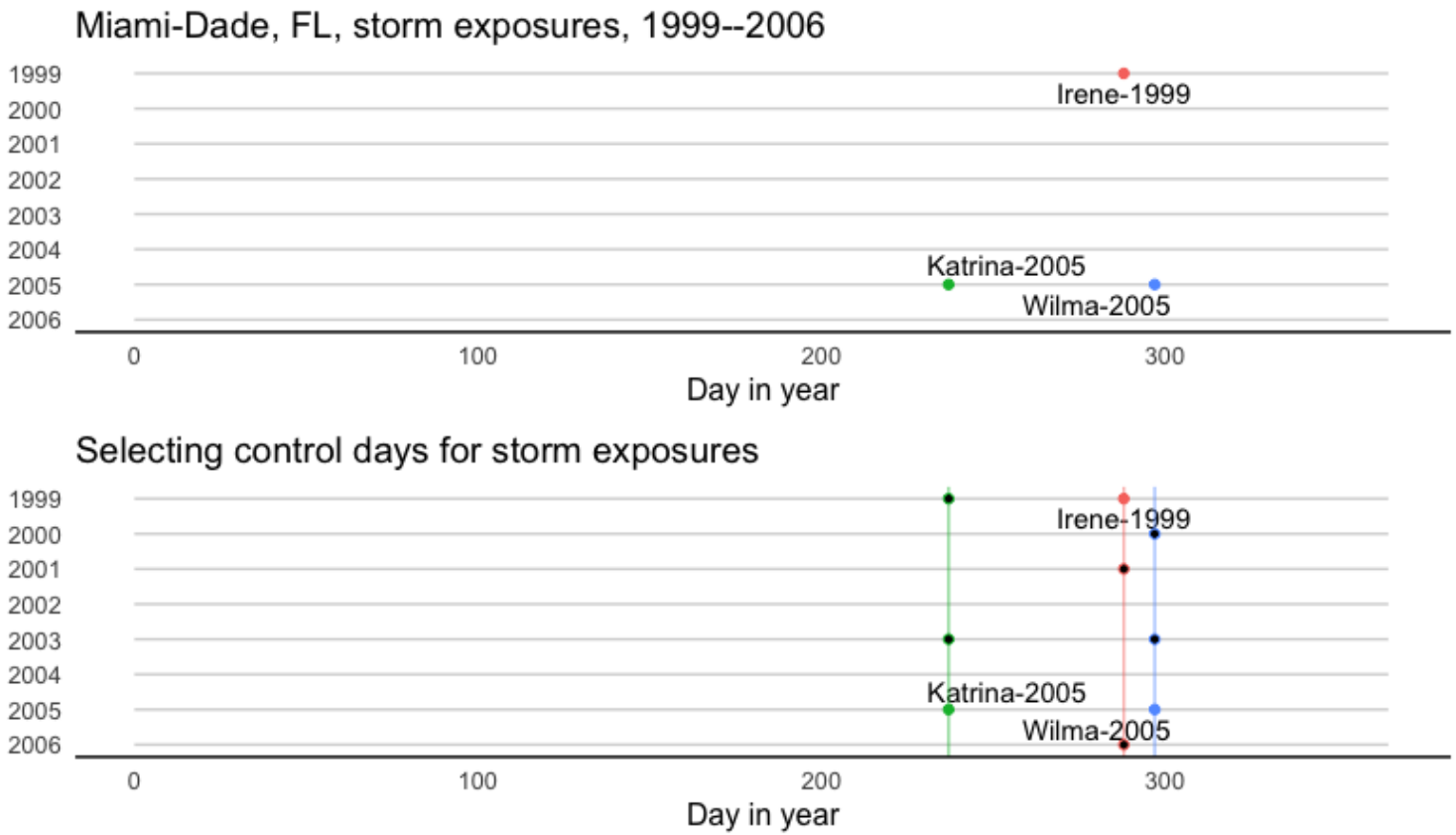


Hurricane Maria example



Source: The New York Times

Matching to control for seasonality



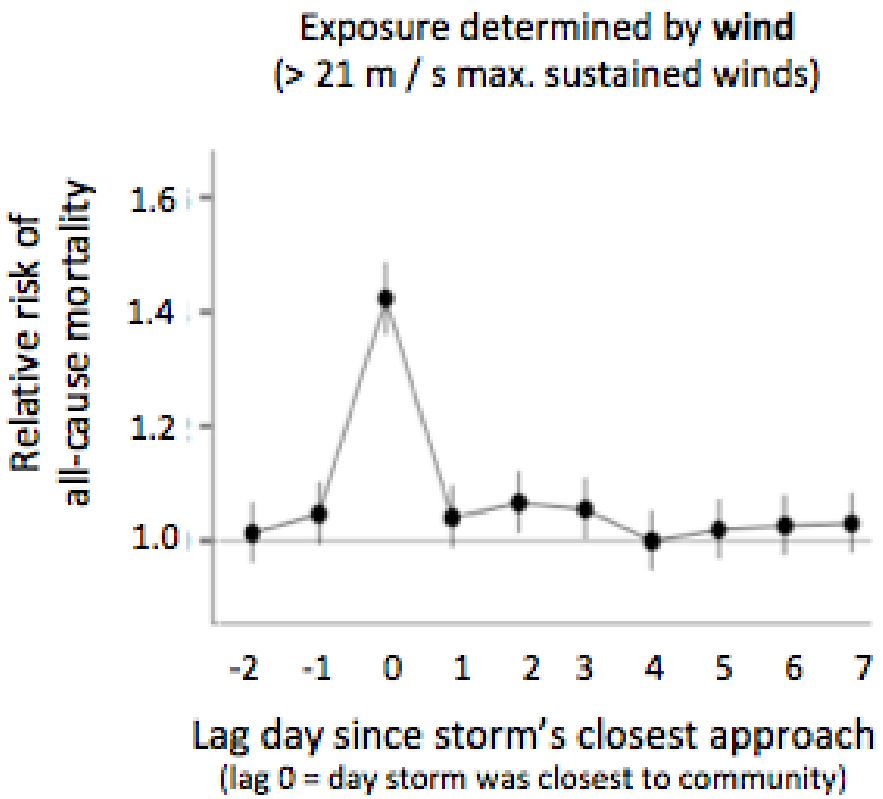
We selected unexposed days in each community, matched to each storm exposed day, ensuring all matches are on similar days of the year.

Relative risk of mortality during storms

Relative risk of mortality associated with tropical storm exposures, as determined by maximum windspeed > 21 m / s

Cause of death	RR on closest day	RR over storm period
All-cause	1.42 (1.36, 1.49)	1.90 (1.58, 2.29)
Cardiovascular	1.15 (1.06, 1.24)	1.30 (0.97, 1.76)
Respiratory	1.13 (0.92,1.38)	1.54 (0.70, 3.39)
Accidental	12.03 (10.87, 13.32)	161.41 (61.62, 422.80)

