Societal and Meteorological Impacts of Inland Moving Tropical Cyclones

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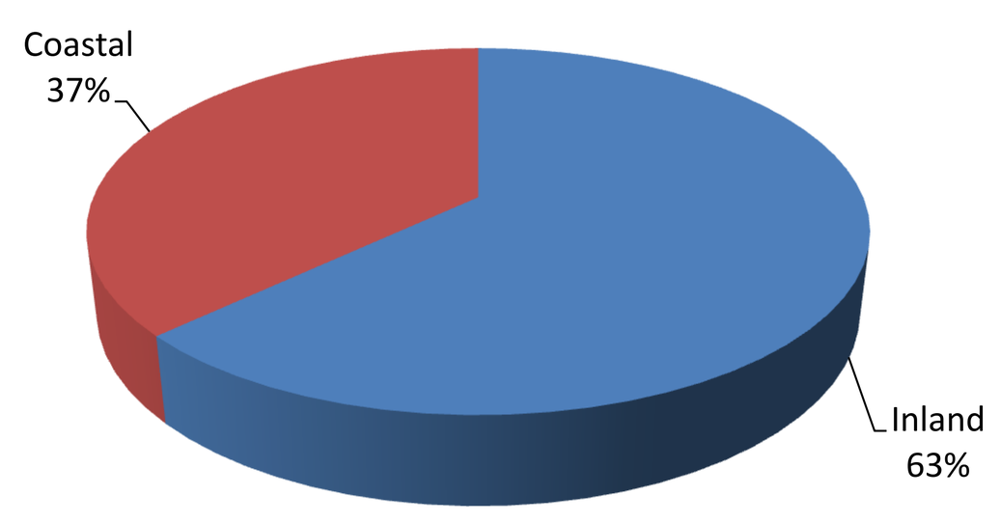
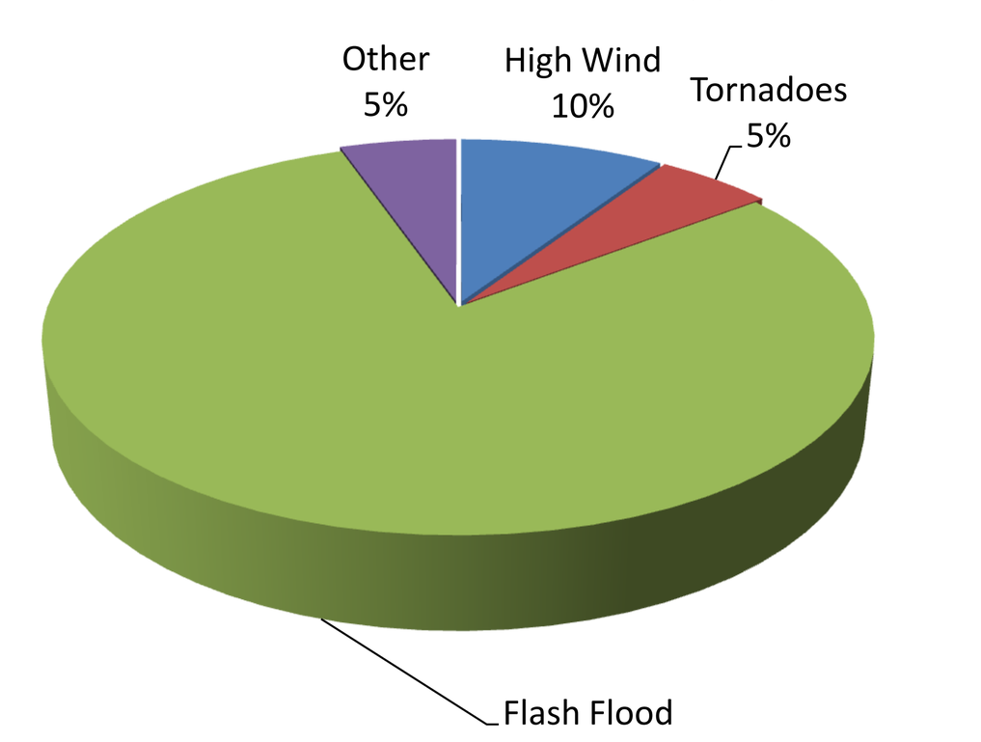
Background

