



# Assessing exposure to hurricanes and other tropical storms for epidemiological research

NCAR Group Meeting Presentation

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# Motivation



# Epidemiologic research on tropical storms

## Outcomes studied for U.S. tropical storms

- Mortality
  - Direct deaths
  - Indirect deaths
- Cardiovascular events
- Birth rates
- Birth outcomes

## Focus of exposure assessment for this study

Multi-storm studies with aggregated daily counts of outcomes (for example, daily deaths by county).



# Assessing exposure

## Challenge for epidemiological research

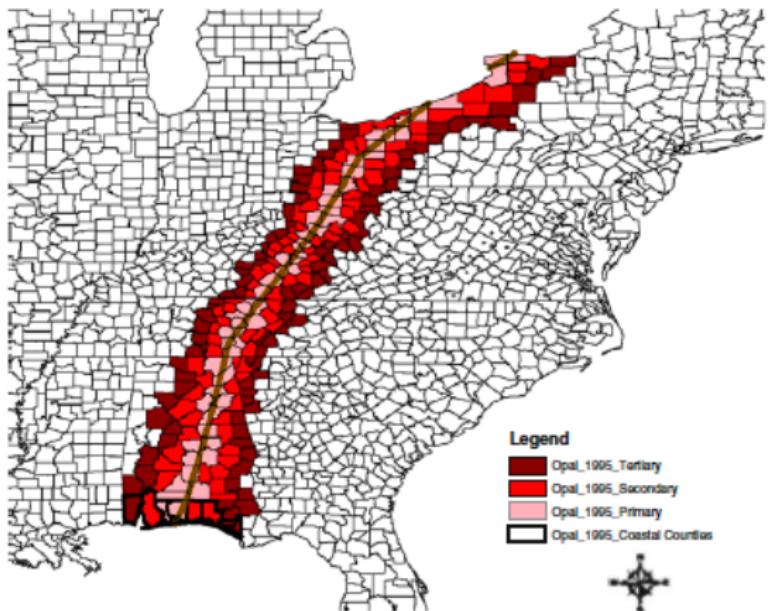
How can we determine whether a county was exposed to a tropical storm?

Previous approaches have varied but include:

- Distance from storm track
- Storm winds above a threshold
- Evacuation orders
- FEMA reports
- Combined metric (property damage, power outages, gas shortages, etc.)



## Assessing exposure



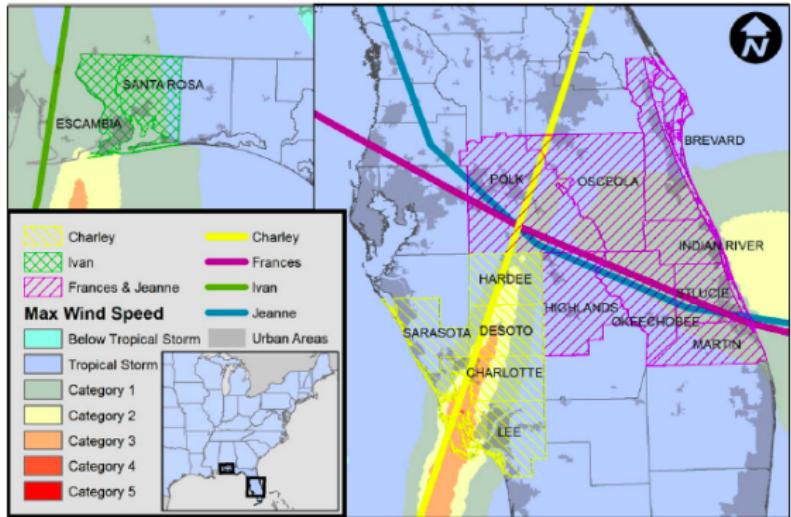
### Example exposure assessment

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

Czajkowski et al. 2011



# Assessing exposure



## Example exposure assessment

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

McKinney et al. 2011



# Project aims

## Project aims

- Develop exposure classifications of all U.S. Atlantic basin tropical storms, 1988–2011, based on reasonable measurements of tropical storm hazards
- Assess agreement between hazard-based classifications for (1) storm severity and (2) county-specific classification
- Make exposure assessments accessible to other researchers for epidemiological and other impact studies



## Hazard-specific metrics

### Tropical storm hazard metrics

- Distance from the storm
- High winds
- Rainfall
- Flood events
- Tornado events



