

# Tropical cyclones and human health

Exploring evidence of associations using environmental epidemiology tools

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Brooke Anderson, Colorado State University  
Department of Environmental & Radiological Health Sciences

✉: [brooke.anderson@colostate.edu](mailto:brooke.anderson@colostate.edu)

🐦: [@gbwanderson](https://twitter.com/gbwanderson)

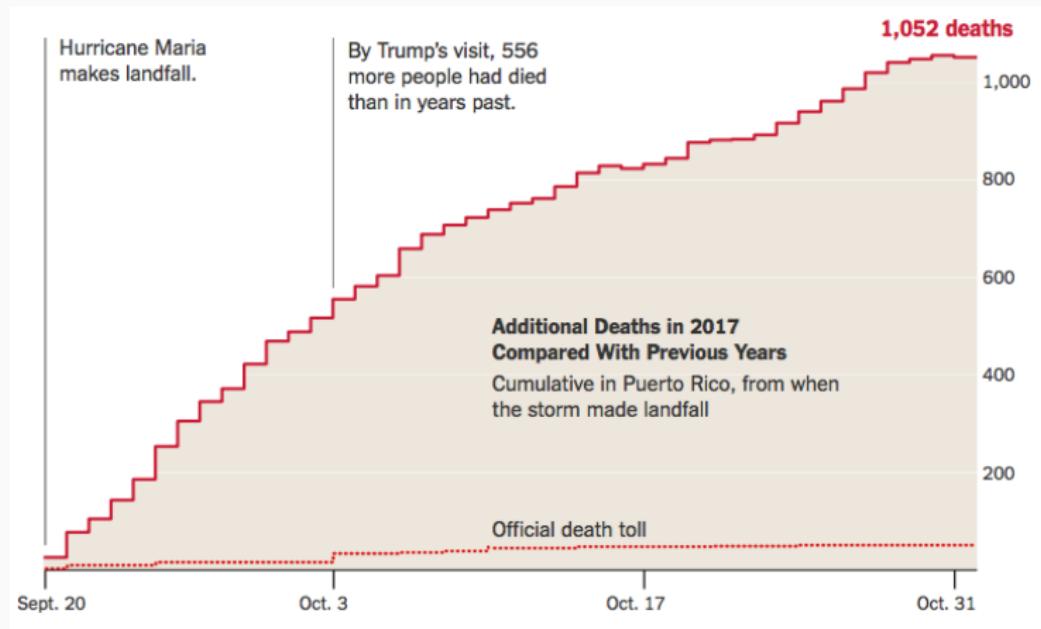
🐙: [github.com/geanders](https://github.com/geanders)

## Motivation

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# Impacts in excess of official death tolls

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



# Counting tropical cyclone fatalities

Exposure to forces of nature: ICD-10 X30—X39	
X30	Exposure to excessive natural heat
X31	Exposure to excessive natural cold
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**

<b>CAUSE OF DEATH (See instructions and examples)</b>		Approximate interval: Onset to death
32. <b>PART I.</b> Enter the <u>chain of events</u> —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.		
<b>IMMEDIATE CAUSE</b> (Final disease or condition -----> resulting in death)  <b>SEQUENTIALLY</b> list conditions, if any, leading to the cause listed on line a. Enter the <b>UNDERLYING CAUSE</b> (disease or injury that initiated the events resulting in death) LAST	a. <u>Crushed chest</u> Due to (or as a consequence of):	----->
	b. <u>Shed collapsed during hurricane</u> Due to (or as a consequence of):	----->
	c. _____ Due to (or as a consequence of):	----->
	d. _____	----->
<b>PART II.</b> Enter other <u>significant</u> conditions contributing to death but not resulting in the underlying cause given in PART I.		33. WAS AN AUTOPSY PERFORMED? <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No
Head trauma		34. WERE AUTOPSY FINDINGS AVAILABLE TO COMPLETE THE CAUSE OF DEATH? <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No
35. DID TOBACCO USE CONTRIBUTE TO DEATH?	36. IF FEMALE: <input type="checkbox"/> Not pregnant within past year <input type="checkbox"/> Pregnant at time of death <input type="checkbox"/> Not pregnant, but pregnant within 42 days of death <input type="checkbox"/> Not pregnant, but pregnant 43 days to 1 year before death <input type="checkbox"/> Unknown if pregnant within the past year	37. MANNER OF DEATH <input type="checkbox"/> Natural <input type="checkbox"/> Homicide <input checked="" type="checkbox"/> Accident <input type="checkbox"/> Pending Investigation <input type="checkbox"/> Suicide <input type="checkbox"/> Could not be determined
<input type="checkbox"/> Yes <input type="checkbox"/> Probably  <input checked="" type="checkbox"/> No <input type="checkbox"/> Unknown		

Source: [https://www.cdc.gov/nchs/data/dvs/hurricane\\_certification.pdf](https://www.cdc.gov/nchs/data/dvs/hurricane_certification.pdf)

# Reporting cause of death

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IMMEDIATE CAUSE (Final disease or condition -----> resulting in death)		
a.	<u>Acute respiratory failure</u> Due to (or as a consequence of): _____	4 hours
b.	<u>Severe emphysema</u> Due to (or as a consequence of): _____	_____
c.	<u>Heat and loss of air conditioner power from hurricane</u> 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? <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No
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Source: [https://www.cdc.gov/nchs/data/dvs/hurricane\\_certification.pdf](https://www.cdc.gov/nchs/data/dvs/hurricane_certification.pdf)