- Numerous studies explore the relationship of coastal damage and hurricane strength or frequency. Few have explored these relationships in inland areas.
- Recent examples of storms with significant inland impacts include Ivan (2004), Floyd (1999), and Hugo (1989).
- Research by Kruk (2010) reveals that tropical storm force wind speeds occur every 2 to 5 years in inland communities in Carolinas northeastward through Virginia and in central Georgia and Alabama.
- These inland-moving tropical cyclones can also produce significant societal impacts, including 63% of all tropical cyclone related deaths from 1970-1999 (Rappaport 2000).
- Coastal vulnerability to tropical cyclones has lessened due in large part to progress in warning technology, evacuation procedures, and hurricane education. There remains a need to extend this same research and education to inland communities.



Tropical Cyclone Deaths from 1970-1999 in Inland or Coastal Counties (Data obtained from Rappaport 2000)



Inland Deaths from 1970-1999 related to Tropical Cyclone Impacts (Data obtained from Rappaport 2000)

Research Question

What are the meteorological effects and social impacts of inland moving tropical cyclones?

- Where do the meteorological effects (i.e. heavy precipitation, tornadoes, high wind) occur relative to the tropical cyclone track and position?
- What attributes of the cyclone and its large scale environment control the occurrence and magnitude of these effects?
- How do inland tropical cyclone and their associated meteorological effects shape societal impacts?

Example of inland flash flooding during Hurricane Floyd (1999) Photo Credit: FEMA