Image sources: Los Angeles Times, NBC

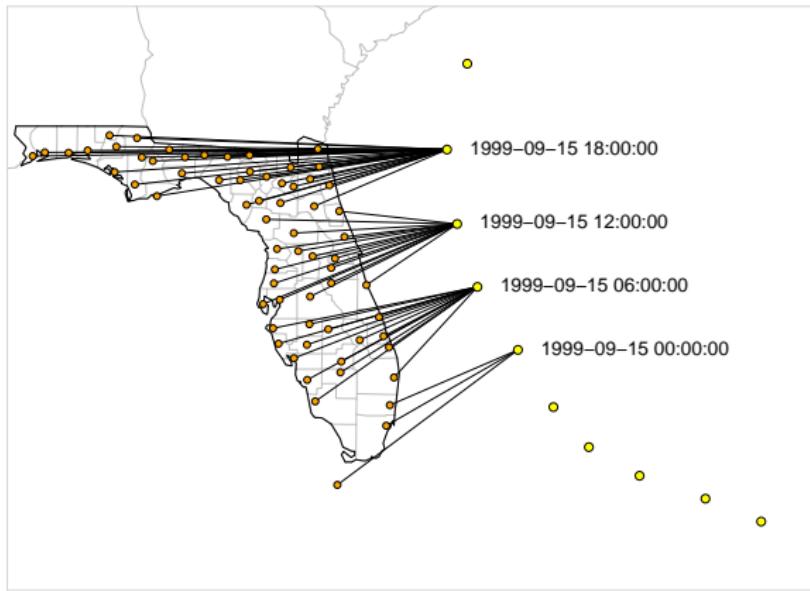


## Assessing exposure



# 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.



# Wind exposure

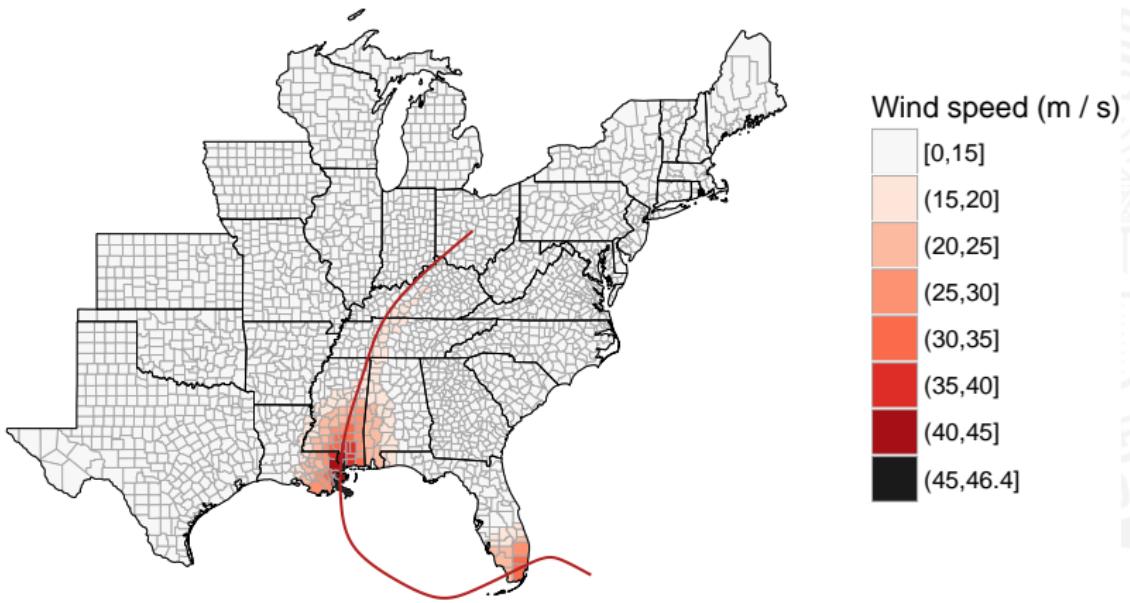
## Details of wind model

We have created an R package that implements this wind model. Full details on the model implementation are available through one of the package vignettes at <https://cran.r-project.org/web/packages/stormwindmodel/vignettes/Details.html>.



# Wind exposure

Modeled winds, Katrina, 2005

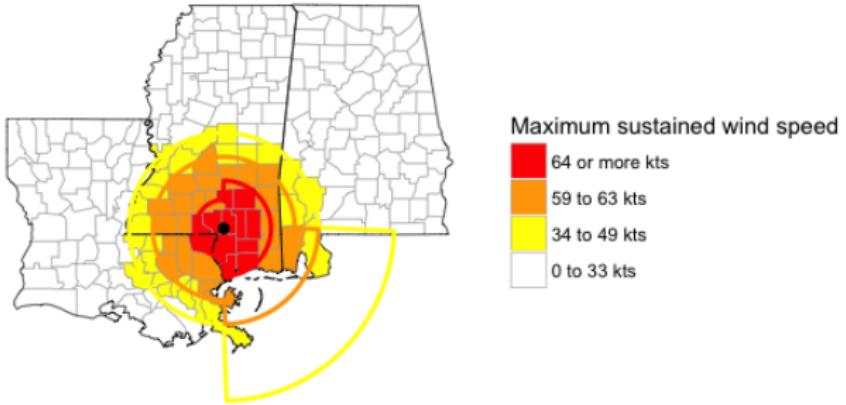




# Wind exposure

## Assessment

To assess results of the storm wind model, we compared modeled results with wind radii from the Extended Best Tracks for each storm.