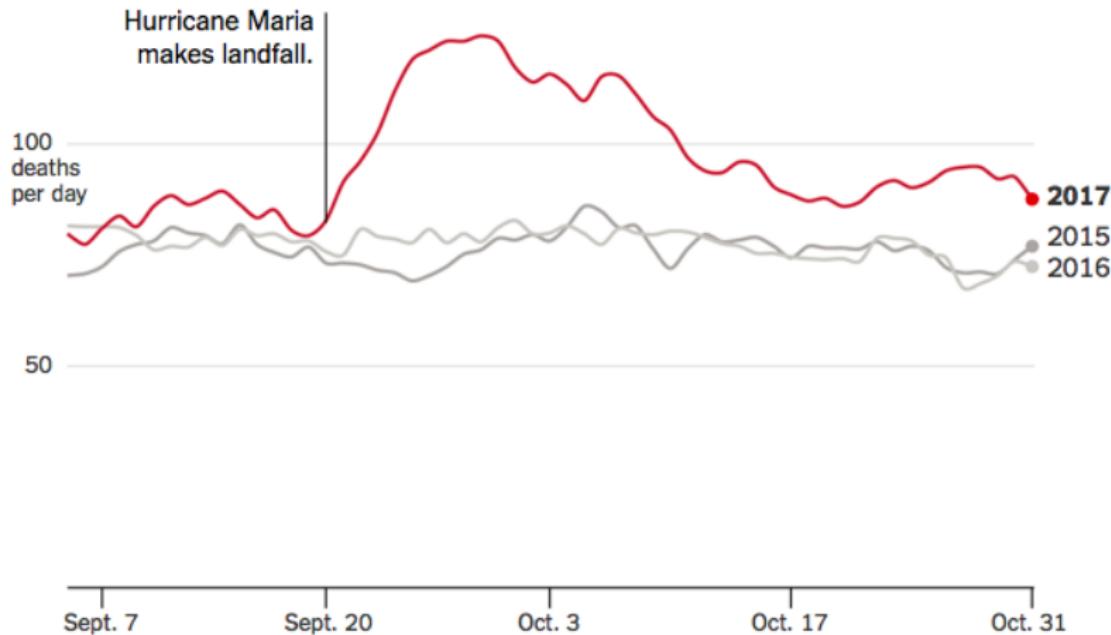
# Reporting cause of death

CAUSE OF DEATH (See instructions and examples)				Approximate interval: Onset to death
<p><b>32. PART I.</b> 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.</p> <p><b>IMMEDIATE CAUSE (Final disease or condition -----&gt; resulting in death)</b></p> <p>a. <u>Massive head trauma</u> Due to (or as a consequence of): _____</p> <p>b. <u>Car collides with falling tree</u> Due to (or as a consequence of): _____</p> <p>c. _____ Due to (or as a consequence of): _____</p> <p>d. _____</p>				
<p><b>PART II.</b> Enter other significant conditions contributing to death but not resulting in the underlying cause given in PART I.</p> <p><b>33. WAS AN AUTOPSY PERFORMED?</b>  <input type="checkbox"/> Yes   <input checked="" type="checkbox"/> No</p> <p><b>34. WERE AUTOPSY FINDINGS AVAILABLE TO COMPLETE THE CAUSE OF DEATH?</b> <input type="checkbox"/> Yes   <input checked="" type="checkbox"/> No</p>				
<p><b>35. DID TOBACCO USE CONTRIBUTE TO DEATH?</b></p> <p><input type="checkbox"/> Yes   <input type="checkbox"/> Probably  <input checked="" type="checkbox"/> No   <input type="checkbox"/> Unknown</p>		<p><b>36. IF FEMALE:</b></p> <p><input type="checkbox"/> Not pregnant within past year  <input type="checkbox"/> Pregnant at time of death  <input type="checkbox"/> Not pregnant, but pregnant within 42 days of death  <input type="checkbox"/> Not pregnant, but pregnant 43 days to 1 year before death  <input type="checkbox"/> Unknown if pregnant within the past year</p>	<p><b>37. MANNER OF DEATH</b></p> <p><input type="checkbox"/> Natural   <input type="checkbox"/> Homicide  <input checked="" type="checkbox"/> Accident   <input type="checkbox"/> Pending investigation  <input type="checkbox"/> Suicide   <input type="checkbox"/> Could not be determined</p>	
<p><b>38. DATE OF INJURY (Mo/Day/Yr) (Spell Month)</b></p> <p>August 29, 2005</p>	<p><b>39. TIME OF INJURY</b></p> <p>1130</p>	<p><b>40. PLACE OF INJURY (e.g., Decedent's home; construction site; restaurant; wooded area)</b></p> <p>In decedent's car on road</p>		<p><b>41. INJURY AT WORK?</b></p> <p><input type="checkbox"/> Yes   <input checked="" type="checkbox"/> No</p>
<p><b>42. LOCATION OF INJURY:</b> State: Mississippi            Street &amp; Number: 800 block of Sylvan Road            City or Town: near Pas Christian            Apartment No.: _____ Zip Code: 39571-1234</p>				
<p><b>43. DESCRIBE HOW INJURY OCCURRED:</b></p> <p>Car collided with falling tree</p>				
<p><b>44. IF TRANSPORTATION INJURY, SPECIFY:</b></p> <p><input checked="" type="checkbox"/> Driver/Operator  <input type="checkbox"/> Passenger  <input type="checkbox"/> Pedestrian  <input type="checkbox"/> Other (Specify)</p>				

# Impacts in excess of official death tolls

Evidence from Hurricane Maria in Puerto Rico.

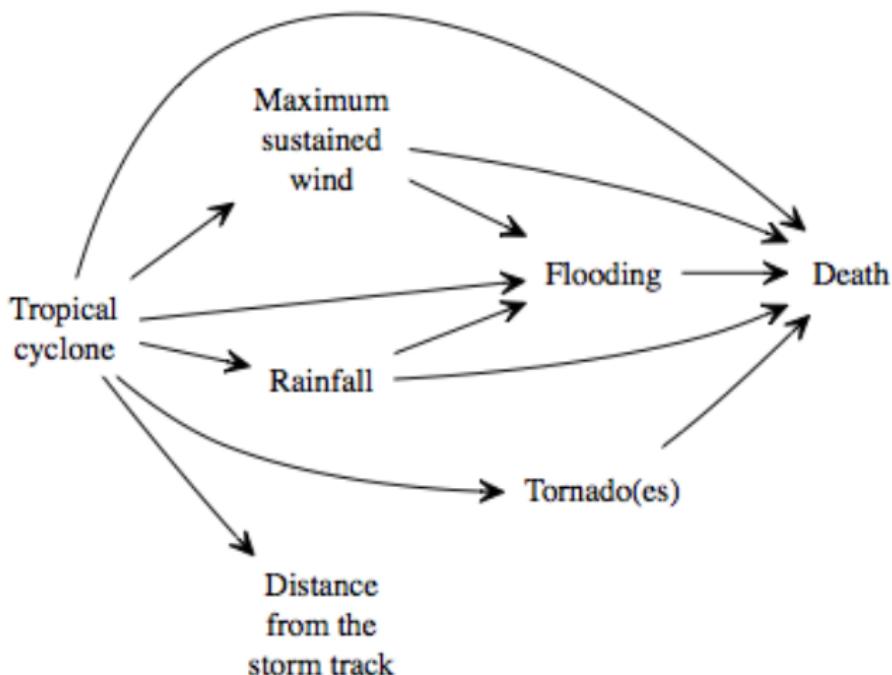
Average Daily Deaths in September and October