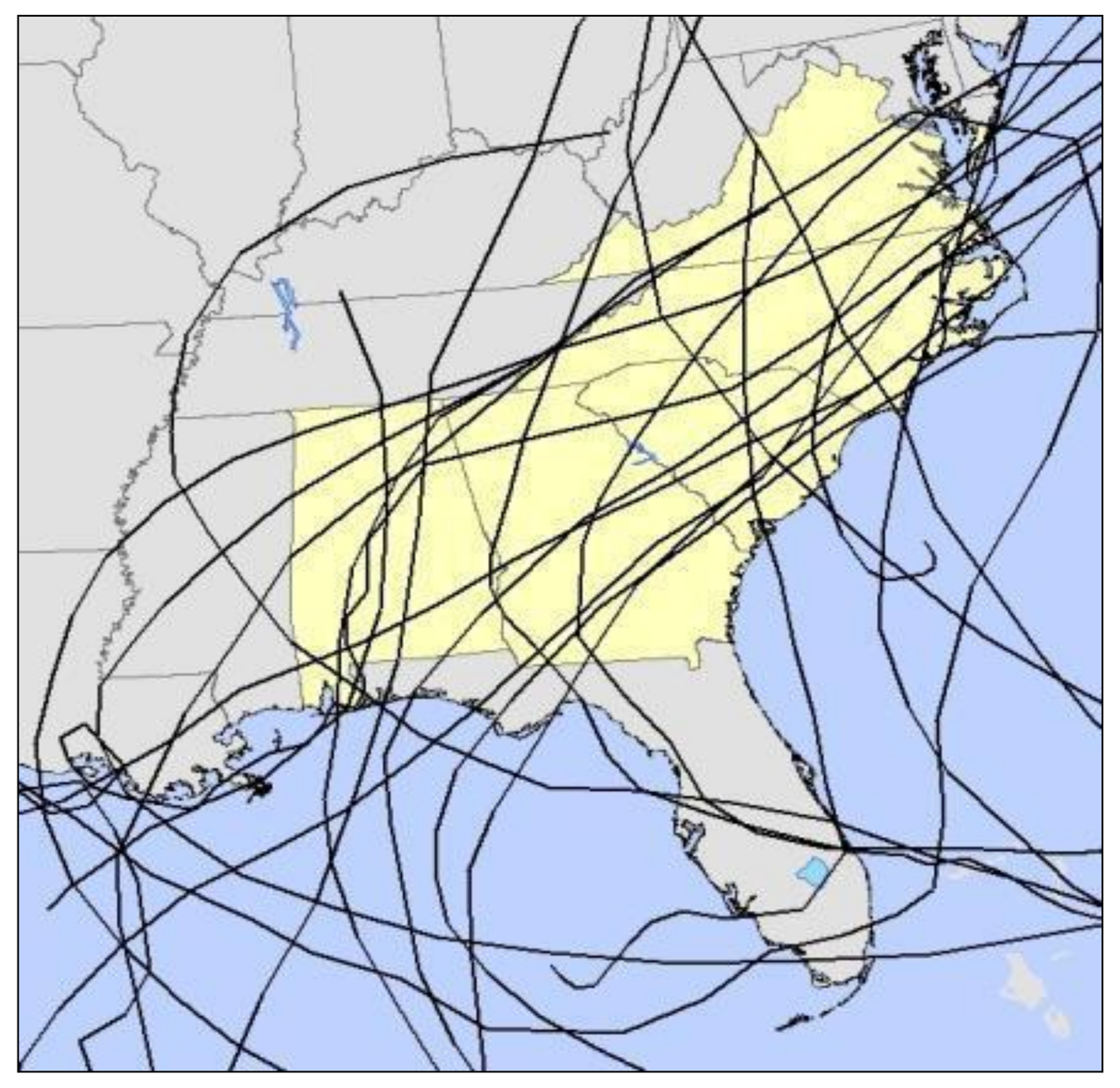
Methodology

Meteorological Effects

- 25 inland tropical cyclones were selected from 1985 – 2006
- Meteorological data was collected from first order weather stations and National Hurricane Center tropical cyclone reports.

Landfall	TS	Cat 1	Cat 2	Cat 3	Cat 4	Cat 5
Gulf	4	4	1	2	1	0
Atlantic	1	1	1	2	0	0
Florida	2	2	1	1	1	0

Table 1: Intensity and location of land falling tropical cyclones in the study.



Tracks of tropical cyclones examined in the study

Sources of Data on Societal Impacts

- NOAA's Storm Events Data
- Urban Newspaper Sources
  - Raleigh-The News and Observer 01/01/1991
  - Macon—The Macon Telegraph 07/01/1994
  - Columbia—The State 12/01/1987
  - Birmingham—The Birmingham News 04/27/1993
  - Huntsville—The Huntsville Times 11/02/1991
  - Atlanta—The Atlanta Journal Constitution 01/01/1985
  - Richmond—The Richmond Times Dispatch 08/19/1985
  - Roanoke—The Roanoke Times 01/03/1990
  - Charlotte—The Charlotte Observer 01/01/1985
  - Greensboro—The News & Record 01/01/1990
  - Spartanburg—The Herald Journal 08/01/1998
  - Anniston—The Anniston Star 05/18/1987
  - Talladega—The Daily Home 08/26/1998
  - Athens—The Athens Banner 01/01/1999
  - Augusta—The Augusta Chronicle 01/01/1994
  - Columbus--Columbus Ledger Enquirer 01/01/1993
  - Fayetteville—The Fayetteville Observer 01/01/1988
  - Winston-Salem—The Winston-Salem Journal 11/1/1997
  - Durham—The Herald Sun 01/01/1995
  - Norfolk –The Virginian Pilot 04/01/1990

Newspaper locations used in the study area

Impact Categories

Deaths/Injuries , Power outages, Infrastructure Damage, Economic costs/lost, Economic benefits/gains, Cancellations of events, Environmental Damage, Agriculture Impacts

Methodology (Continued)

GIS employed to estimate the following:

Impact occurrence relative to the track at the **time** of occurrence
- Direction of movement at impact occurrence