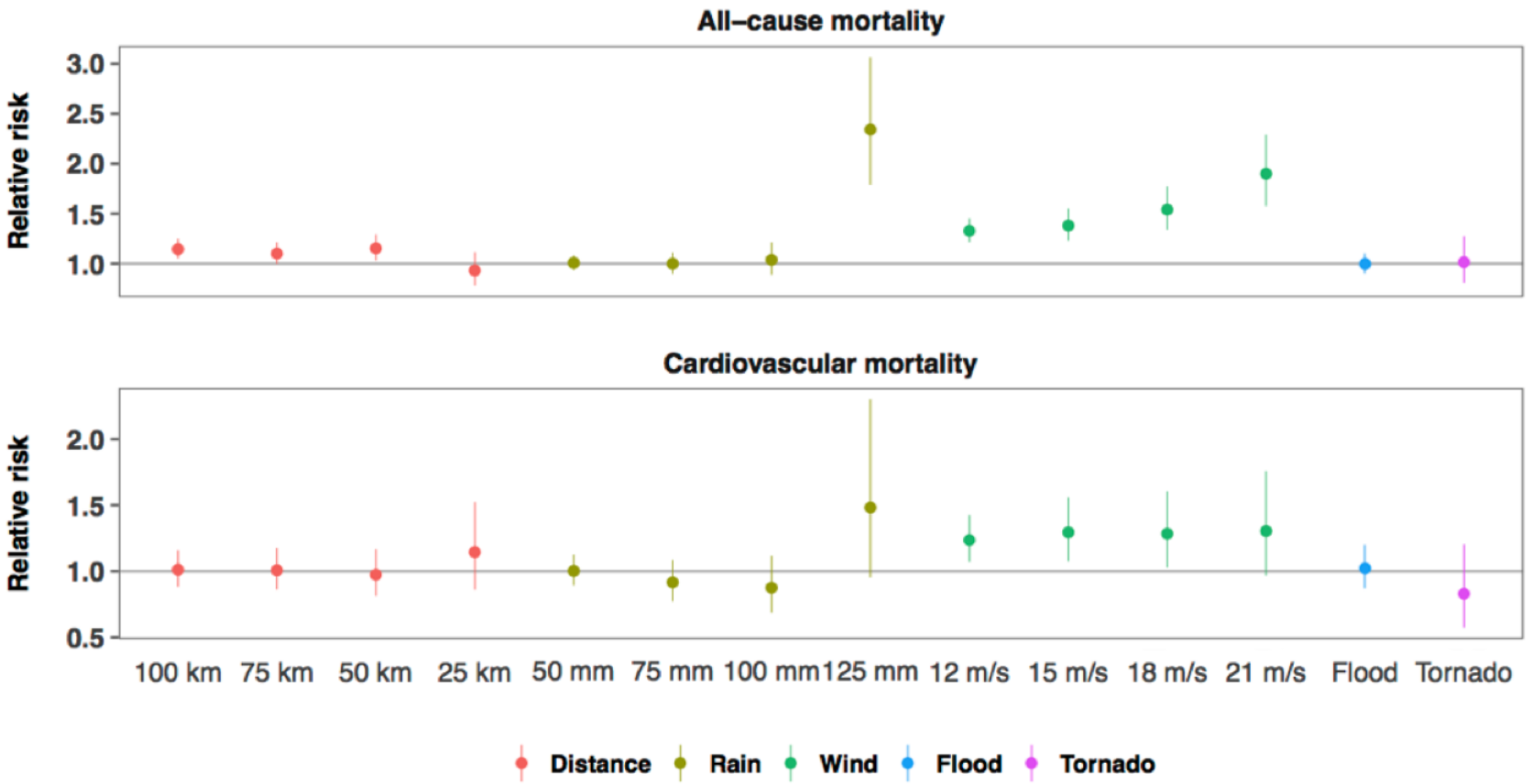
Mortality risks by day during storm period



Risks by day

- For all-cause deaths, RRs were highest on storm's closest day
- There was some evidence of elevated risk before and after the storm
- Lag patterns were similar for cardiovascular and accidental deaths

Mortality risk by exposure metric



Cumulative relative risk of mortality from two days before to seven days after tropical storm exposure for different metrics of exposure to tropical storms.

Sharing exposure assessments

Project software

'hurricaneexposure'

Create county-level exposure time series for tropical storms in U.S. counties. Exposure can be determined based on several hazards (e.g., distance, wind, rain), with user-specified thresholds. On CRAN.