## Measuring tropical cyclone exposure

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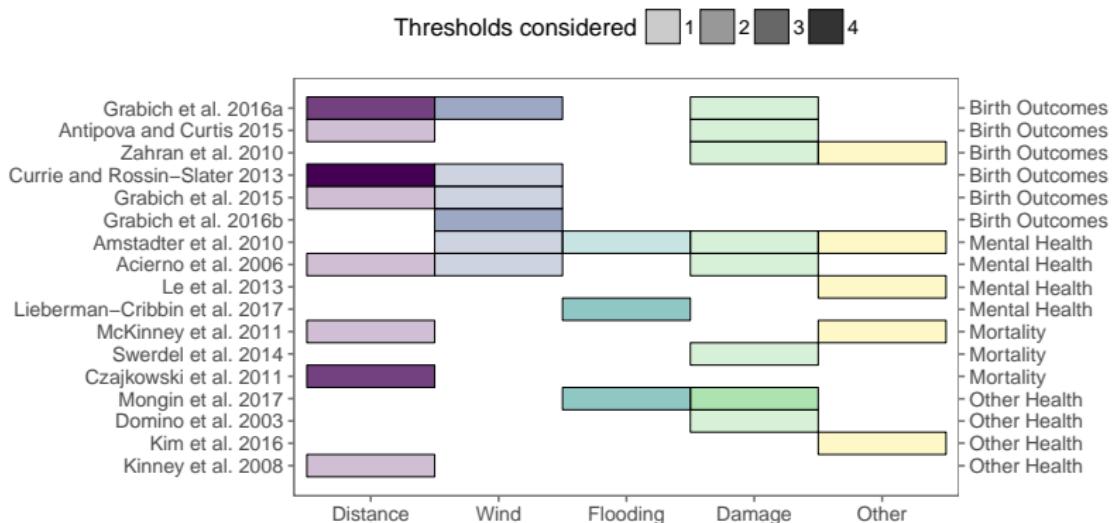
## Potential pathways through which tropical cyclone exposure might increase mortality risk



# 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

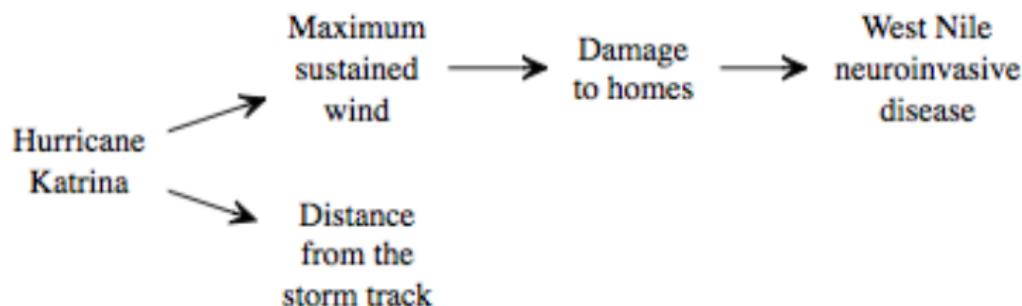
Kevin A. Caillouët,\* Sarah R. Michaels,\* Xu Xiong,\* Ivo Foppa,\* and Dawn M. Wesson\*

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.



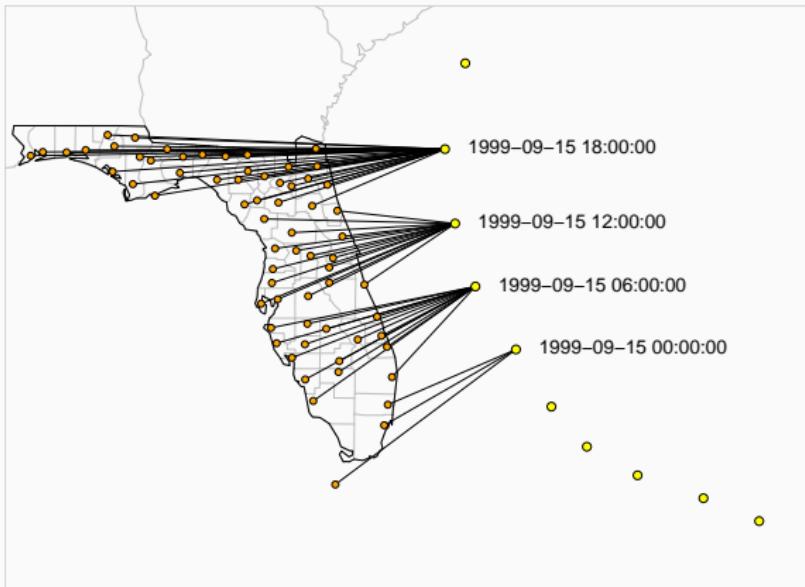
Figure 1. Hurricane Katrina track and hurricane-affected Louisiana parishes and Mississippi counties. Affected parishes and counties (gray) were defined as those in which >50% of the total area was  $\leq 50$  miles of the hurricane track coordinates.

