Tropical cyclones and human health

Exploring evidence of associations using environmental epidemiology tools

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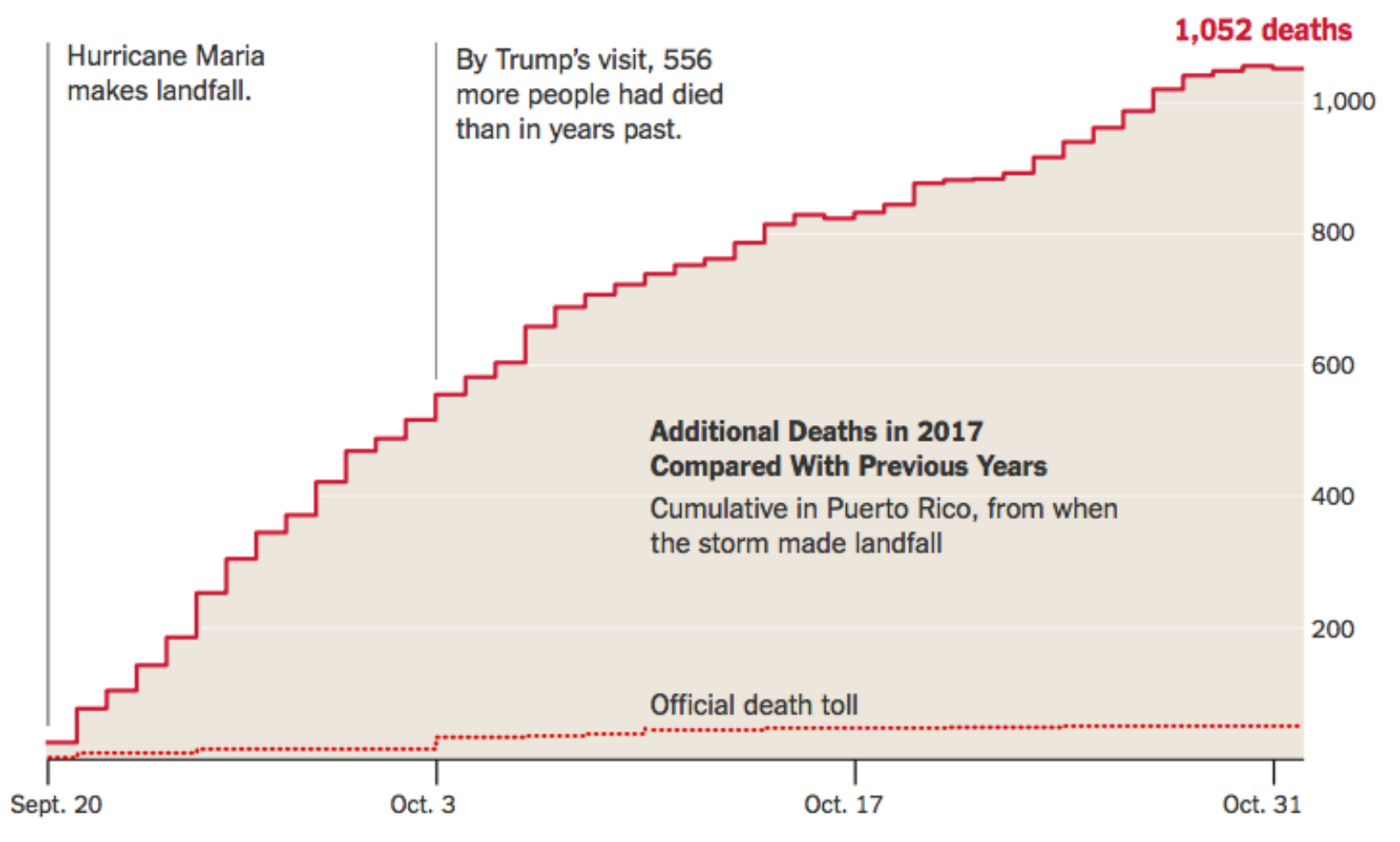
Motivation

Impacts in excess of official death tolls

Evidence from Hurricane Maria in Puerto Rico of extensive mortality impacts.



Source: The New York Times

Counting tropical cyclone fatalities

Exposure to forces of nature: ICD-10 X30—X39	
X30	Exposure to excessive natural heat
X31	Exposure to excessive natural code
X32	Exposure to sunlight
X34	Earthquake
X35	Volcanic eruption
X36	Avalanche, landslide, and other earth movements
X37	Cataclysmic storm
X38	Flood
X39	Exposure to other forces of nature

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

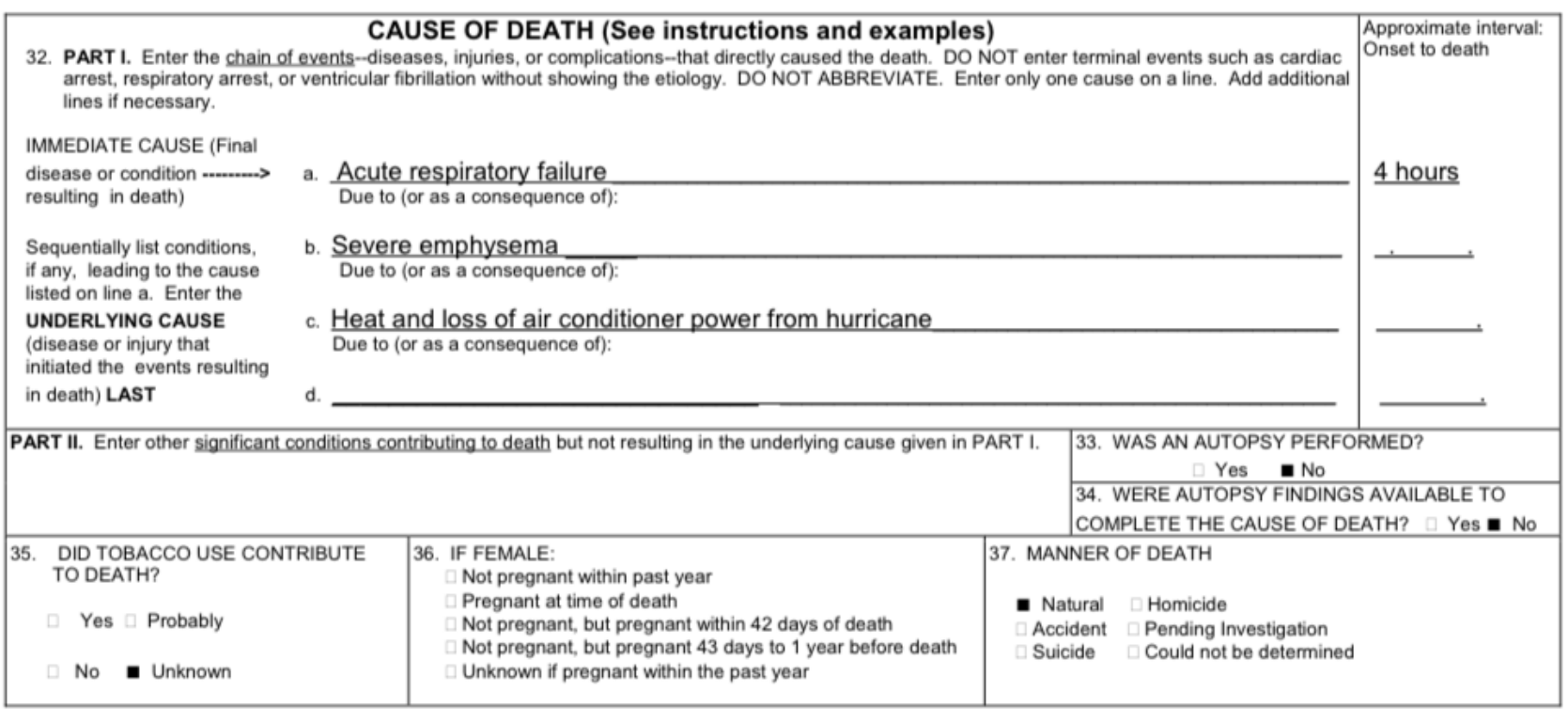
35. DID TOBACCO USE CONTRIBUTE TO DEATH?
☐ Yes ☐ Probably
■ No ☐ Unknown

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



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Approximate interval: Onset to death

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

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

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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Reporting cause of death

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Approximate interval: Onset to death

IMMEDIATE CAUSE (Final disease or condition ---------> resulting in death)
a. Massive head trauma
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. Car collides with falling tree
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.

33. WAS AN AUTOPSY PERFORMED? ☐ Yes ■ No

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

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

38. DATE OF INJURY (Mo/Day/Yr) (Spell Month): August 29, 2005

39. TIME OF INJURY: 1130

40. PLACE OF INJURY (e.g., Decedent's home; construction site; restaurant; wooded area): In decedent's car on road

41. INJURY AT WORK? ☐ Yes ■ No

42. LOCATION OF INJURY: State: Mississippi City or Town: near Pas Christian
Street & Number: 800 block of Sylvan Road Apartment No.: Zip Code: 39571-1234

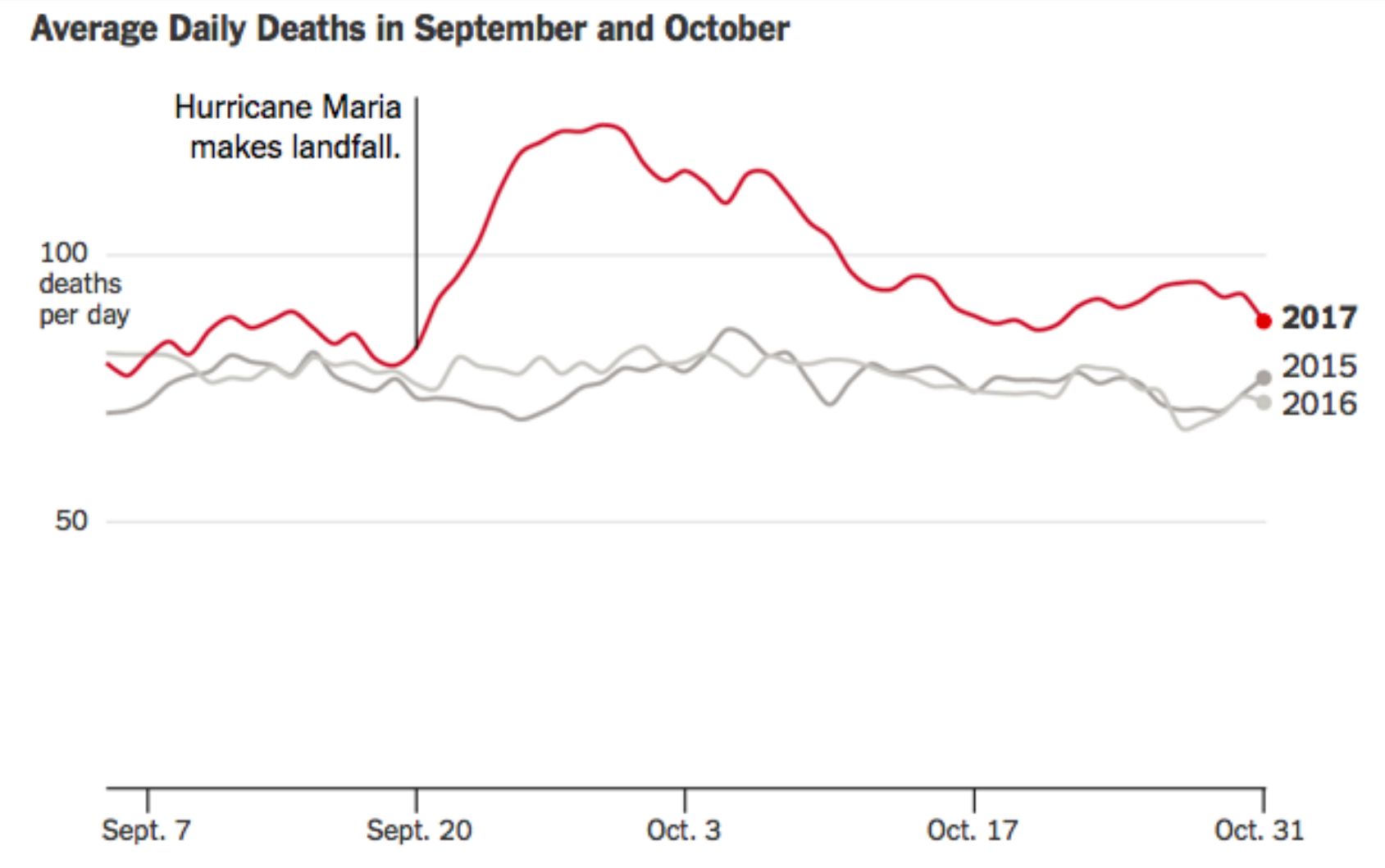
43. DESCRIBE HOW INJURY OCCURRED: Car collided with falling tree