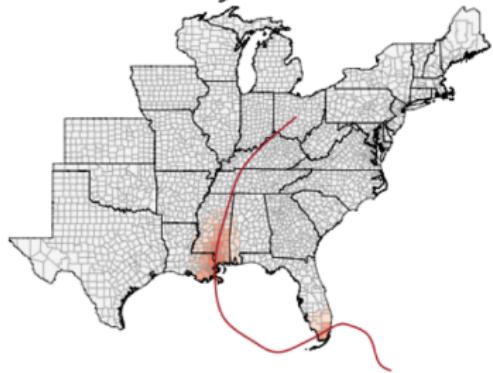




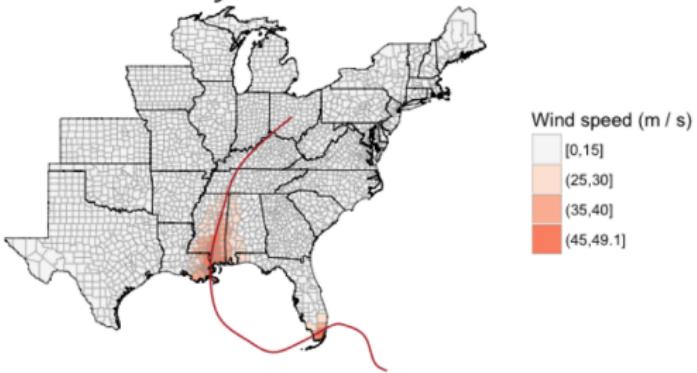
# Wind exposure

Comparison of modeled wind versus wind radii, Katrina, 2005

Willoughby Wind Model



Extended Best Tracks



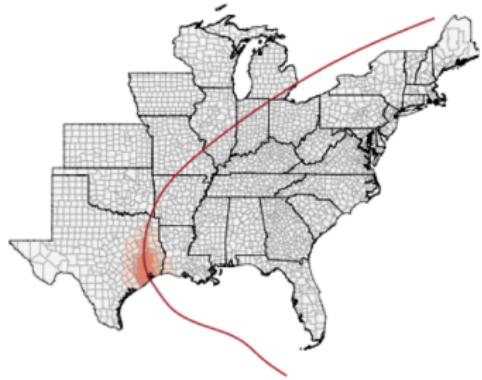
Wind speed (m / s)
[0,15]
(25,30]
(35,40]
(45,49.1]



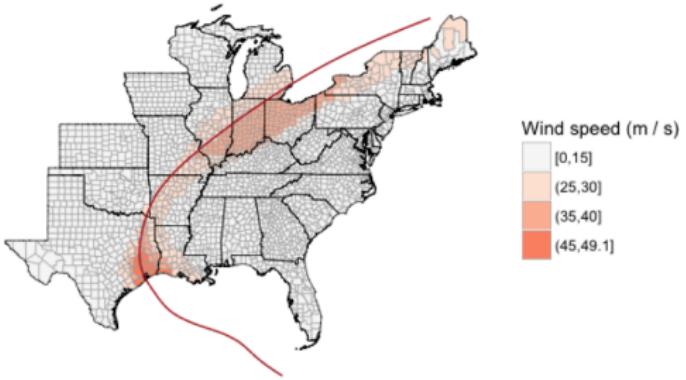
# Wind exposure

Comparison of modeled wind versus wind radii, Ike, 2008

Willoughby Wind Model



Extended Best Tracks



Wind speed (m / s)
[0,15]
(25,30]
(35,40]
(45,49.1]