## 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

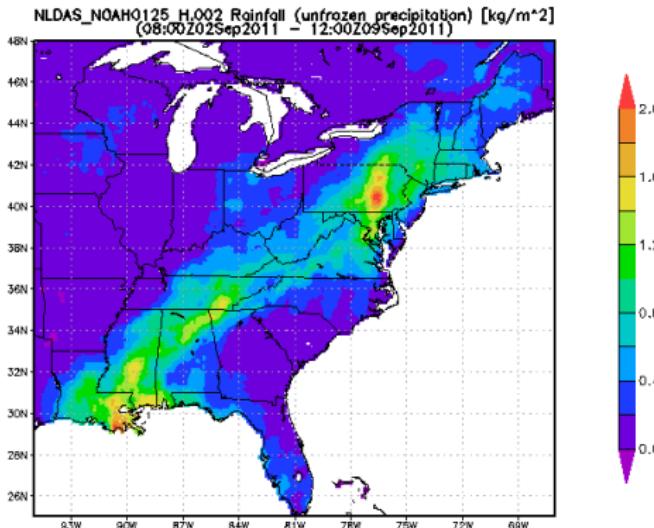


## Wind metric

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



### 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.

Image source: Goddard Earth Sciences DISC

# Flood and tornado events

The screenshot shows the NOAA National Centers for Environmental Information (NCEI) website. The header features the NOAA logo, the text "NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION", and "NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION". Below the header, there is a navigation bar with links for "Home", "Contact Us", "About NCEI", and "Help". A breadcrumb trail indicates the current page is "NCEI > Storm Events Database". On the left, a sidebar for the "Storm Events Database" contains sections for "Data Access" (with links to "Search", "Bulk Data Download (CSV)", and "Storm Data Publication"), "Documentation" (with links to "Database Details", "Version History", "Storm Data FAQ", "NOAA's NWS Documentation", and "Tornado EF Scale"), and "External Resources". The main content area is titled "Storm Events Database" and describes the database as containing records used to create the official [NOAA Storm Data publication](#), documenting three types of events: a. the occurrence of storms and other significant weather phenomena having sufficient intensity to cause loss of life, injuries, significant property damage, and/or disruption to commerce; b. rare, unusual, weather phenomena that generate media attention, such as snow flurries in South Florida or the San Diego coastal area; and c. other significant meteorological events, such as record maximum or minimum temperatures or precipitation that occur in connection with another event.

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

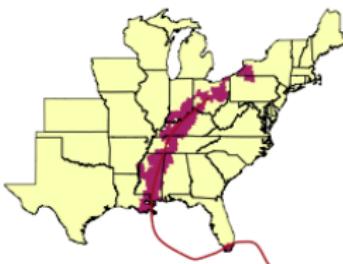
# Tropical storm exposure classifications for Hurricane Katrina

Katrina (2005)

Distance-based metric



Rain-based metric



Wind-based metric



Flood-based metric



Tornado-based metric



Unexposed  
Exposed

## County-level agreement in storm exposure

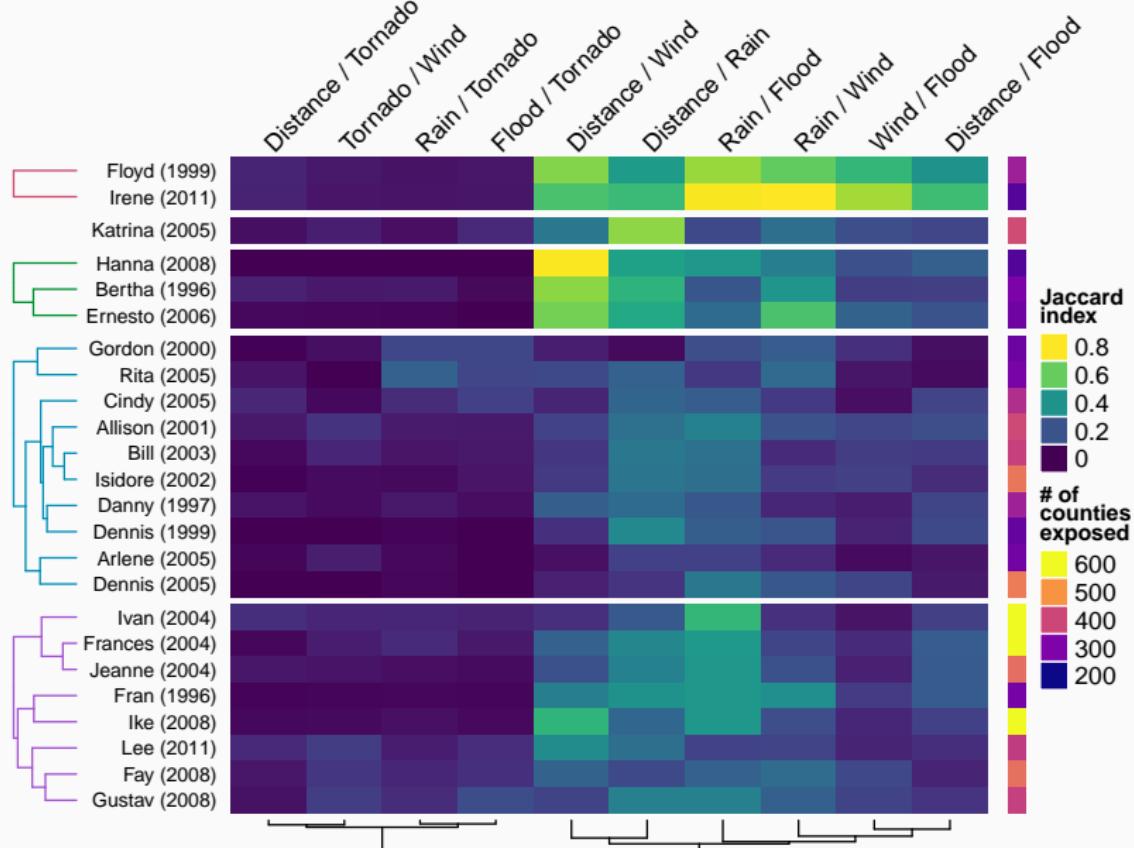
### Assessing agreement in county classifications

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

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# Open data / reproducible research

 American Journal of Epidemiology  
Copyright © 2006 by the Johns Hopkins Bloomberg School of Public Health  
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Vol. 163, No. 9  
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.