44. IF TRANSPORTATION INJURY, SPECIFY:
■ Driver/Operator
☐ Passenger
☐ Pedestrian
☐ Other (Specify)

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

Impacts in excess of official death tolls

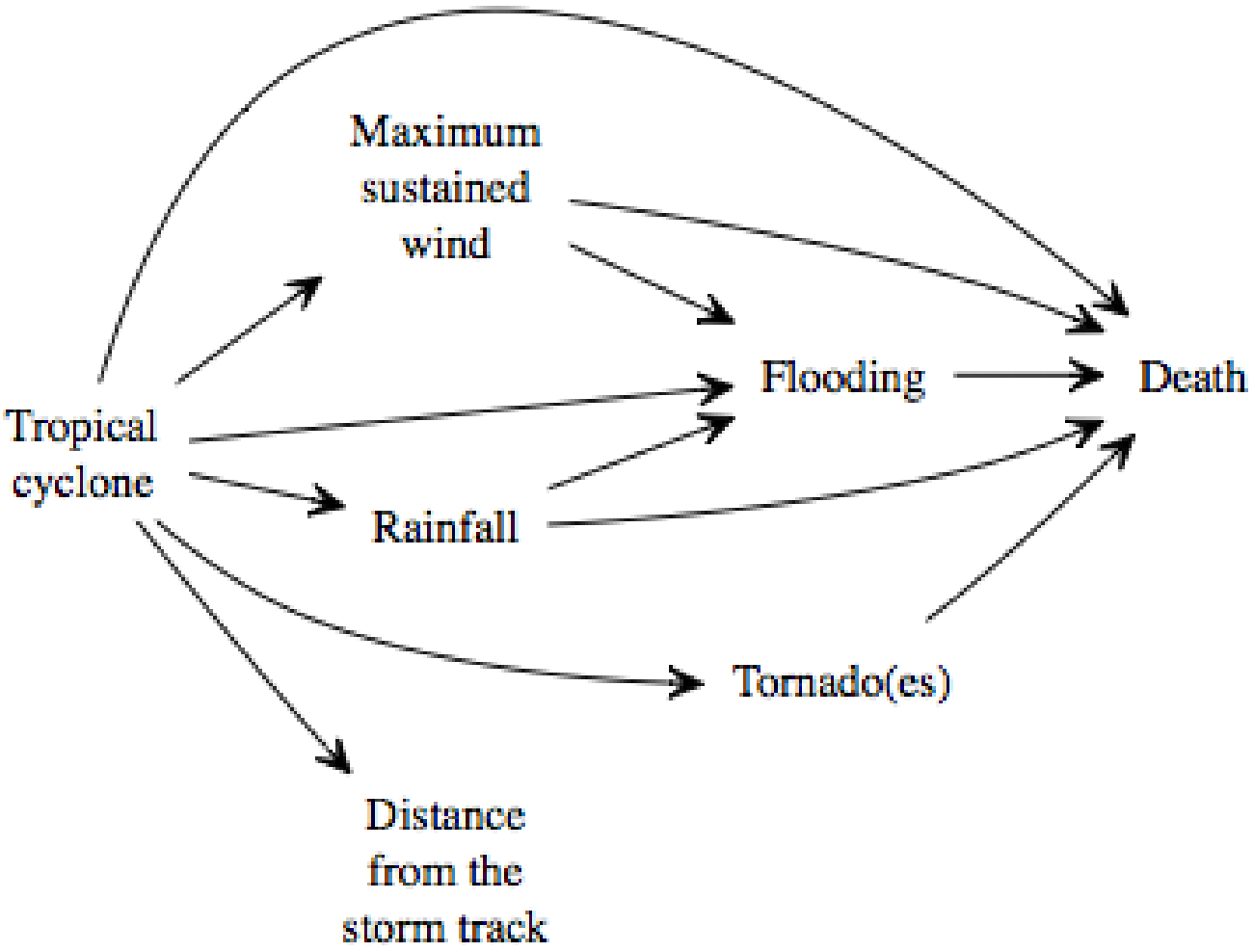
Evidence from Hurricane Maria in Puerto Rico.



Source: The New York Times

Measuring tropical cyclone exposure

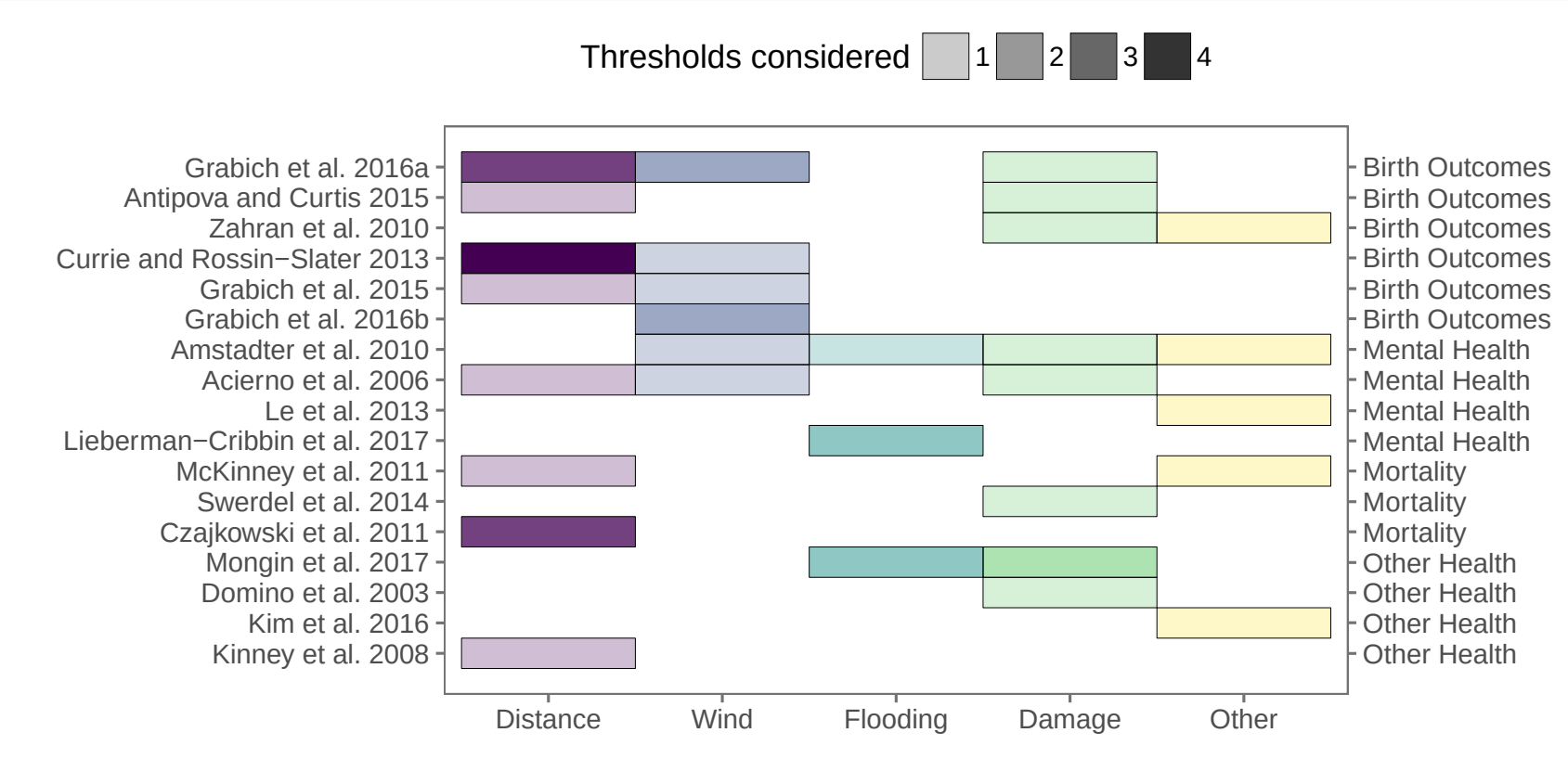
Potential pathways through which tropical cyclone exposure might increase mortality risk



Assessing tropical storm exposure

Challenge for epidemiological research

How should we determine whether a county was exposed to a tropical storm for epidemiological research?



Distance as a surrogate 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.

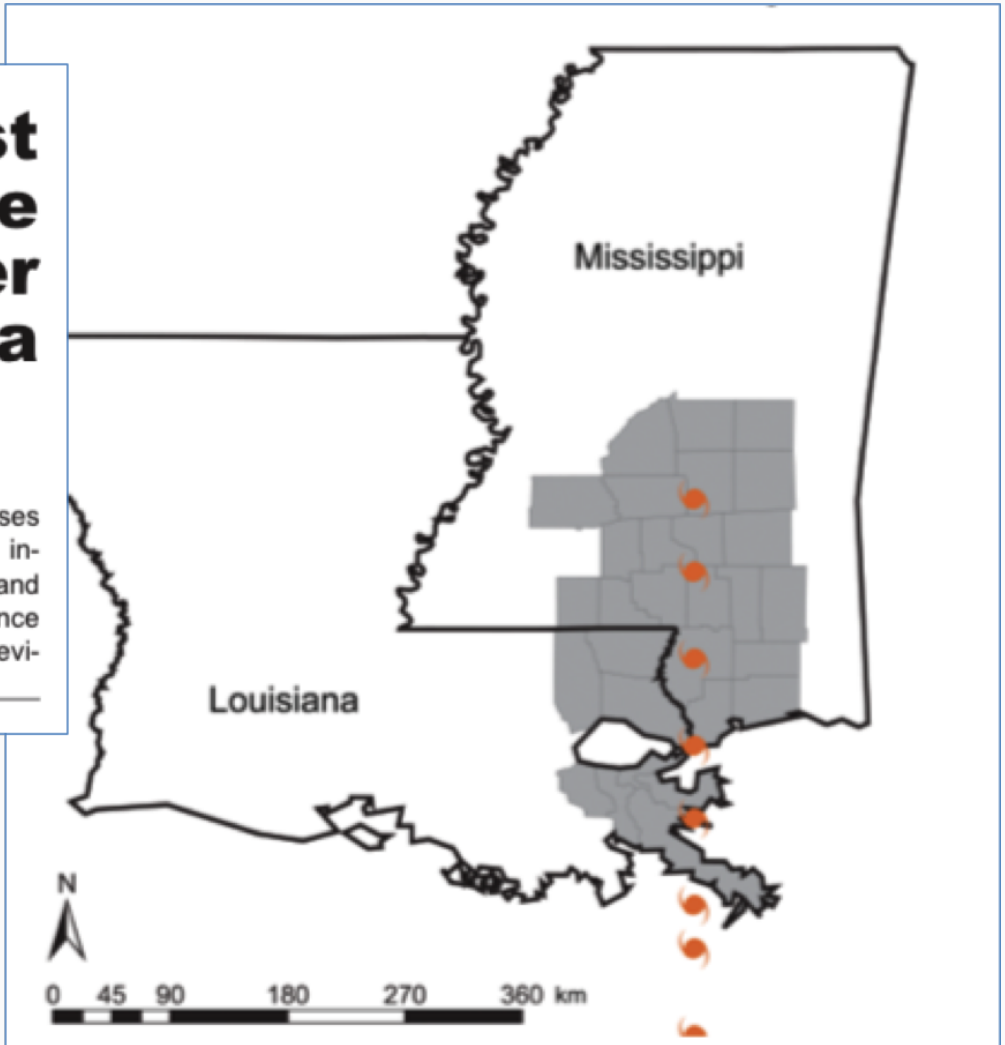
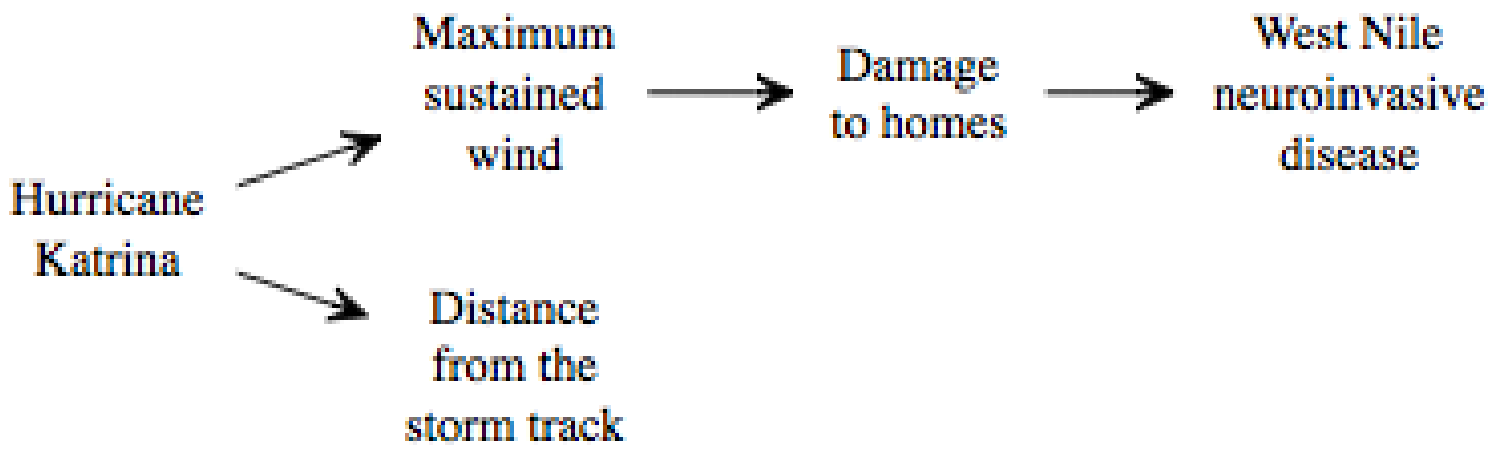