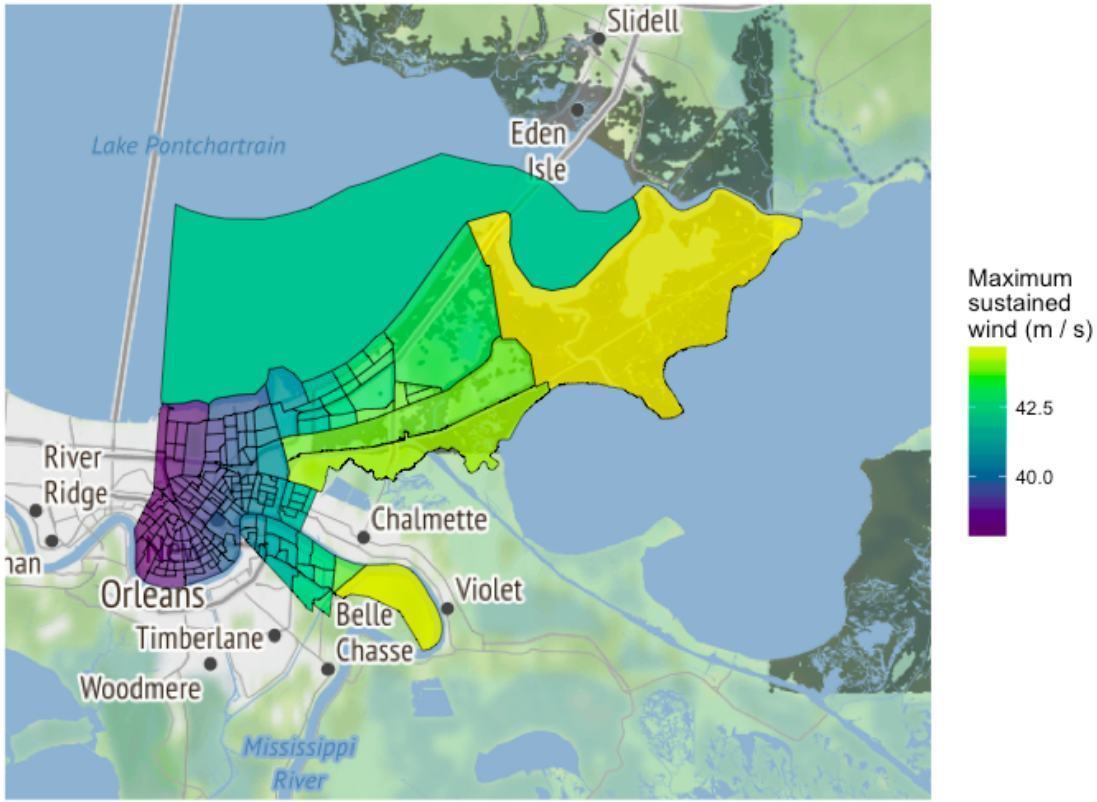
```
county_rain(counties = c("22071", "51700"), rain_limit = 100,
            start_year = 1995, end_year = 2005, dist_limit = 100,
            days_included = c(-1, 0, 1))
```

```
## # A tibble: 4 x 5
##   storm_id     fips  closest_date storm_dist tot_precip
##   <chr>        <chr> <chr>             <dbl>      <dbl>
## 1 Bill-2003    22071 2003-06-30         38.8       141.
## 2 Charley-2004 51700 2004-08-14         43.0       136.
## 3 Cindy-2005   22071 2005-07-06         32.2       113.
## 4 Floyd-1999   51700 1999-09-16         46.5       208.
```

Project software

'stormwindmodel'

Model storm winds from Best Tracks data at U.S. locations. Includes modeling sustained and gust winds, as well as duration of sustained and gust winds above a specified threshold. On CRAN.



Project software

'countyweather', 'countyfloods'

Download weather monitor data through NOAA and USGS APIs by U.S. county. Includes functions to map available monitors / gages for each county. On CRAN.

'noaastormevents'

Download and explore listings from the NOAA Storm Events database. Includes the ability to pull events based on a tropical storm, using events listed close in time and distance to the storm's tracks. On CRAN.

'countytimezones'

Convert time-stamps from UTC to local time zones for U.S. counties based on county FIPs. Facilitates merging weather observations with locally measured data, including health outcomes. On CRAN.

Continuing / future work

- Improving flood exposure metric
- Improving wind model for inland locations
- Influence of most notable storms on mortality risk estimates
- Effect modification of power outages
- Hospitalization impacts among Medicare beneficiaries

Acknowledgements

Funding

This work was supported in part by grants from the National Institute of Environmental Health Sciences (R00ES022631), the National Science Foundation (1331399), and a NASA Applied Sciences Program/Public Health Program Grant (NNX09AV81G).

Collaborators

Meilin Yan, Joshua Ferreri, Ander Wilson, Roger Peng, Dirk Eddelbuettel, Mohammad Al-Hamdan, William Crosson, Andrea Schumacher, Seth Guikema, and Steven Quiring collaborated on research and software shown here.