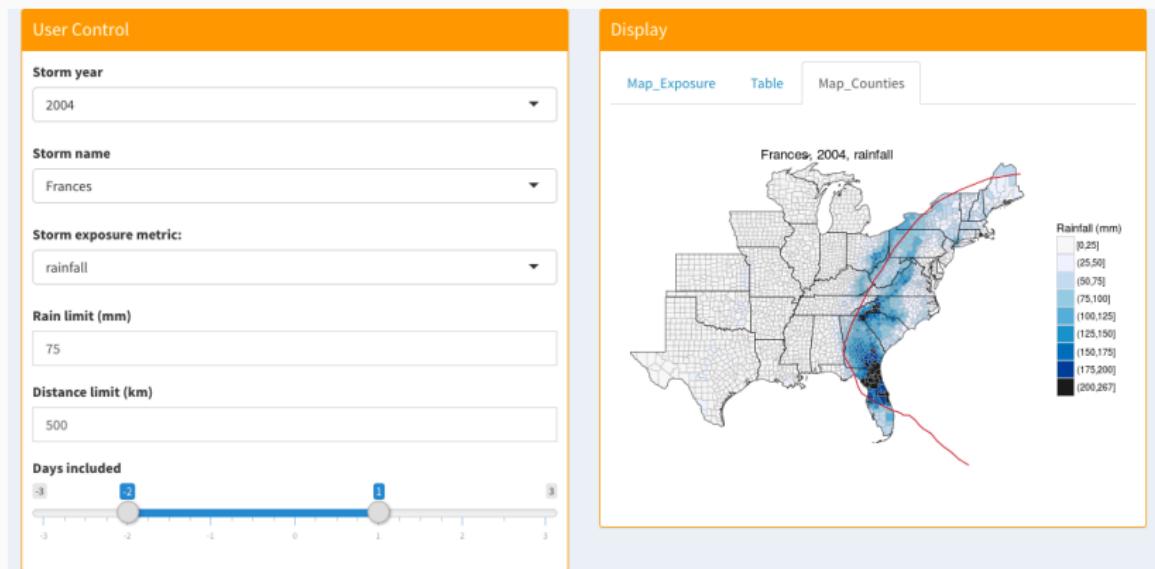
Exposure can be determined based on several hazards (e.g., distance, wind, rain), with user-specified thresholds. <https://github.com/geanders/hurricaneexposure>

```
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

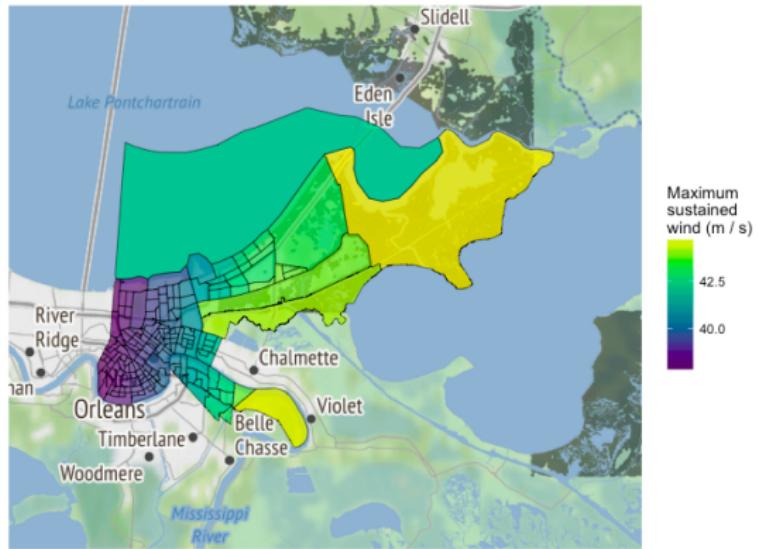
## Web application interface to 'hurricaneexposure'



# 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

The screenshot shows a web page for a Coursera specialization. On the left, a sidebar lists navigation links: 'About This Specialization', 'Courses', 'Creators', and 'FAQs'. Below these is a large title: 'Mastering Software Development in R Specialization'. A horizontal blue bar is positioned under the title. The main content area features a map of the United States with a color-coded overlay, transitioning from grey to dark blue across different regions. Overlaid on the map is the text 'Build the Tools for Better Data Science'. Below the map, a subtitle reads 'Learn to design software for data tooling, distribute R packages, and build custom visualizations'. At the bottom of the main content area, there is another 'About This Specialization' section and a descriptive paragraph about the specialization's focus on R software development.