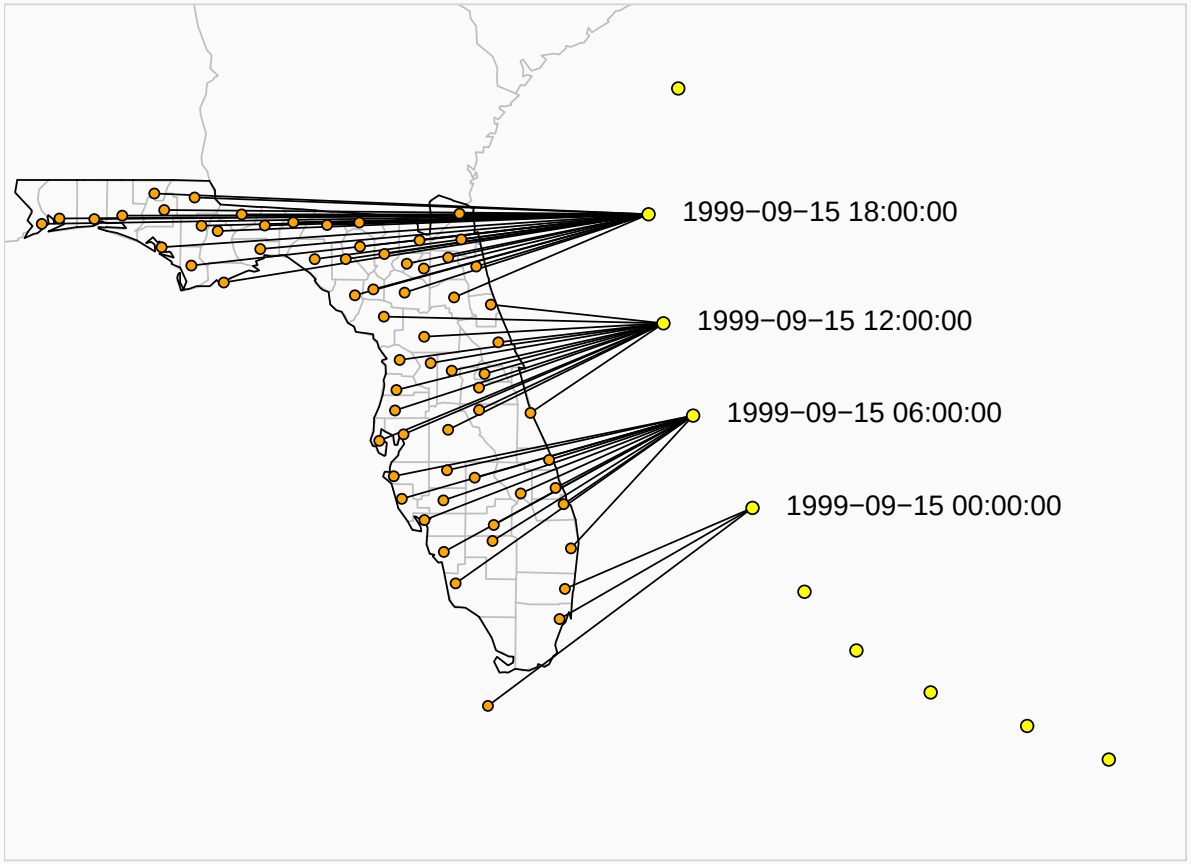
Figure 1. Hurricane Katrina track and hurricane-affected Louisiana parishes and Mississippi counties. Affected parishes and counties (gray) were defined as those in which >50% of the total area was ≤50 miles of the hurricane track coordinates.

Potential pathway for effects of Katrina on West Nile risk



Distance from storm

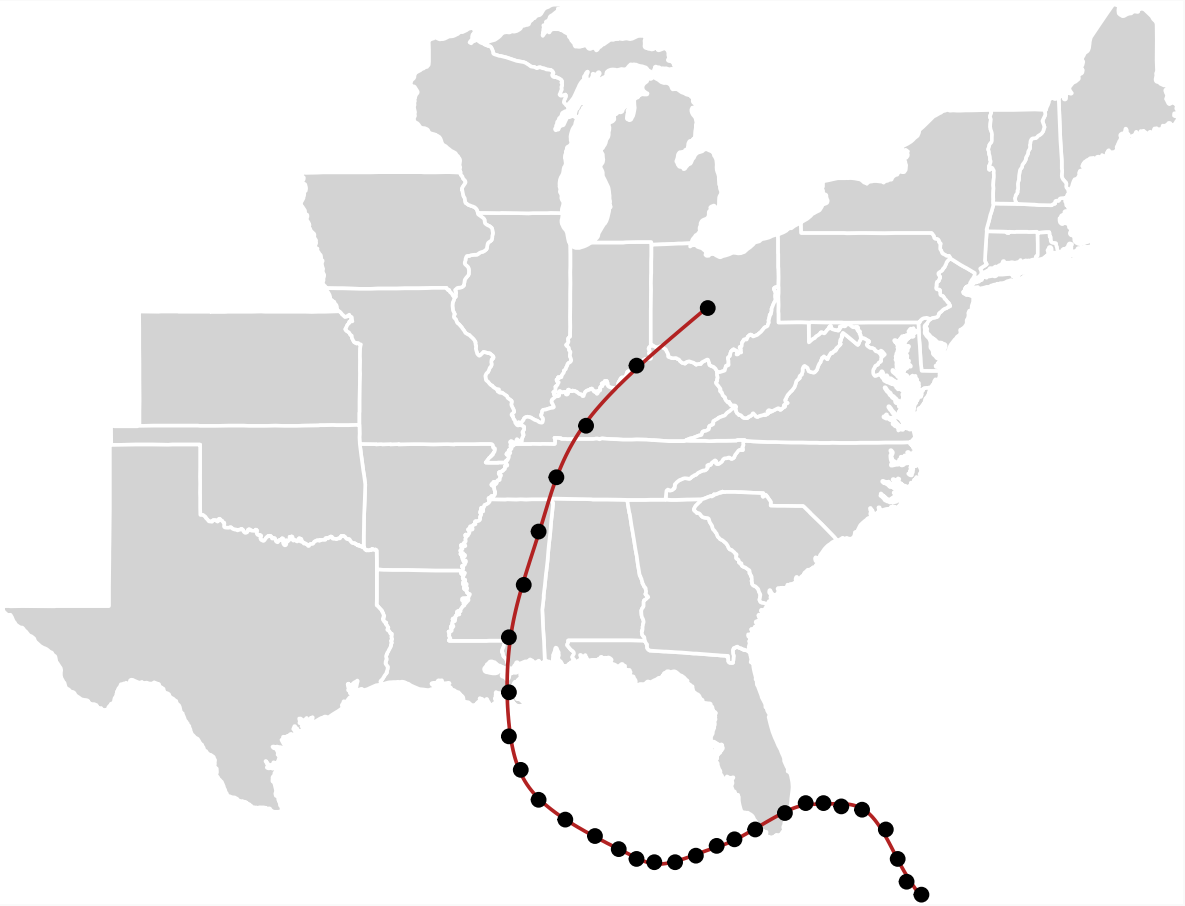
Tropical storm "Best Track" data



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.

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.