# Rain exposure

## Rain during Tropical Storm Lee

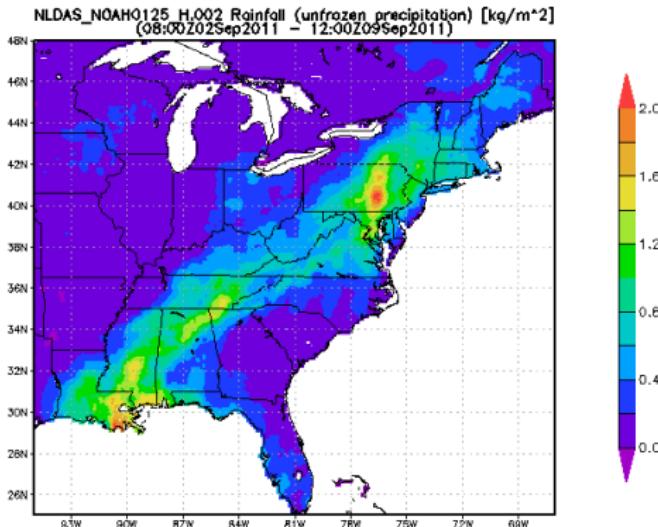
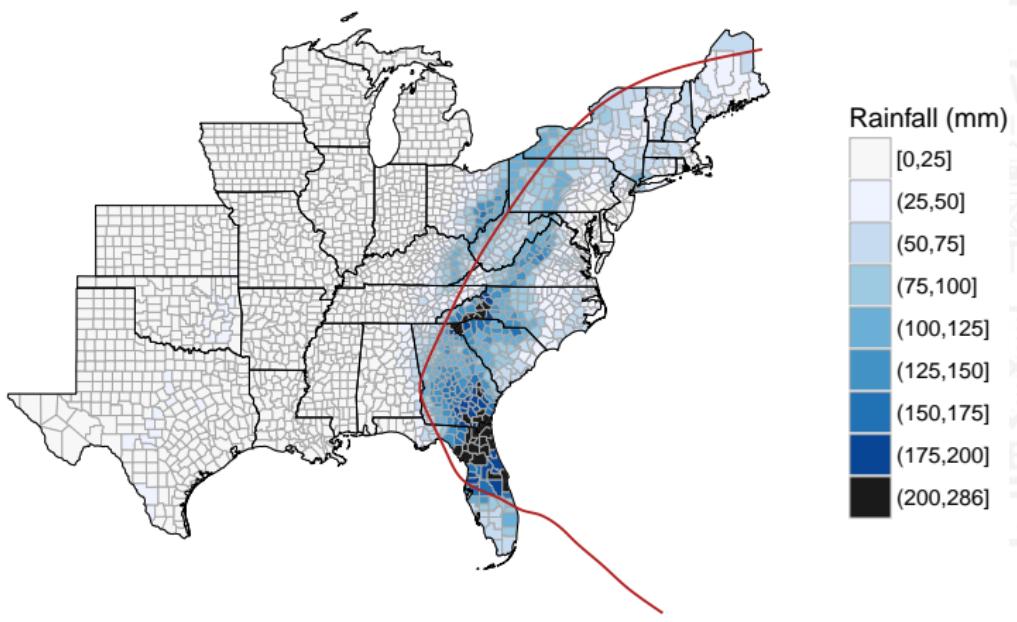


Image source: Goddard Earth Sciences DISC



# Rain exposure

Rainfall during Frances, 2004

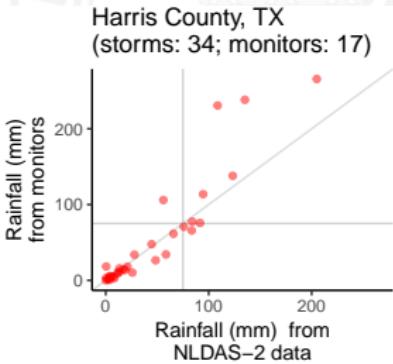
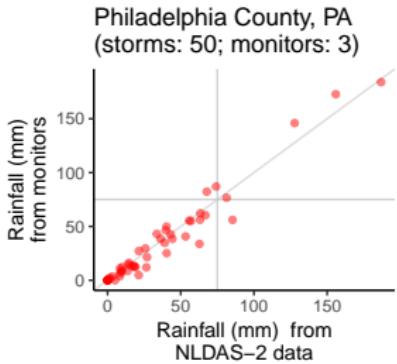
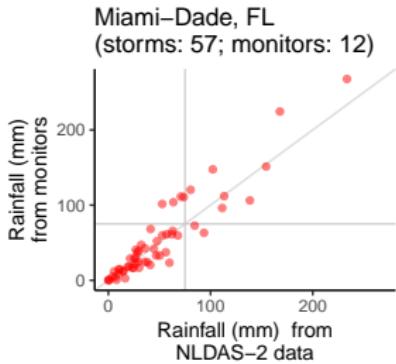