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

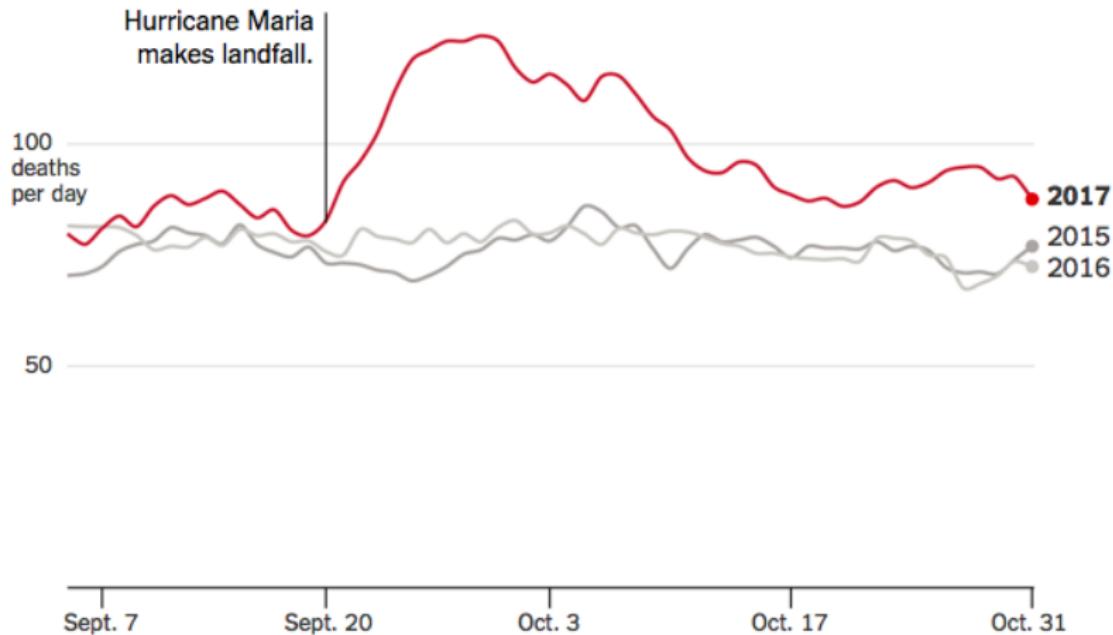
## **Associations between tropical cyclone exposure and mortality**

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# Impacts in excess of official death tolls

Evidence from Hurricane Maria in Puerto Rico.

Average Daily Deaths in September and October



## Relative risk of mortality associated with storm exposure

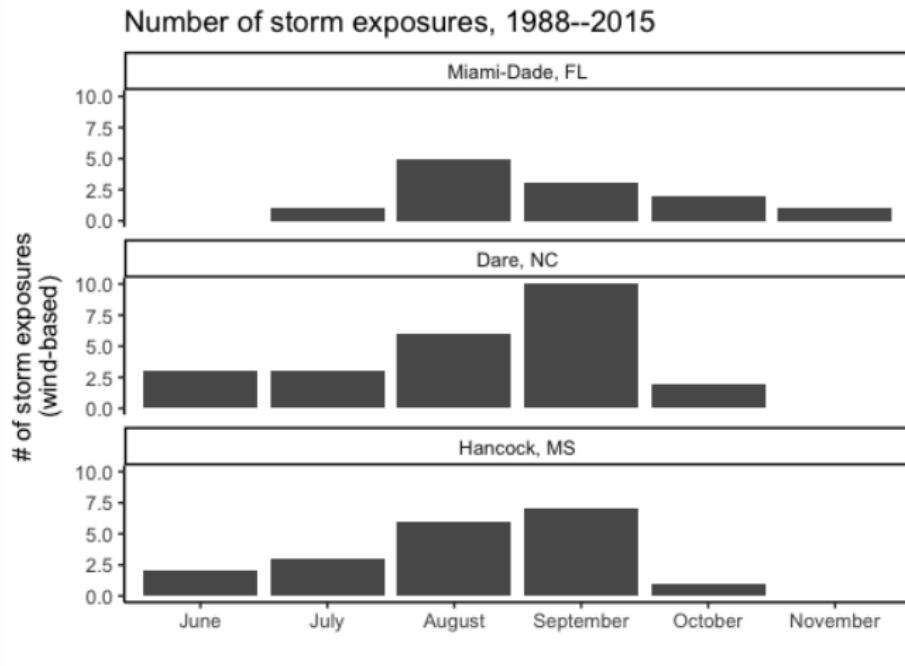
### Relative risk of mortality associated with storm exposure

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:

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

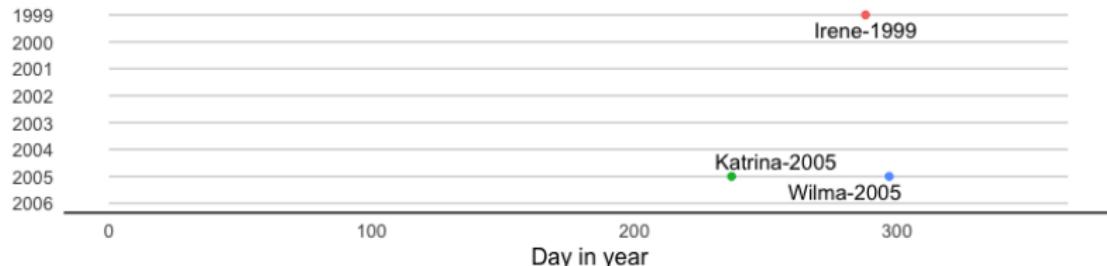
# Seasonality in tropical cyclones

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

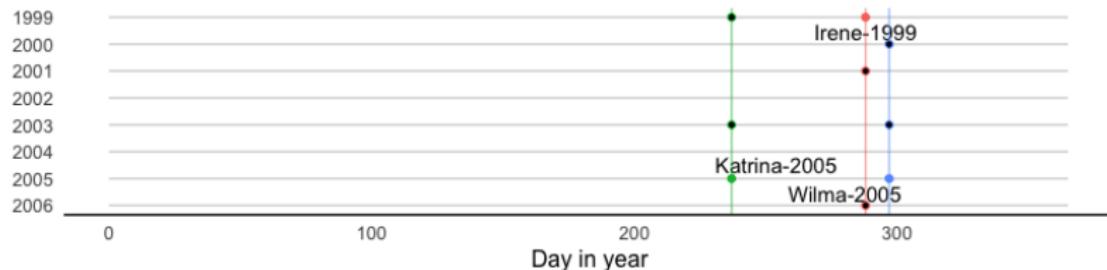


# Matching to control for seasonality

Miami-Dade, FL, storm exposures, 1999--2006



Selecting control days for storm exposures