Rain exposure

Rain during Tropical Storm Lee

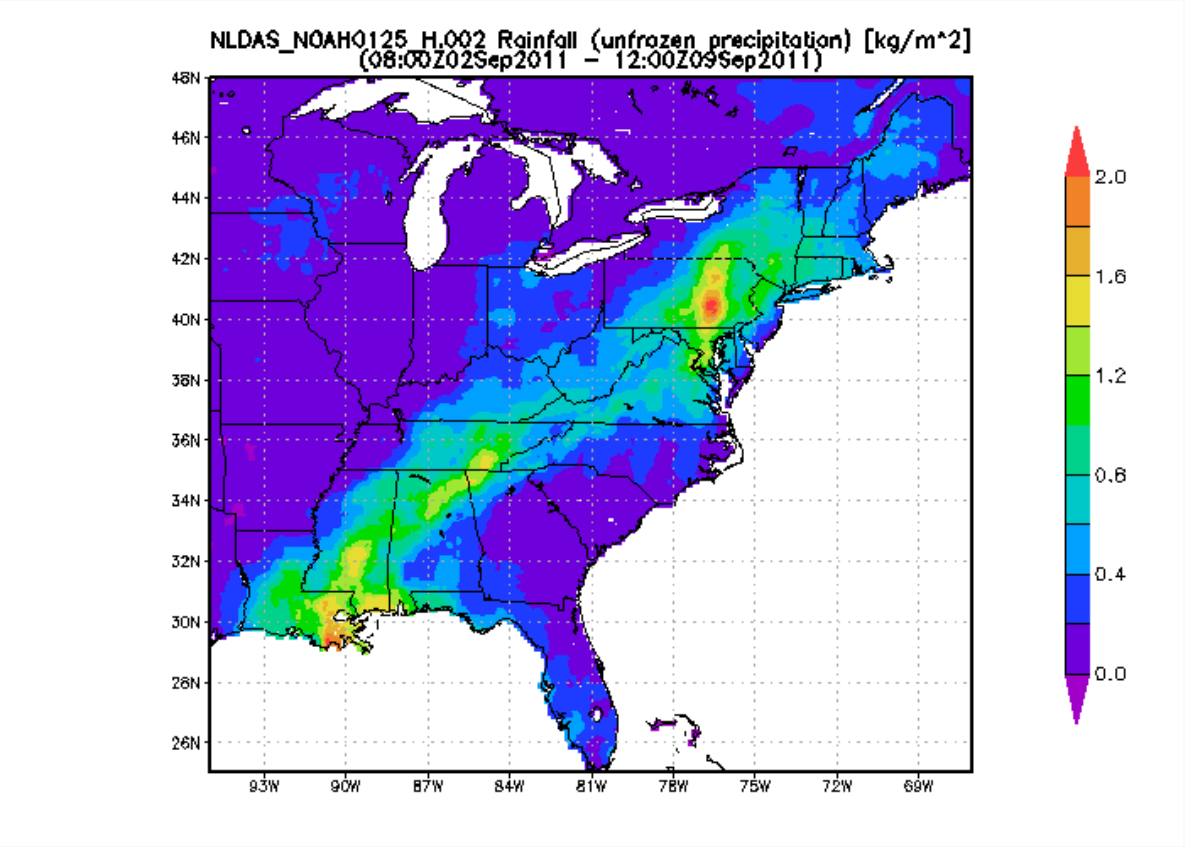
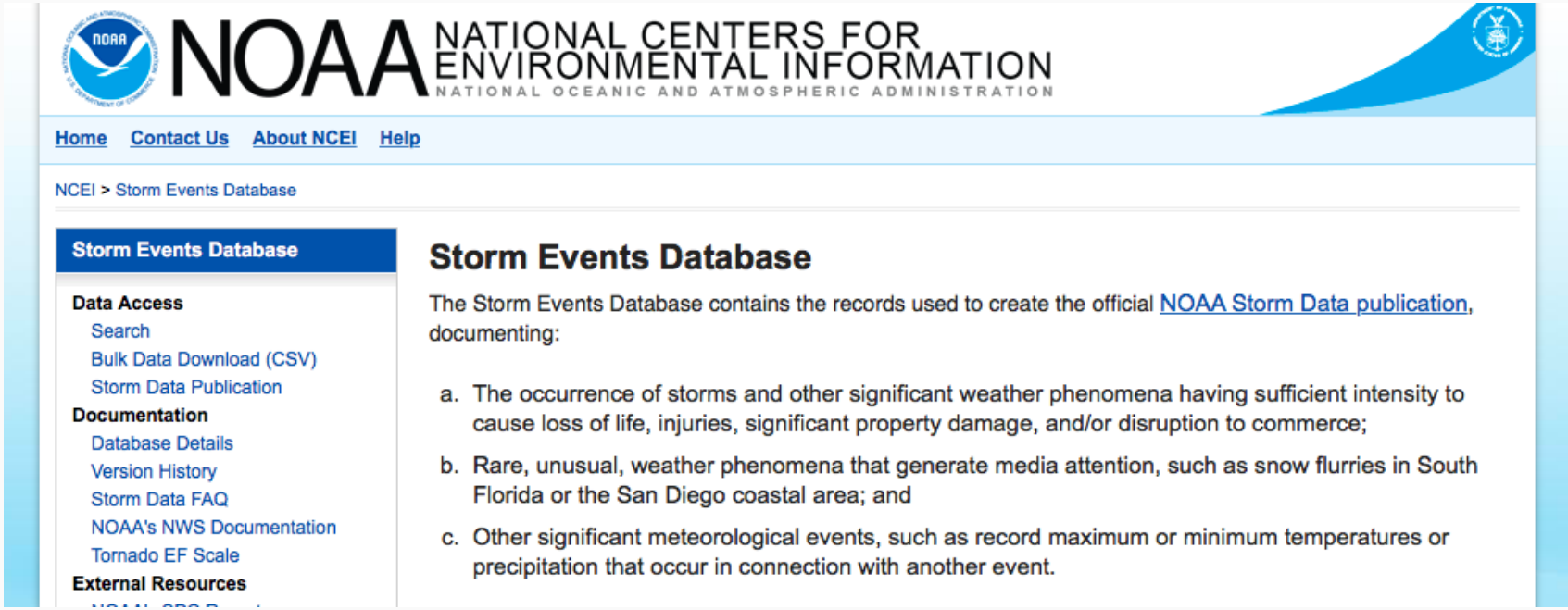


Image source: Goddard Earth Sciences DISC

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.

Flood and tornado events

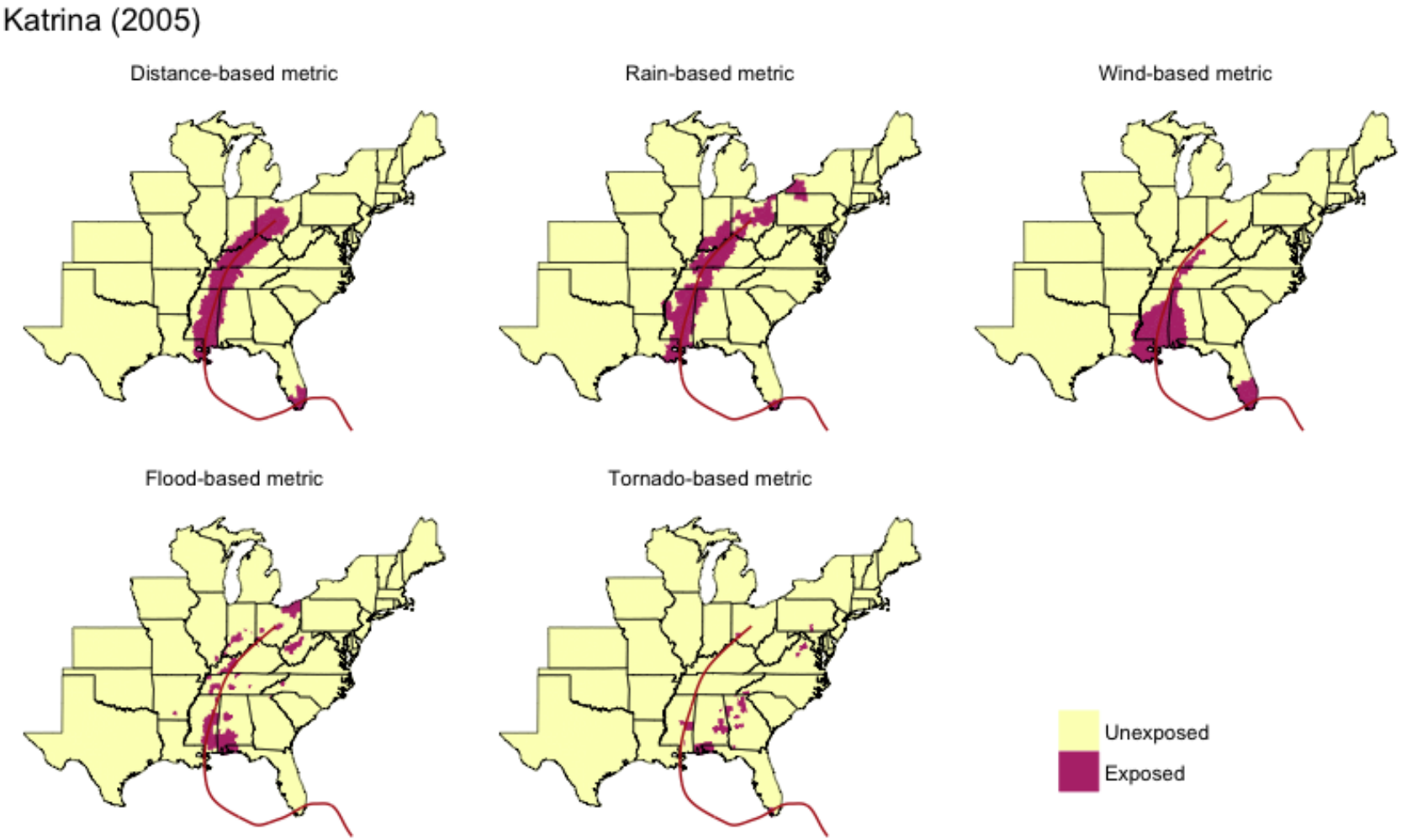


Website: https://www.ncdc.noaa.gov/stormevents/

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

Tropical storm exposure classifications for Hurricane Katrina



County-level agreement in storm exposure

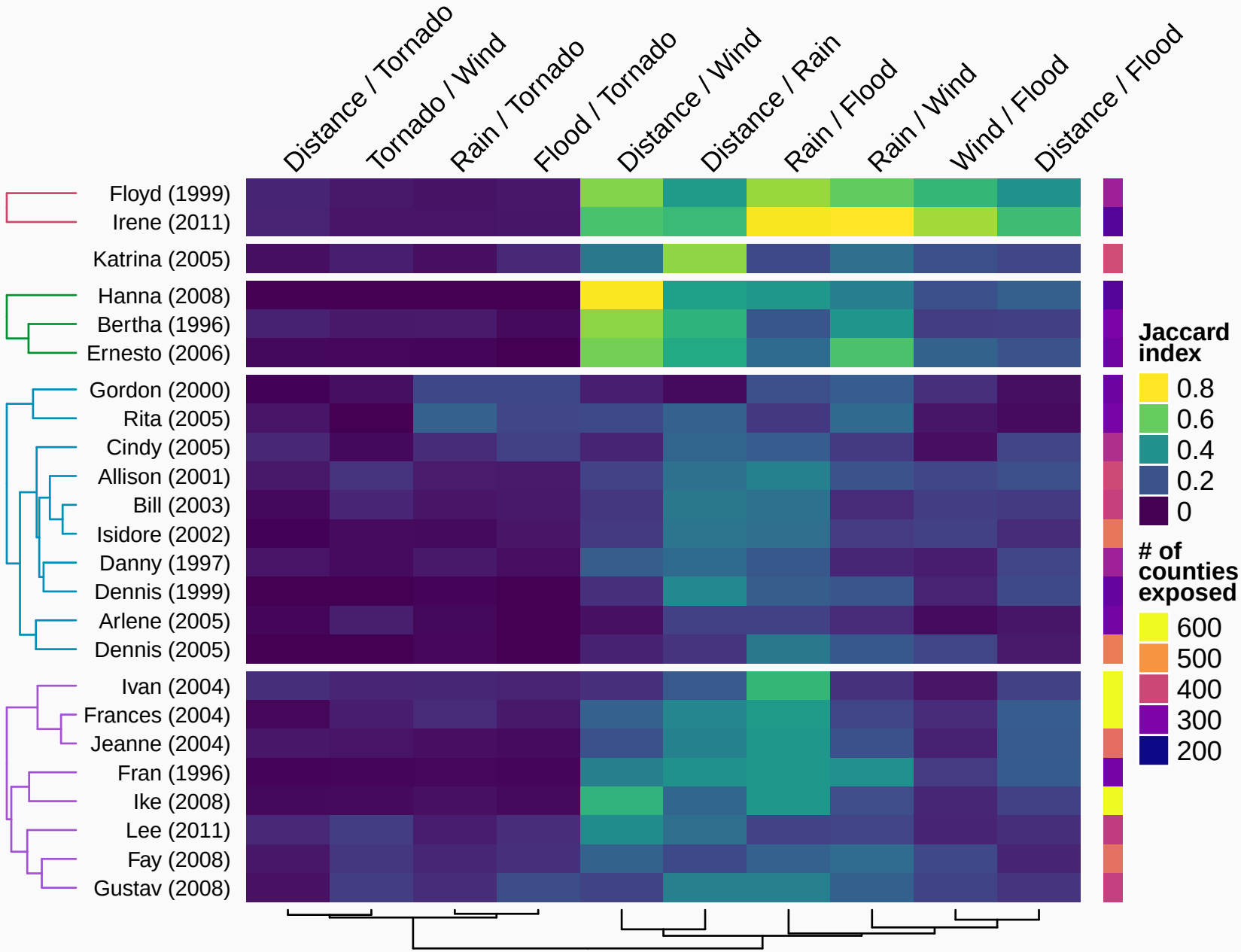
Assessing agreement in county classifications

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.