# Rain exposure

## Assessment

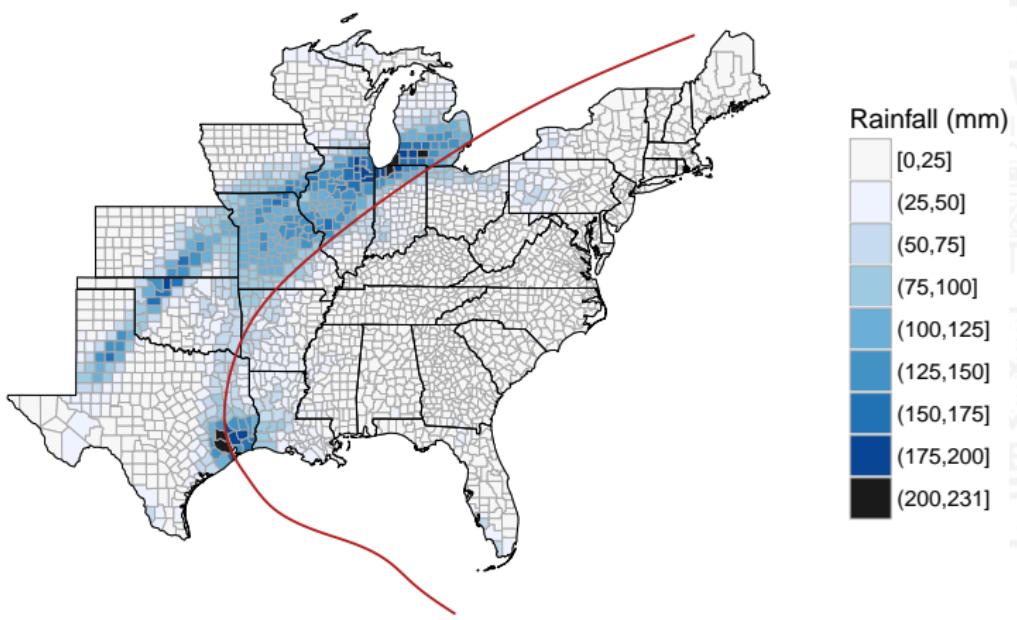
To assess this rain metric, we compared it to rainfall measured at weather stations. X-axis: Rainfall summed for days near storm; y-axis: average of summed rain at each monitor for the same days.





# Rain exposure

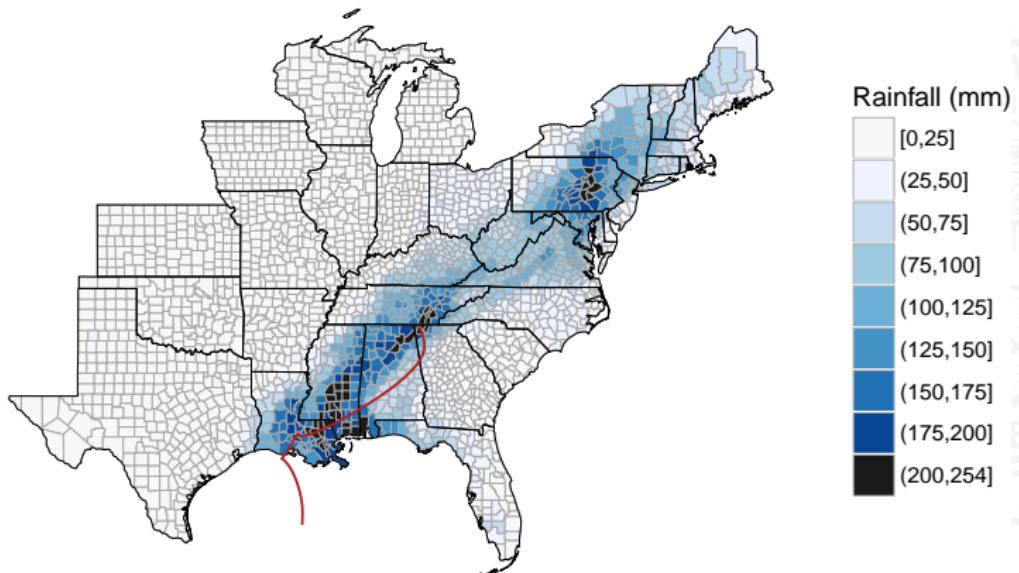
Rainfall during Ike, 2008





# Rain exposure

Rainfall during Lee, 2011





# Flood and tornado events

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NCEI > Storm Events Database

**Storm Events Database**

The Storm Events Database contains the records used to create the official [NOAA Storm Data publication](#), documenting:

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

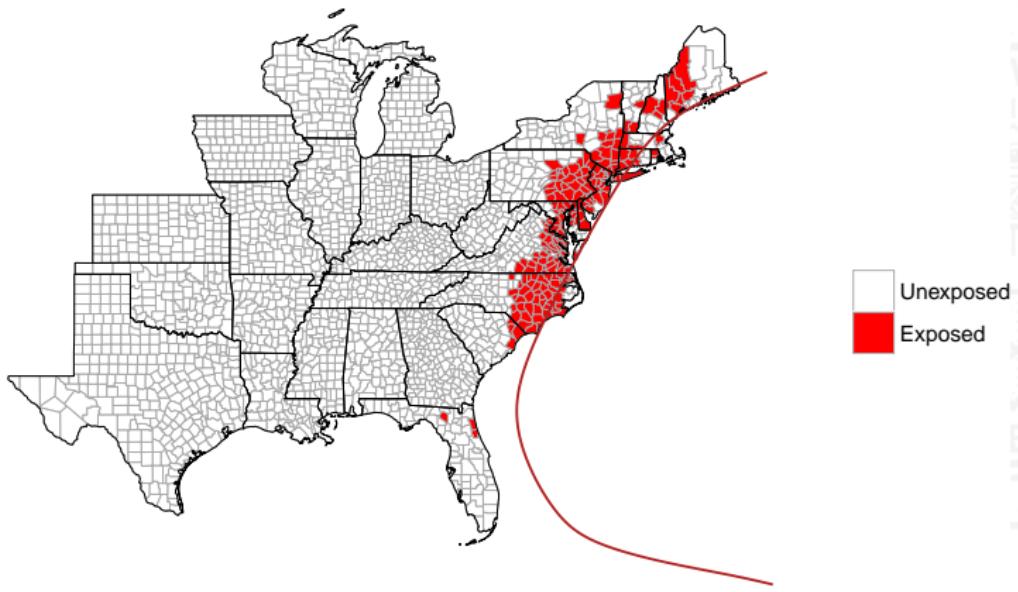
c. Other significant meteorological events, such as record maximum or minimum temperatures or precipitation that occur in connection with another event.