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

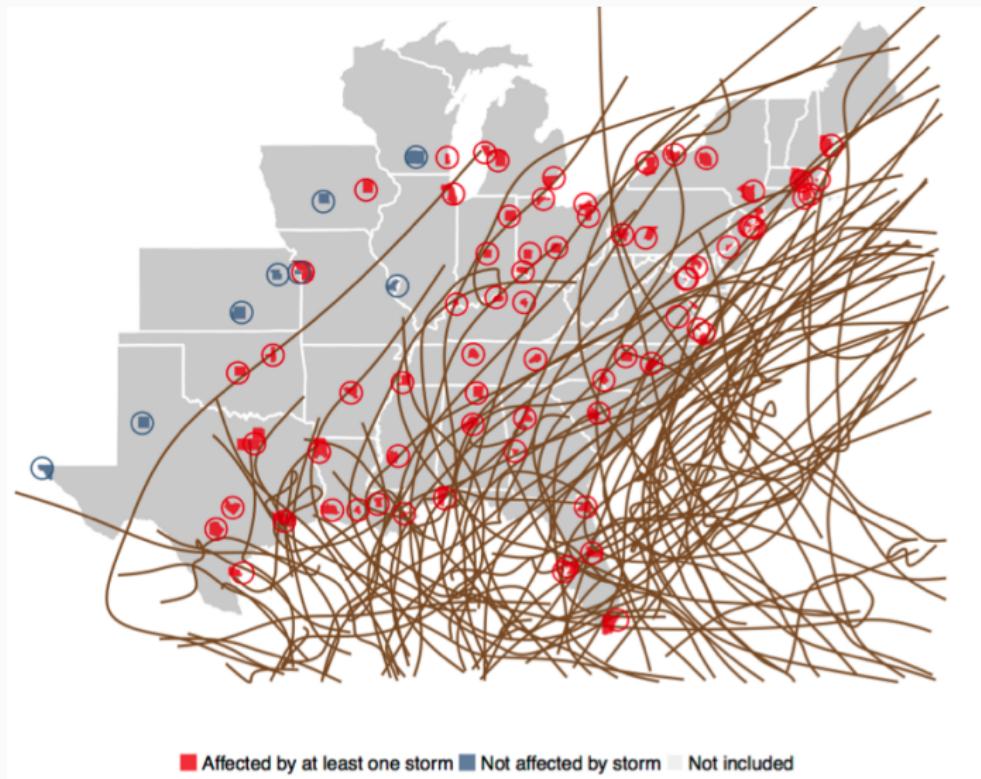
## Estimating relative risk of mortality

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:

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

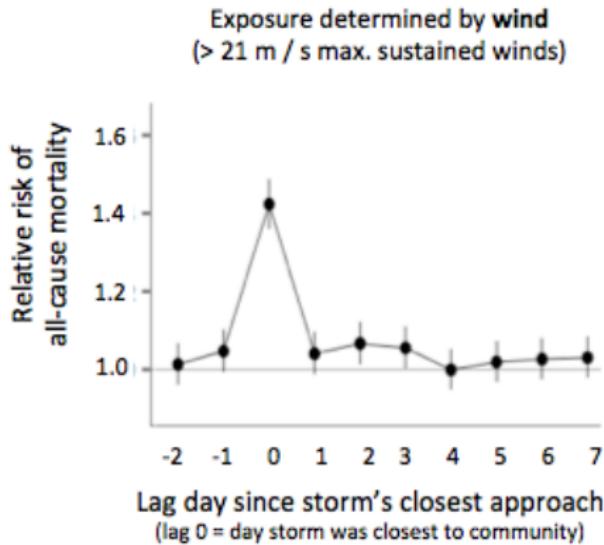
where  $Y_t^c$ : observed death count on day  $t$  in community  $c$ ;  $n^c$ : population size in community  $c$  in year of day  $t$ ;  $\alpha$ ,  $\alpha^c$ : overall intercept and community random effect intercepts, respectively;  $x_{t-l}^c$ : indicator of whether the day at lag  $l$  from day  $t$  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

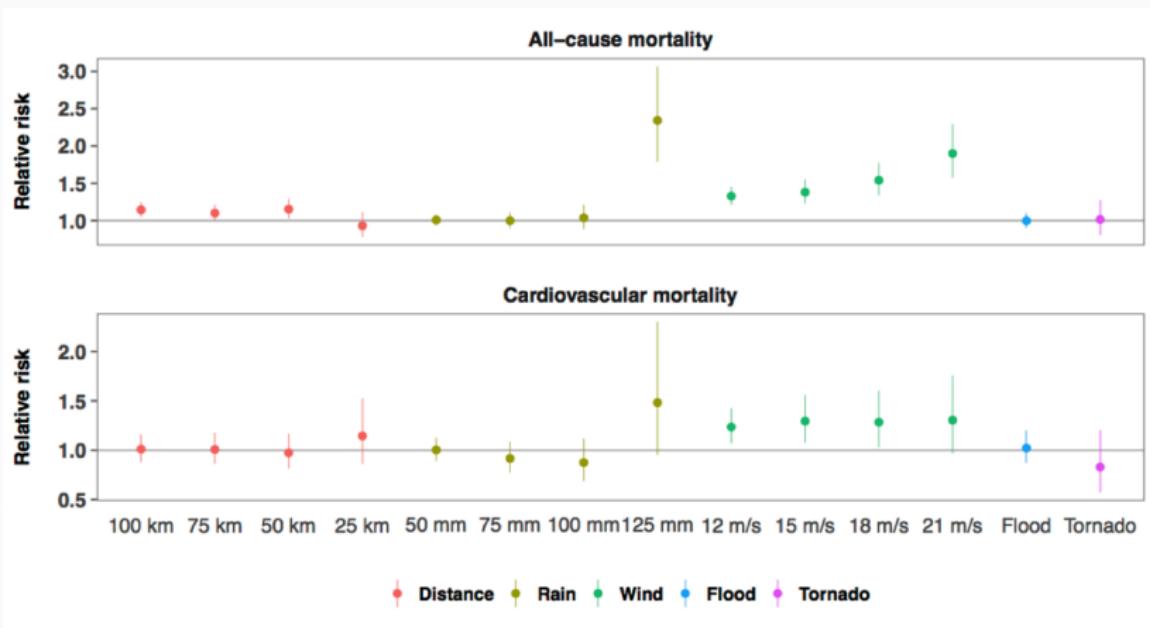


## Risks by day

- 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

Source: Preliminary results, Yan et al.

# Mortality risk by exposure metric



Source: Preliminary results, Yan et al.

## Final thoughts

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# 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/>

R Programming for Research

Online course book, ERHS 535

Course Information

I Part I: Preliminaries