Similarity among tropical cyclone hazards



Software

Open data / reproducible research

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DOI: 10.1093/aje/kwj093
Advance Access publication March 1, 2006

Commentary

Reproducible Epidemiologic Research

OPEN ACCESS Freely available online
PLoS BIOLOGY

Community Page

The Open Knowledge Foundation: Open Data Means Better Science

Jennifer C. Molloy*
Department of Zoology, University of Oxford, Oxford, United Kingdom

Annals of Internal Medicine | ACADEMIA AND CLINIC

Reproducible Research: Moving toward Research the Public Can Really Trust

Christine Laine, MD, MPH; Steven N. Goodman, MD, PhD, MHS; Michael E. Griswold, PhD; and Harold C. Sox, MD

Project software

'hurricaneexposure'

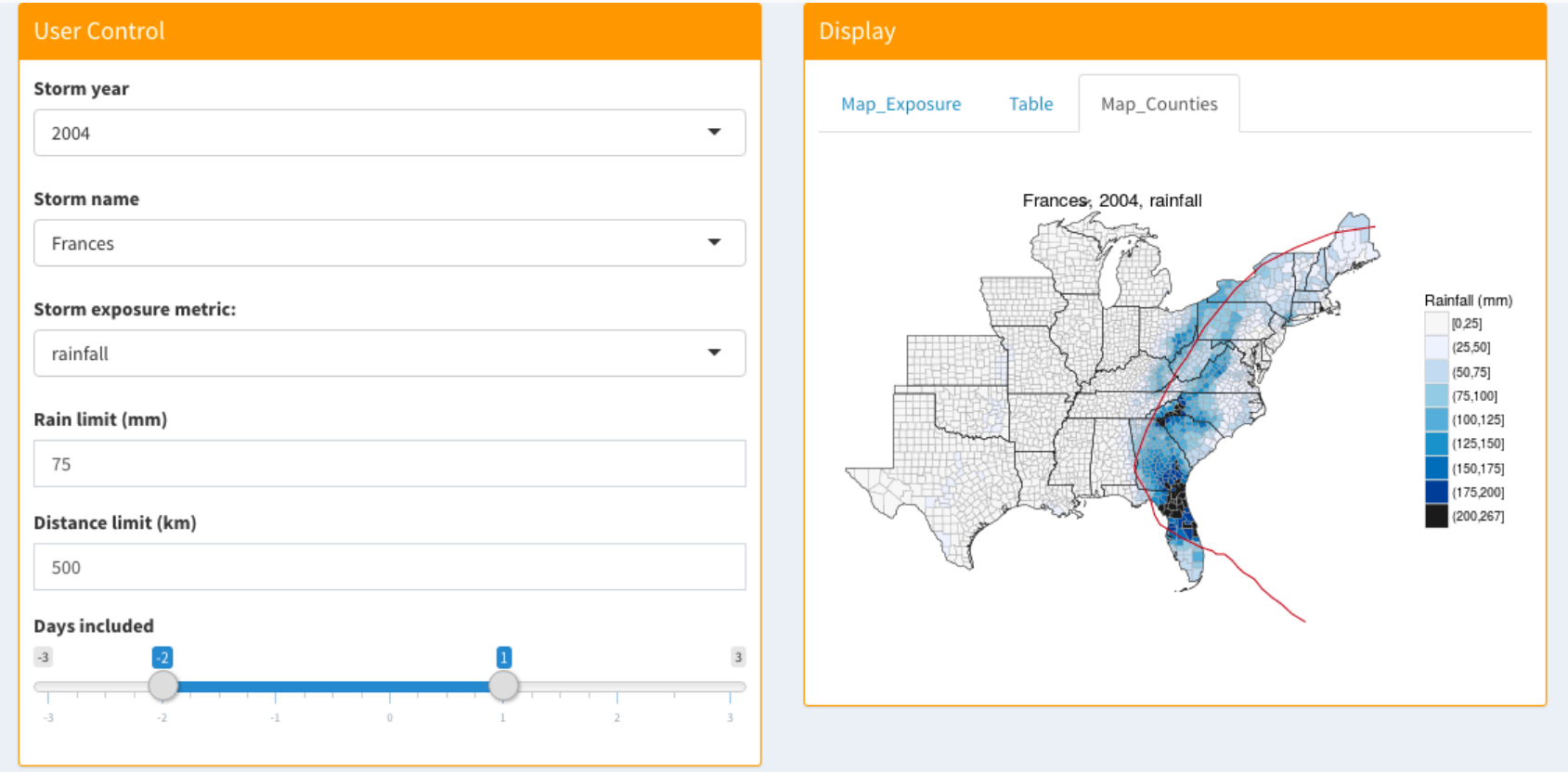
Create county-level exposure time series for tropical storms in U.S. counties. Exposure can be determined based on several hazards (e.g., distance, wind, rain), with user-specified thresholds. https://github.com/geanders/hurricaneexposure

```
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: 6 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.
## 5 Isidore-2002 22071 2002-09-26          6.38       249.
## 6 Katrina-2005 22071 2005-08-29         36.9        196.
```

Project software

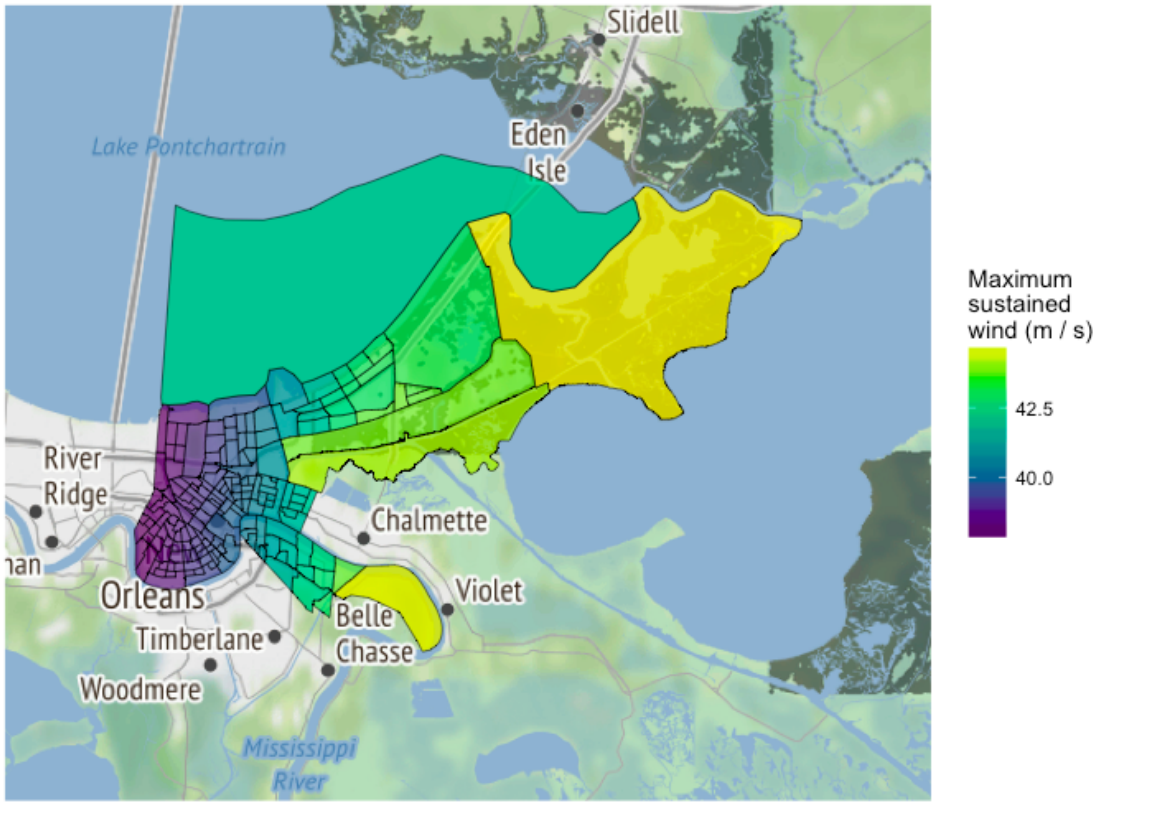
Web application interface to ‘hurricaneexposure‘



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

‘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.
https://github.com/zailchen/noaastormevents

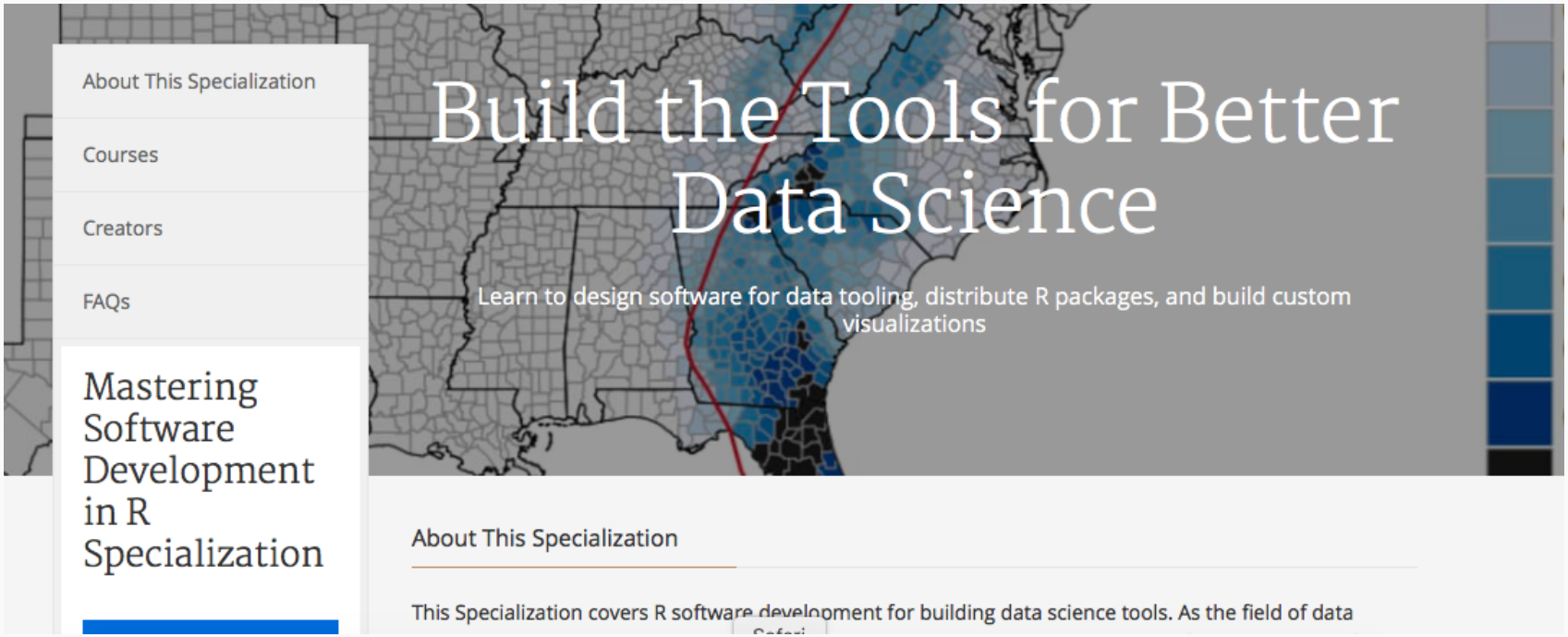
‘countytimezones‘

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.

‘countyweather‘

Download weather monitor data through NOAA API by U.S. county. Includes functions to map available monitors for each county. On CRAN.