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



# Flood and tornado events

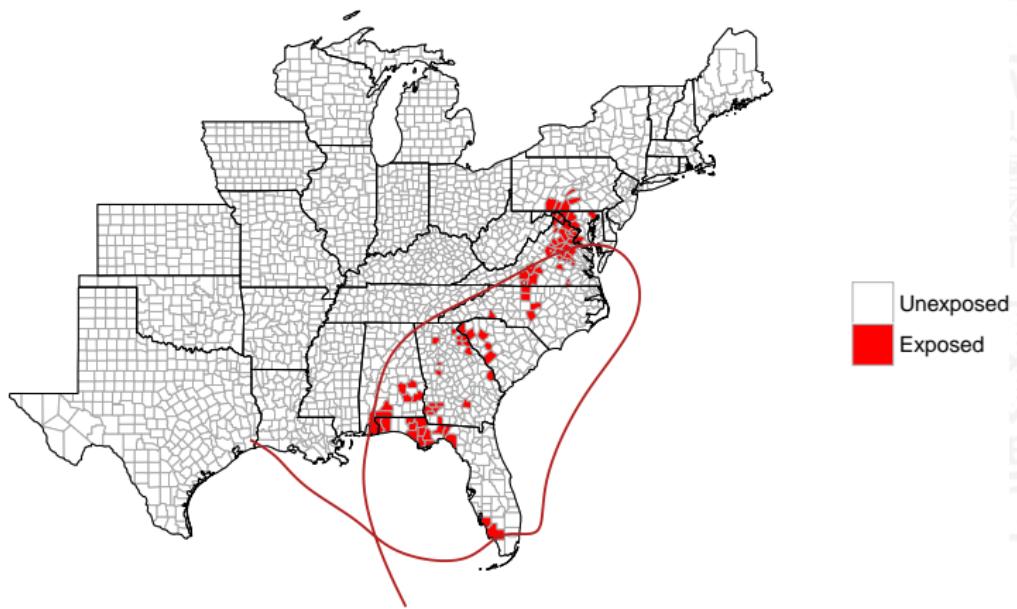
Flood events during Floyd, 1999





# Flood and tornado events

Tornado events during Ivan, 2004





## Agreement between exposure metrics



# 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



## Storm exposure

Exposure metric	Median number of exposed counties (IQR)	Storm with most counties exposed
Distance	62 (12, 156)	Beryl, 1994 (330)
Rain	32 (4, 133)	Frances, 2004 (464)
Wind	26 (3, 65)	Ike, 2008 (355)
Flood	9 (0, 39)	Ivan, 2004 (317)
Tornado	1 (0, 9)	Ivan, 2004 (91)

\*Note: Flood and Tornado events only include storms in 1996–2011. All other event listings cover storms in 1988–2011.



## Storm-specific severity

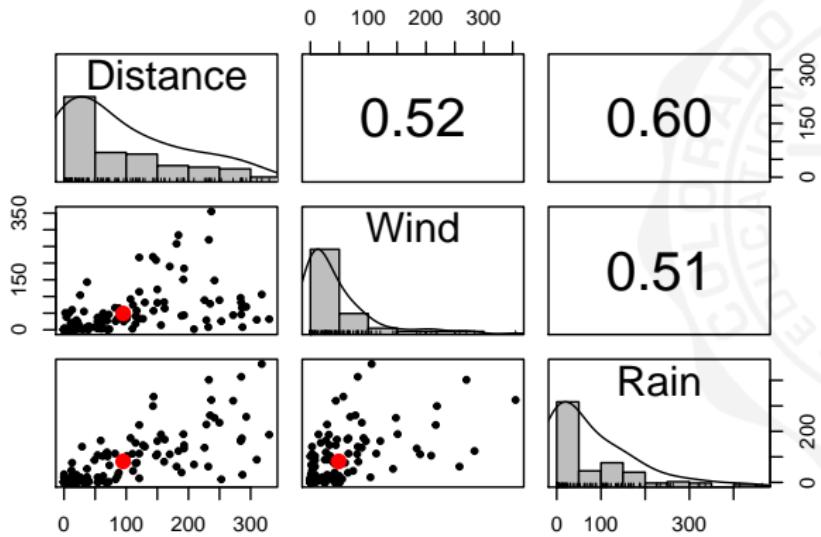
### Assessing agreement in storm severity across metrics