1 R Preliminaries

II Part II: Basics

2 Entering and cleaning data #1

3 Exploring data #1

Appendices

A Appendix A: Vocabulary

B Appendix B: Homework

Published with bookdown

R Programming for Research

Colorado State University, ERHS 535

Brooke Anderson and Rachel Severson

2018-09-05

Online course book, ERHS 535

This is the online book for Colorado State University's ERHS 535 *R Programming for Research* course. This book includes course information, course notes, links to download pdfs of lecture slides, in-course exercises, homework assignments, and vocabulary lists for quizzes for this course.

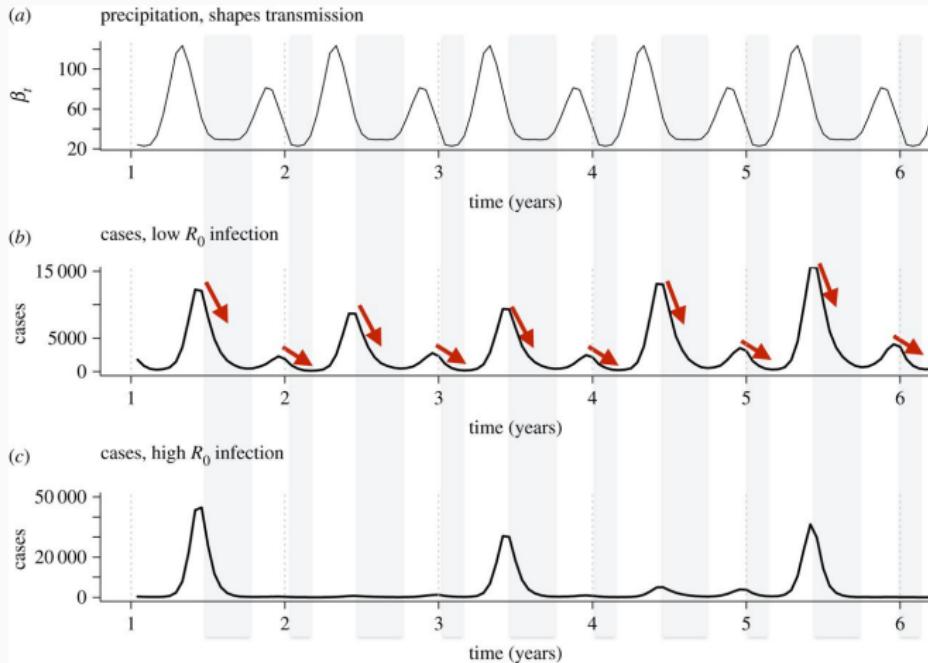
# Partnership for Air Quality, Climate, and Health



## PARTNERSHIP FOR AIR QUALITY, CLIMATE, & HEALTH

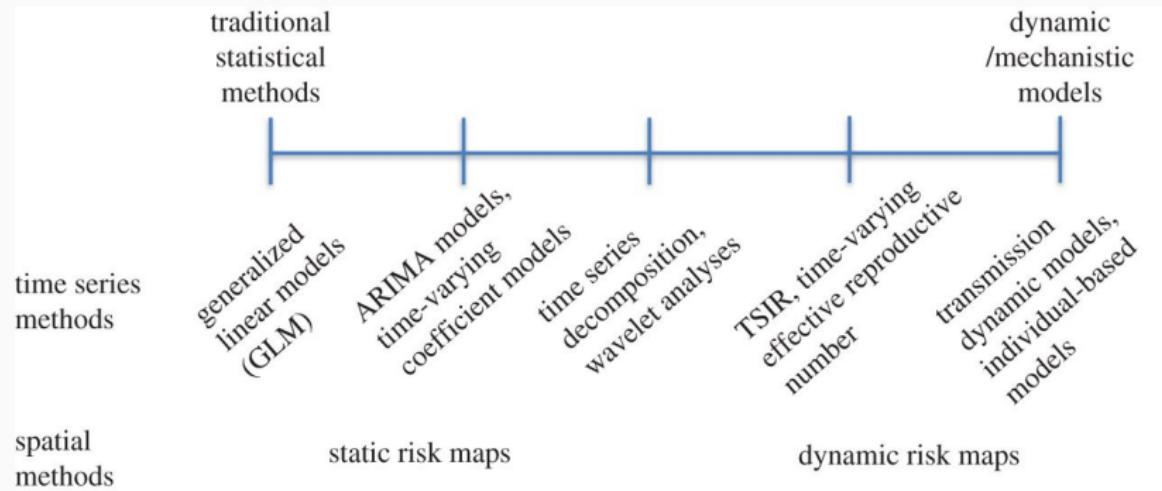
Colorado State University

# Statistics for dynamic / mechanistic models



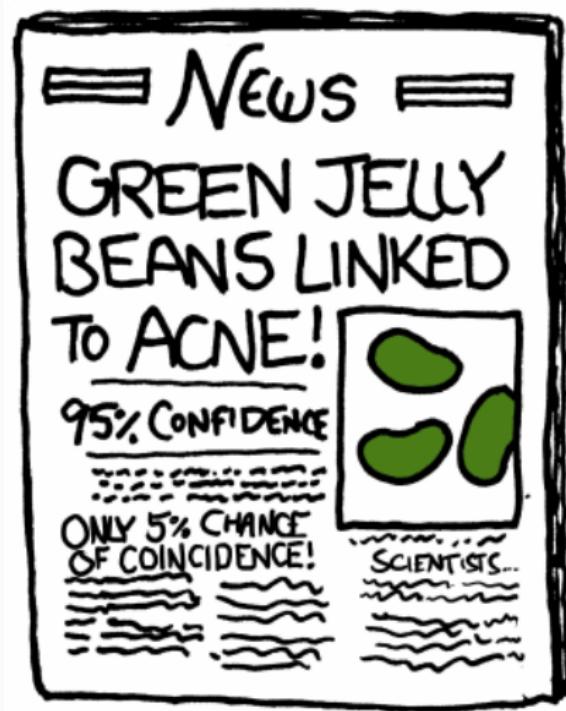
Source: Metcalfe et al., 2017. Identifying climate drivers of infectious disease dynamics: recent advances and challenges ahead. *Proc. R. Soc. B.*

# 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