Software as a research product

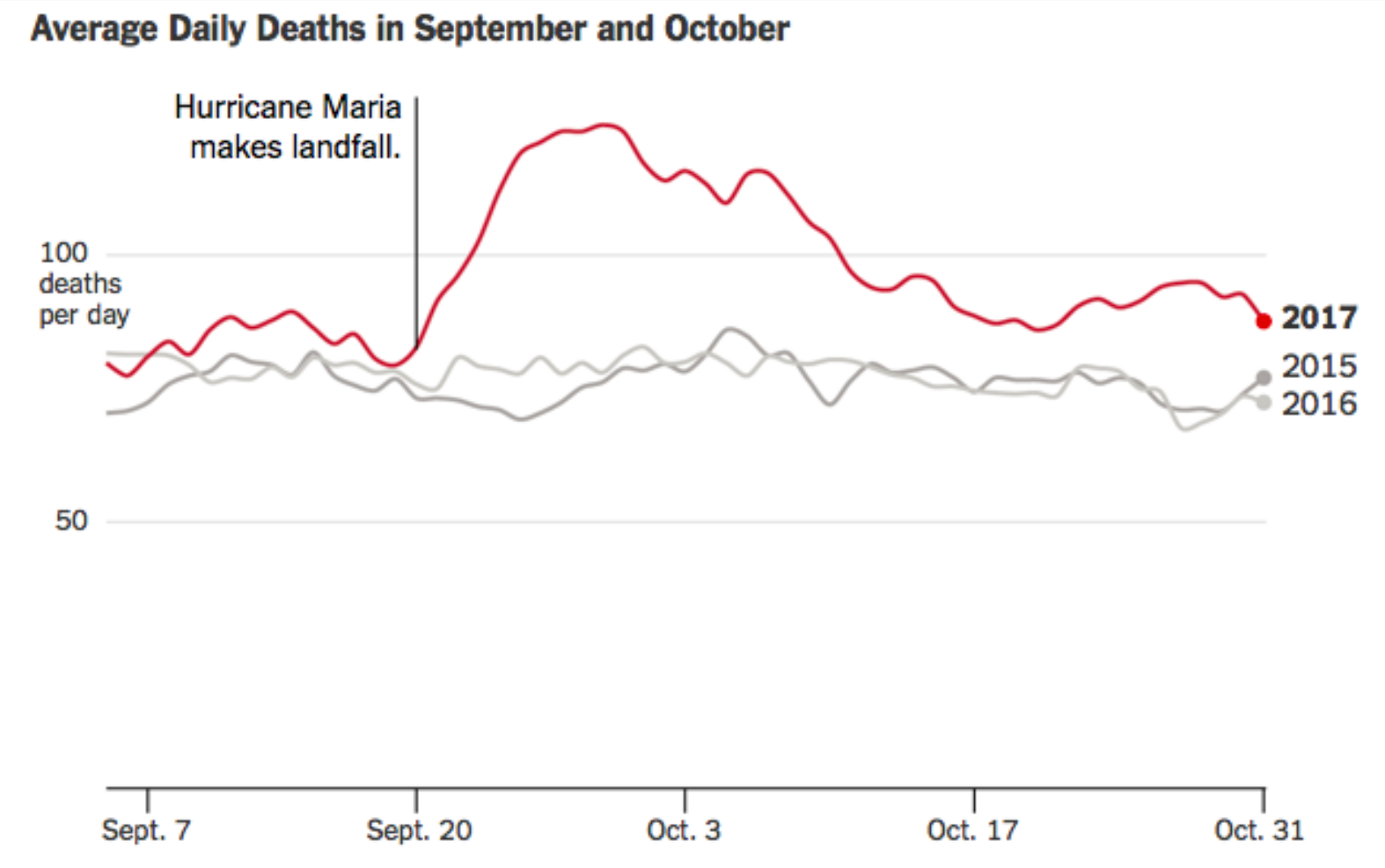


Courses: https://www.coursera.org/specializations/r Course book: https://bookdown.org/rdpeng/RProgDA/

Associations between tropical cyclone exposure and mortality

Impacts in excess of official death tolls

Evidence from Hurricane Maria in Puerto Rico.



Source: The New York Times

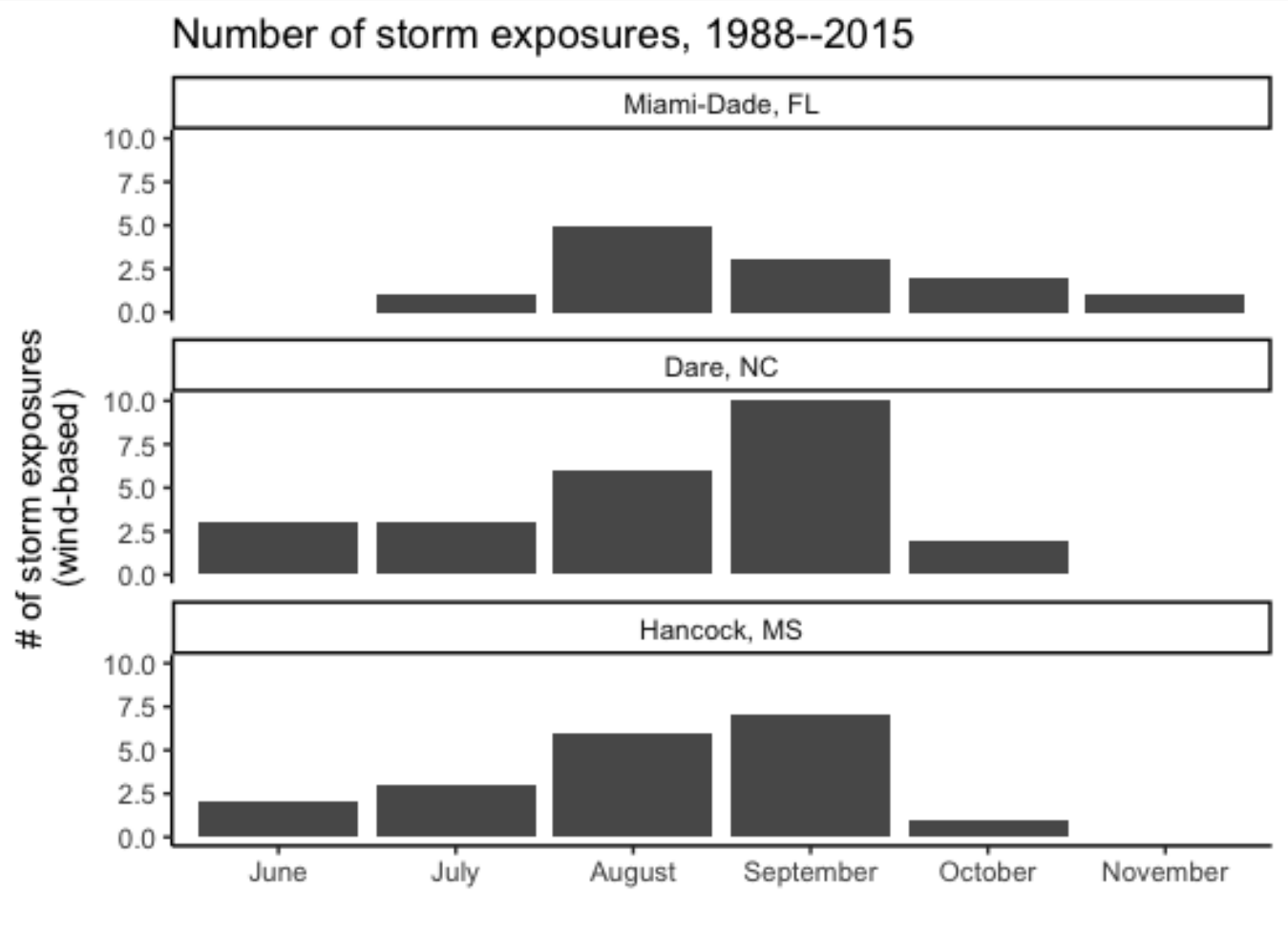
Relative risk of mortality associated with storm exposure

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:

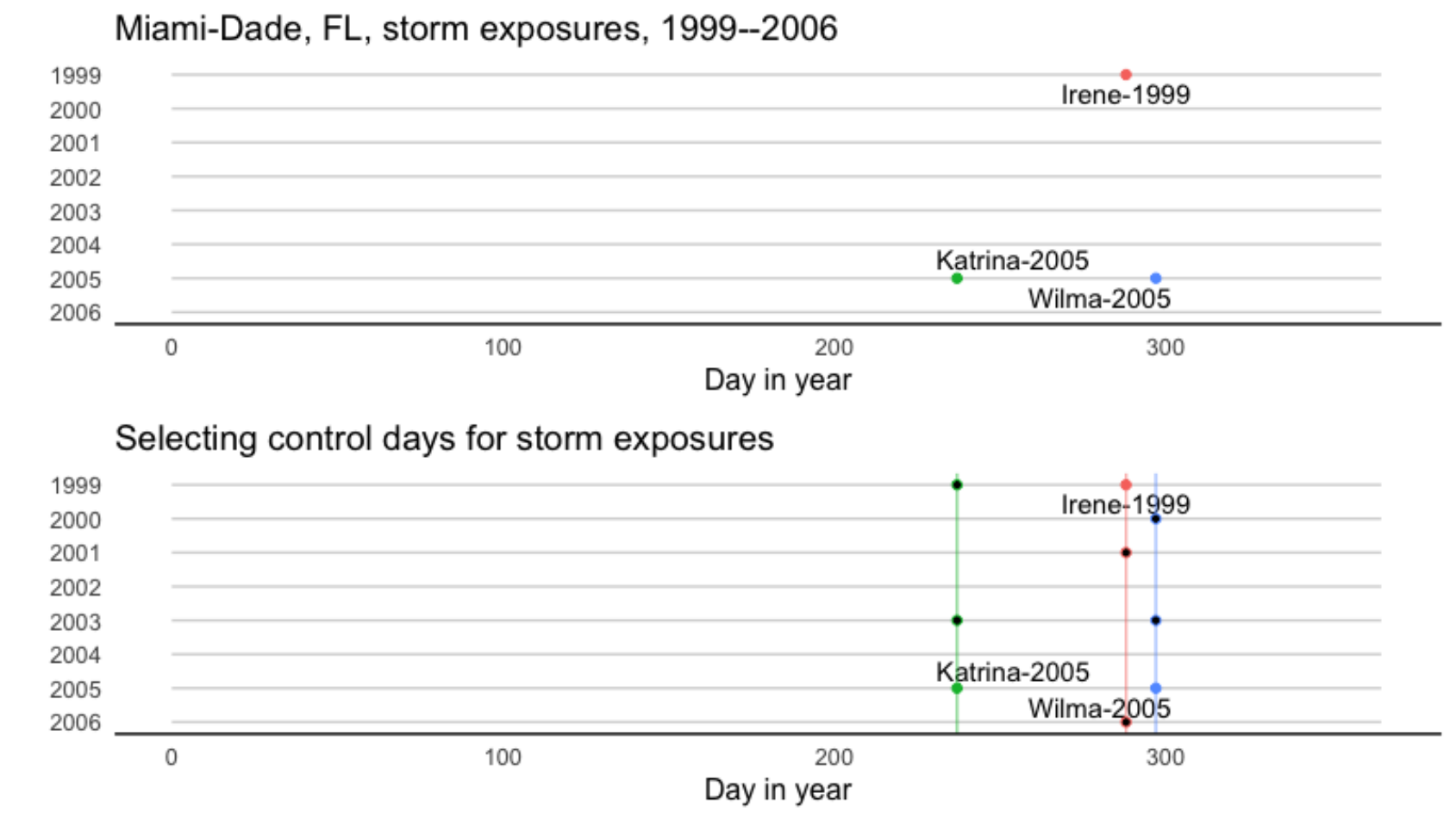
$$RR = \frac{\text{Community-wide risk of death during storm}}{\text{Expected community-wide risk of death without storm}}$$

Seasonality in tropical cyclones

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



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.