- For this assessment, we measured **storm-specific severity** as the number of counties classified as exposed by a given metric for a given storm
- We measured this storm-specific severity for every storm and every metric (1988–2011 for distance, rain, wind; 1996–2011 for flood and tornado)
- We measured the rank correlation (Kendall's  $\tau$ ) between storm severity for each pair of exposure metrics



## Storm-specific severity

Agreement in storm severity for distance, wind, and rain metrics





## Storm-specific severity

Agreement in storm severity for exposure metrics

	Distance	Rain	Wind	Flood	Tornado
Distance	-	-	-	-	-
Rain	0.60	-	-	-	-
Wind	0.52	0.51	-	-	-
Flood	0.35	0.43	0.32	-	-
Tornado	0.32	0.38	0.34	0.62	-

The table gives Kendall's  $\tau$  for each pair of exposure metrics. All comparisons that include flood or tornado metrics are limited to storms since 1996.



## County-specific classification

### Assessing agreement in county classifications

For each storm and each pair of metrics, we measured the probability a county was classified as exposed by one of the metrics conditional on it being classified as exposed by the other metric:

$$Pr(Exposure_Y = 1 | Exposure_X = 1) \quad (1)$$



## County-specific classification– Floyd, 1999

	Distance	Rain	Wind	Flood	Tornado
Distance		0.93	0.99	0.72	0.08
Rain	0.44		0.65	0.69	0.04
Wind	0.64	0.88		0.68	0.05
Flood	0.47	0.94	0.68		0.05
Tornado	0.92	0.92	0.92	0.83	

### County agreement

Above the diagonal shows the probability that, given the county was exposed based on the metric for that row, it was also exposed based on the metric for that column. Below the diagonal shows the probability that, given the county was exposed based on the metric for that column, it was also exposed based on the metric for that row.



## County-specific classification– All storms

	Distance	Rain	Wind	Flood	Tornado
Distance		0.41	0.33	0.18	0.04
Rain	0.47		0.3	0.34	0.07
Wind	0.65	0.5		0.23	0.06
Flood	0.4	0.69	0.27		0.07
Tornado	0.37	0.53	0.28	0.27	

### County agreement

Above the diagonal shows the probability that, given the county was exposed based on the metric for that row, it was also exposed based on the metric for that column. Below the diagonal shows the probability that, given the county was exposed based on the metric for that column, it was also exposed based on the metric for that row.



# Software



# 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>

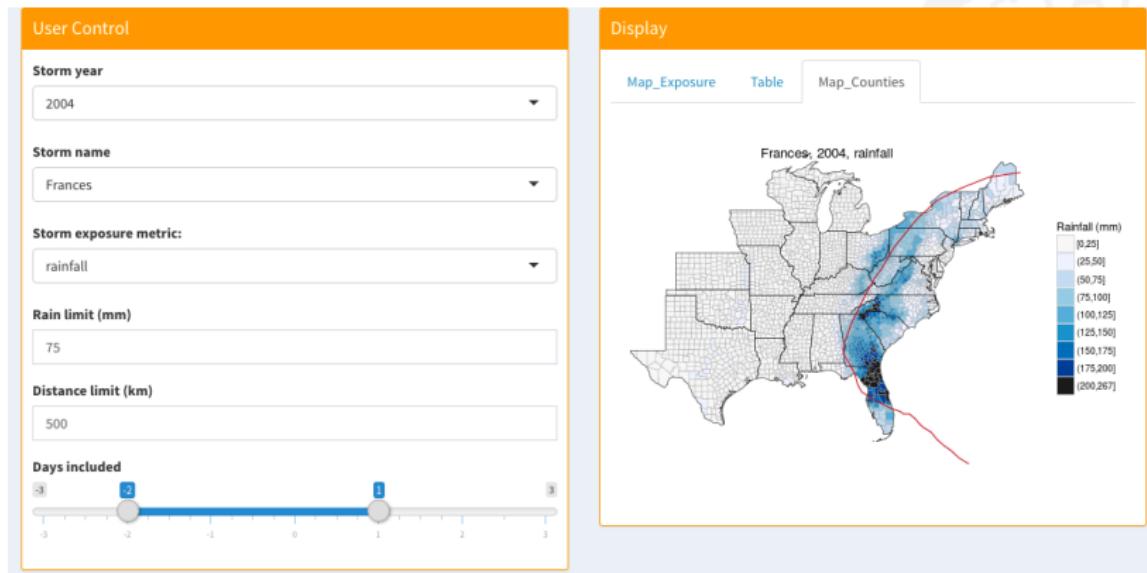
```
county_rain(counties = c("22071", "51700"), rain_limit = 100,  
            start_year = 1995, end_year = 2005, dist_limit = 100,  
            days_included = c(-1, 0, 1))
```

```
##      storm_id  fips closest_date storm_dist tot_precip  
## 1    Bill-2003 22071   2003-06-30     38.78412    141.1  
## 2 Charley-2004 51700   2004-08-14     43.01152    136.2  
## 3 Cindy-2005 22071   2005-07-06     32.21758    113.2  
## 4 Floyd-1999 51700   1999-09-16     46.50729    207.5  
## 5 Isidore-2002 22071   2002-09-26      6.37844    249.0
```



# Project software

## Web application interface to 'hurricaneexposure'

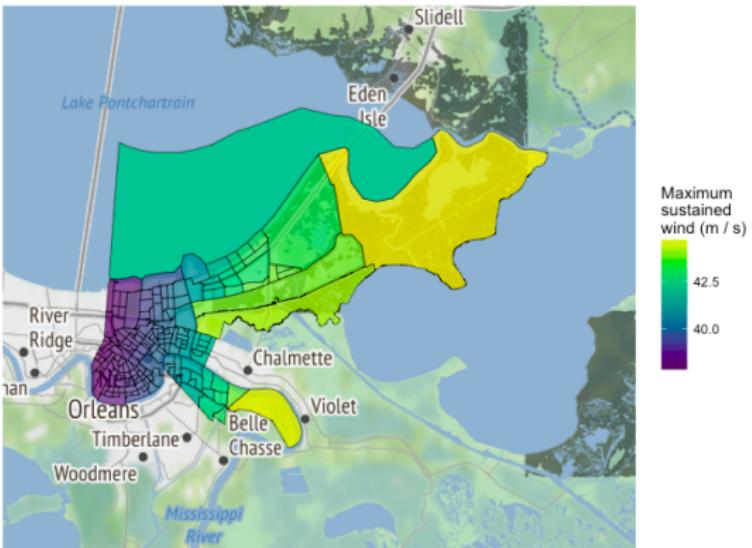




## Project software

### '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.



# Future work

## Future work

- Epidemiological study of mortality risk and tropical storm hazards
- Exploring alternative measures of flood and tornado exposure
- Improving wind model for extra-tropical storms
- Incorporating metrics of infrastructure damage



## R tools for open science



# Open data / reproducible research

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Advance Access publication March 1, 2006

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**Commentary**

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**Reproducible Epidemiologic Research**

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OPEN  ACCESS Freely available online

PLOS BIOLOGY

**Community Page**

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**The Open Knowledge Foundation: Open Data Means Better Science**

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

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**Annals of Internal Medicine**

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**ACADEMIA AND CLINIC**

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**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



# Software as a research product

The screenshot shows the landing page for the 'Mastering Software Development in R Specialization'. On the left, there's a sidebar with links: 'About This Specialization', 'Courses', 'Creators', and 'FAQs'. Below these is a large title: 'Mastering Software Development in R Specialization'. To the right is the main content area, which features a map of the United States with a red diagonal line running from the northwest to the southeast. 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's another 'About This Specialization' link and a brief description of the specialization's focus on R software development for data science tools.

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



# R package repositories

## Sharing R packages

R packages can be shared with others through:

- By sharing a `.tar.gz` file
- Through the Comprehensive R Archive Network (CRAN)
- Through GitHub (packages can be installed from GitHub with the `install_github` function from the `devtools` package)
- Through a drat repository, hosted locally or through GitHub pages



# Software vignettes

## Documenting R Software

R packages can include **vignettes**, which provide tutorials or documentation for users. These vignettes can be written in RMarkdown, which allows a mix of executable R code and text, figures, tables, etc.

## Example vignettes

The `stormwindmodel` package has two vignettes:

- "Overview" vignette: <https://cran.r-project.org/web/packages/stormwindmodel/vignettes/Overview.html>
- "Details" vignette: <https://cran.r-project.org/web/packages/stormwindmodel/vignettes/Details.html>



# Shiny web applications

## Shiny web applications

Web applications that run R code can be created using Shiny. You can use these to "wrap" an R package and make it accessible to non-R users. Shiny web apps can:

- Be freely hosted through <https://www.shinyapps.io>
- Allow users to upload and download data and create figures
- Be extensively customized

## Help with Shiny

- Lots of tutorials are available through RStudio:  
<http://shiny.rstudio.com/>
- The Shiny Gallery provides simple to advanced examples, with code: <https://shiny.rstudio.com/gallery/>



## Peer-review options

### Peer-review for R software

R packages do not undergo peer review for CRAN and most other repositories. However, there are a few avenues for partial or full peer review of packages:

- *ROpenSci*: Includes the option for community-contributed packages. These undergo peer review through GitHub. The full source code is reviewed and comments must be addressed before the package is added to the ROpenSci repository
- *The Journal of Open Source Software*: Very short articles, peer review of code
- *The R Journal, Journal of Statistical Software*: Peer-review of articles, but may include some suggestion for software