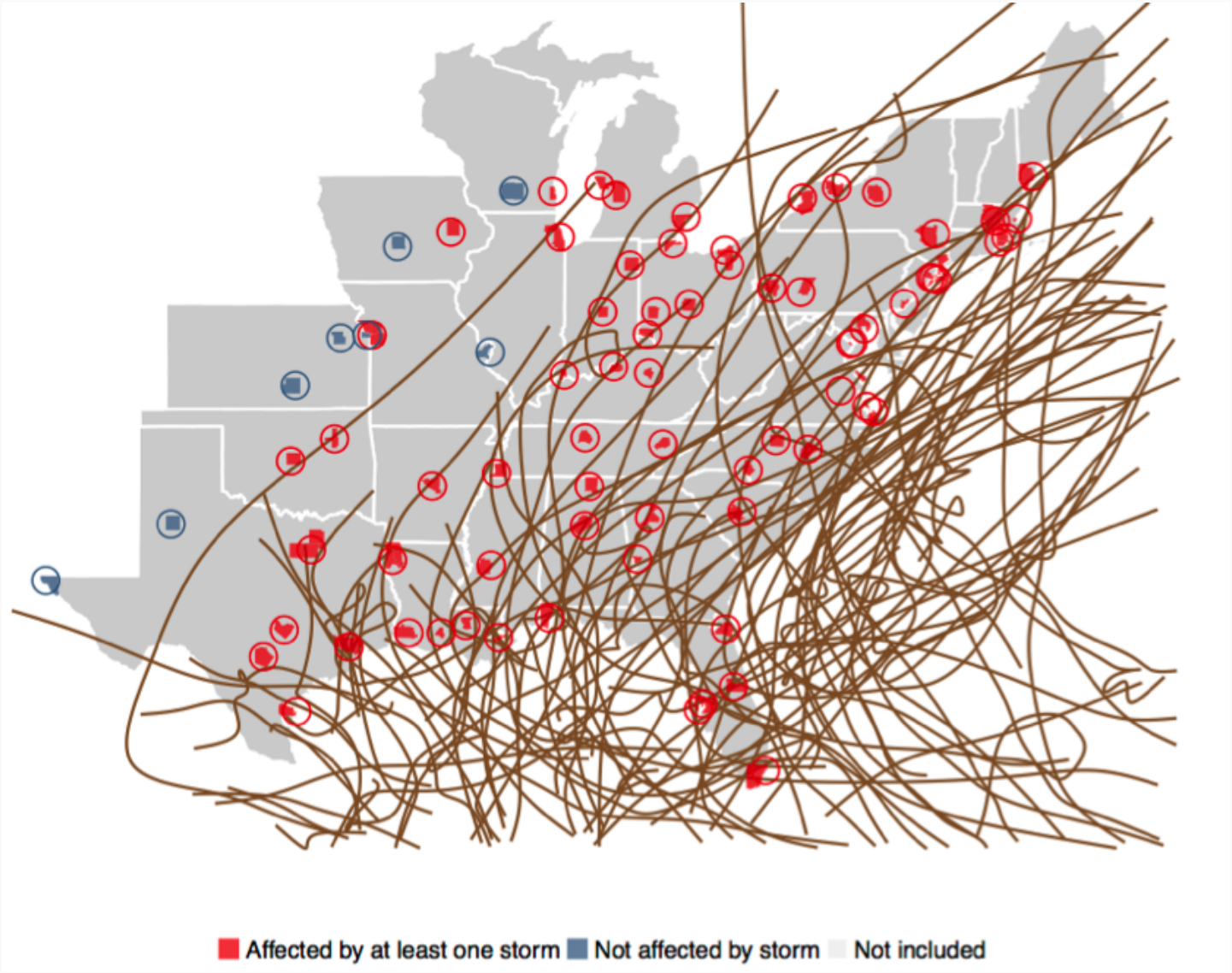
Estimating relative risk of mortality

To this matched data, we fit a random effects generalized linear model, using an **unconstrained distributed lag approach** to explore risks in the period surrounding the storm:

$$log[E(Y_t^c)] = log(n^c) + \alpha + \alpha^c + \beta \sum_{l=-2}^{7} x_{t-l}^c + \delta Year_t^c + \gamma DOW_t^c$$

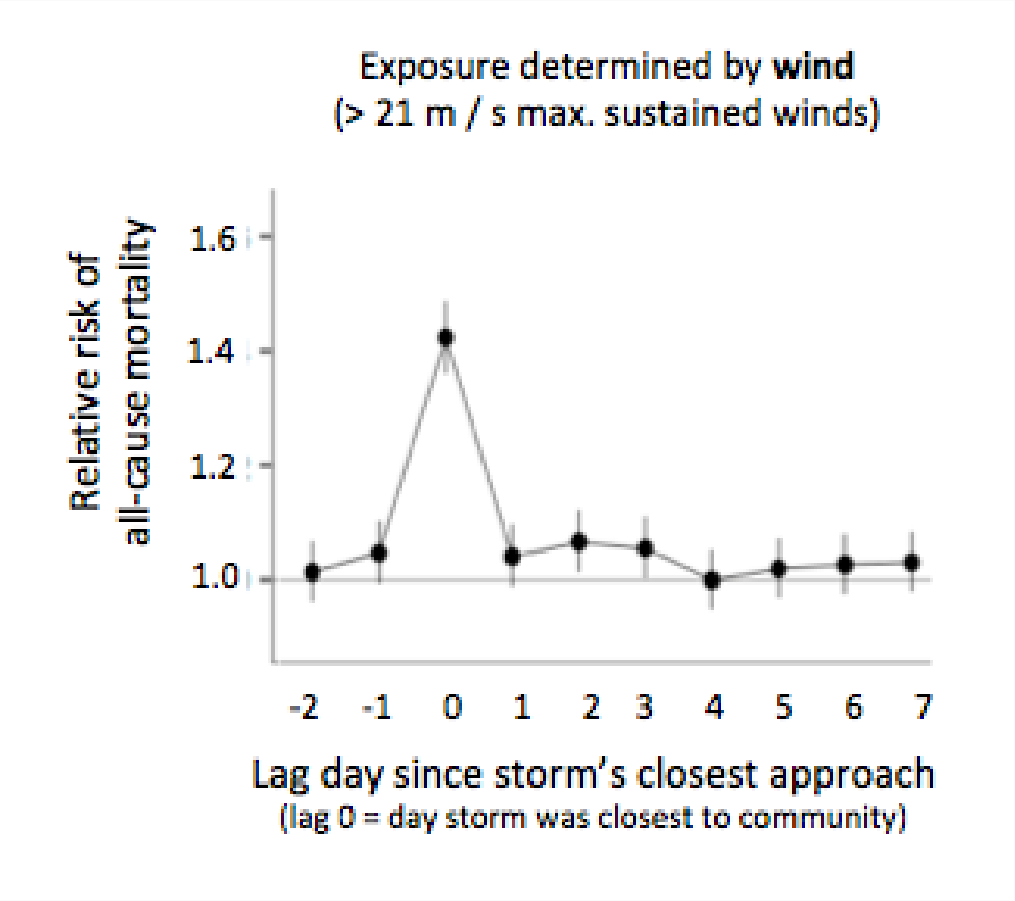
where Y_t^c: observed death count on day t in community c; n^c: population size in community c in year of day t; α, α^c: overall intercept and community random effect intercepts, respectively; x_{t-l}^c: indicator of whether the day at lag l from day t was exposed to the storm in community c; $Year_t^c$: year of day t; and DOW_t^c: day of week of day t.

Study storms and communities



Source: Preliminary results, Yan et al.

Mortality risks by day during storm period

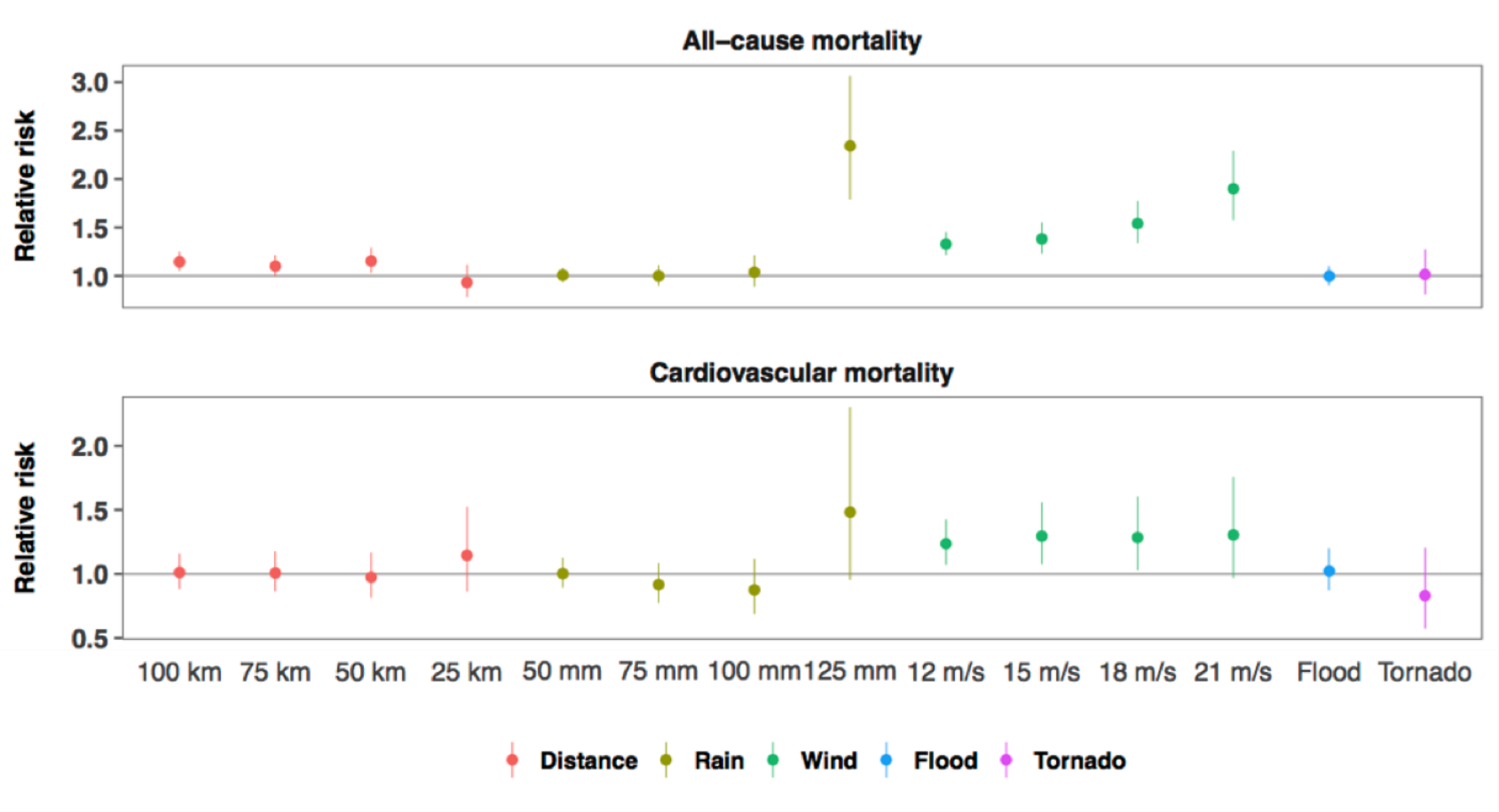


Source: Preliminary results, Yan et al.

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

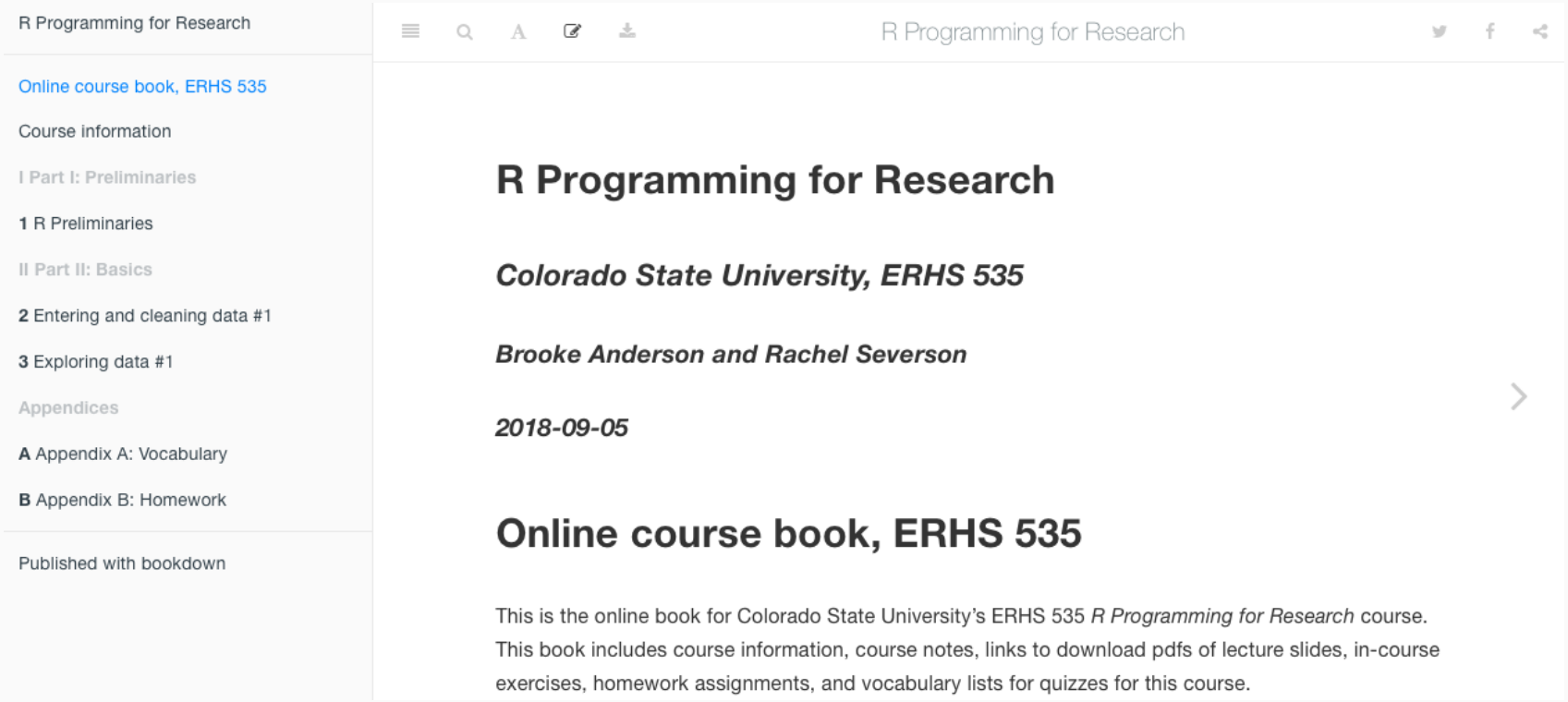


Source: Preliminary results, Yan et al.

Final thoughts

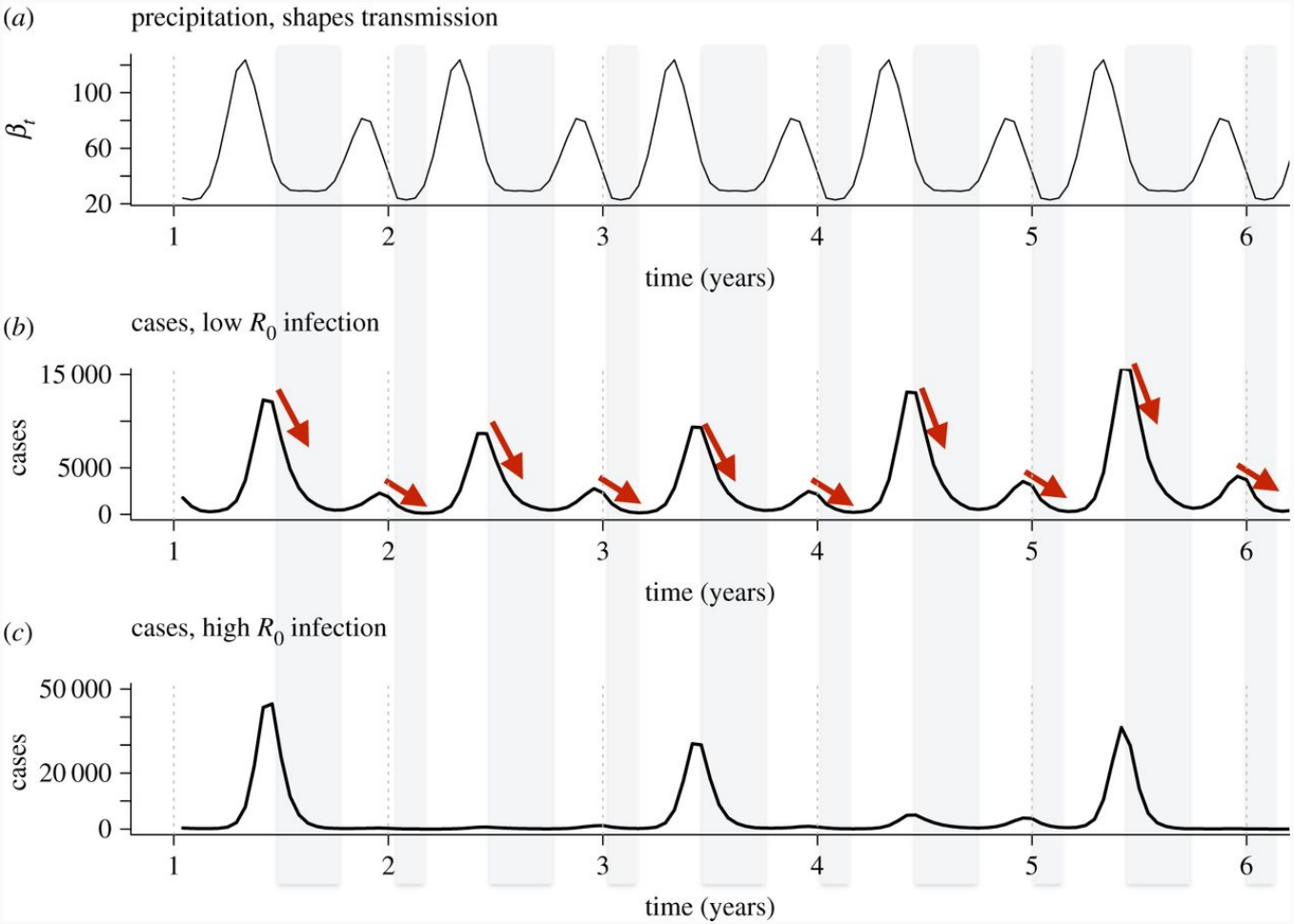
CSU R Programming course

I teach a course each fall in R Programming (ERHS 535). The coursebook is available online:
https://geanders.github.io/RProgrammingForResearch/



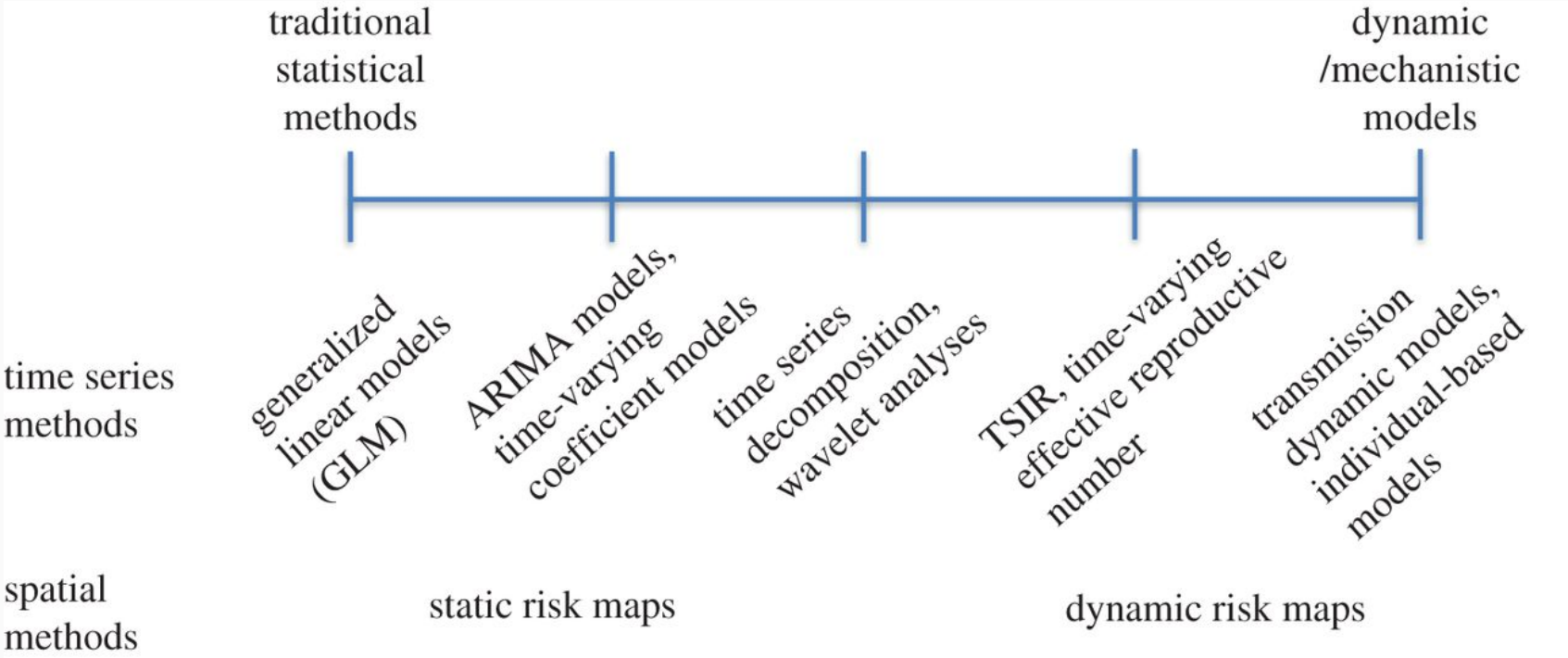
Partnership for Air Quality, Climate, and Health

Statistics for dynamic / mechanistic models



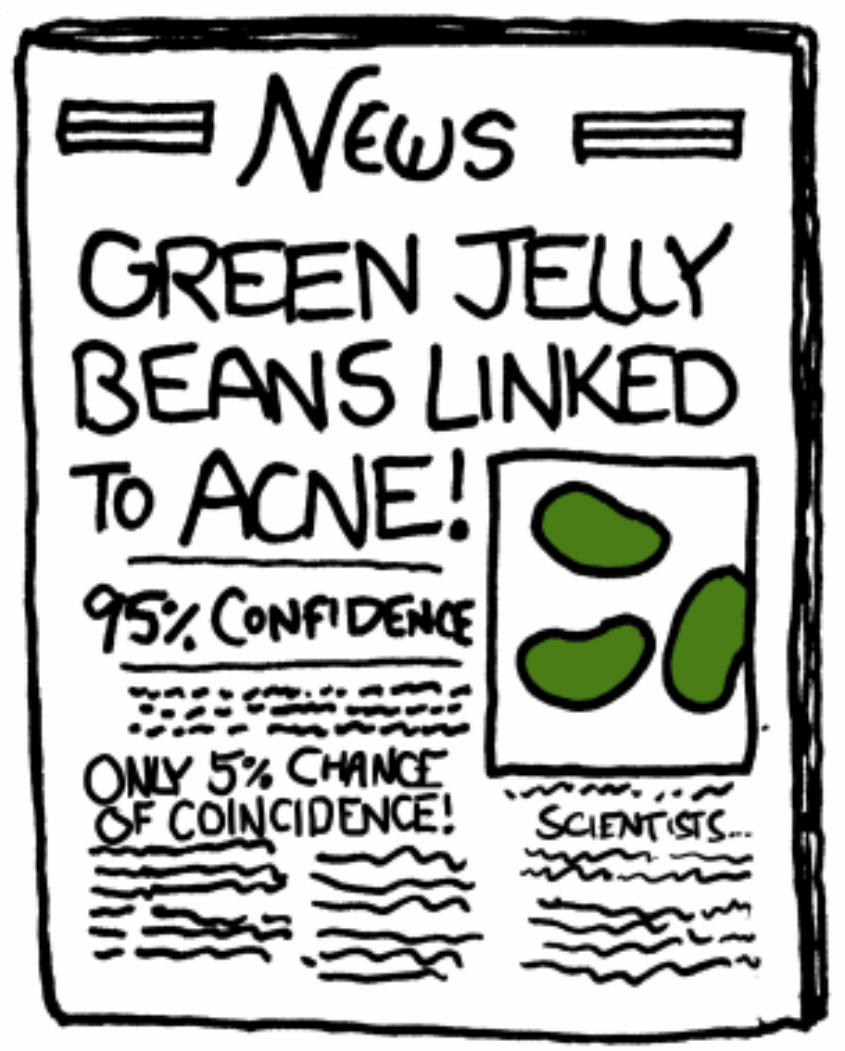
Source: Metcalfe et al., 2017. Identifying climate drivers of infectious disease dynamics: recent advances and challenges ahead. *Proc. R. Soc. B*.

Statistics for dynamic / mechanistic models



Source: Metcalfe et al., 2017. Identifying climate drivers of infectious disease dynamics: recent advances and challenges ahead. *Proc. R. Soc. B*.

Multiple hypothesis testing



Source: xkcd