Impact occurrence relative to cyclone track
- Right or Left of Track?
- Direct Distance from impact to track (km)

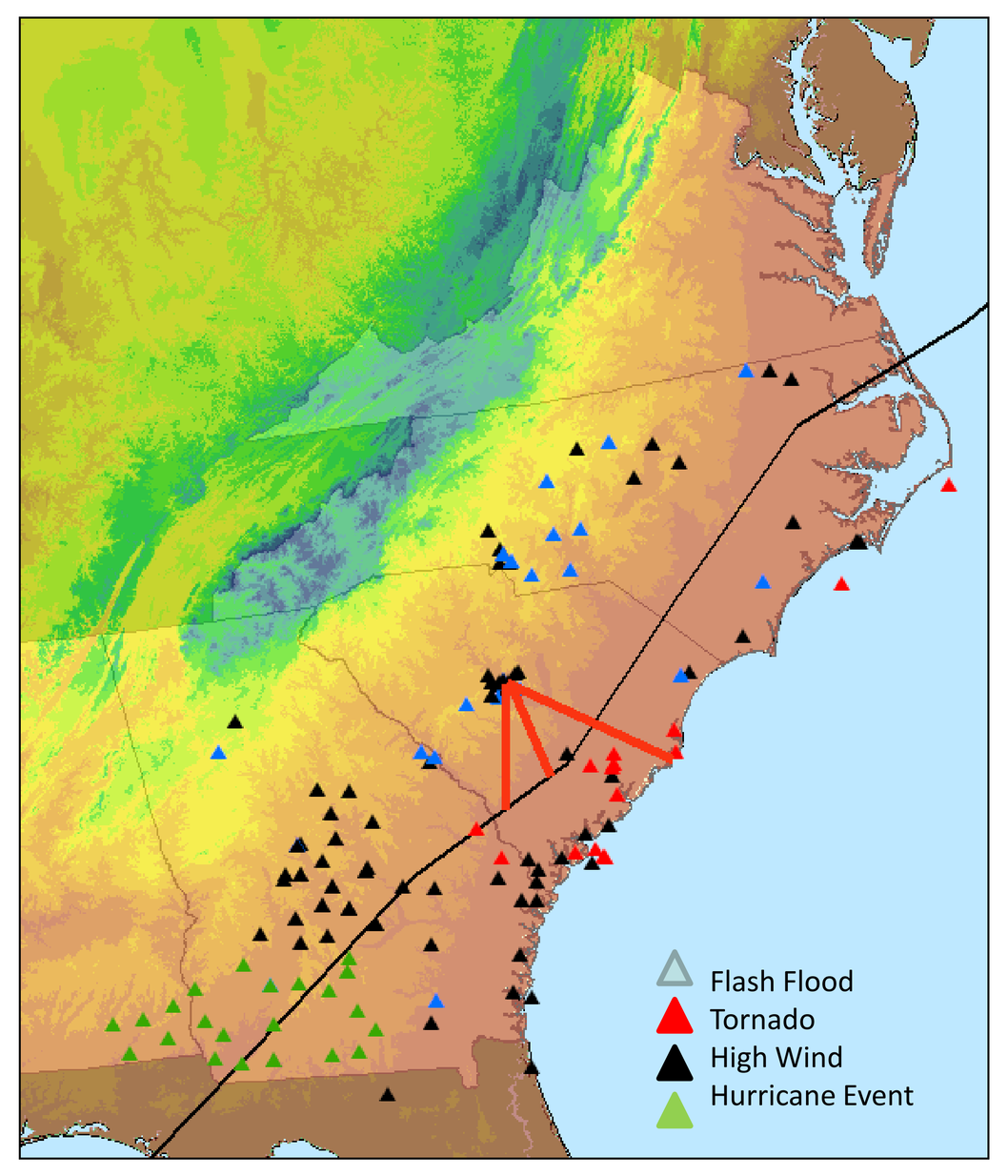
Distance from Coastline to Impact

Impact location relative to the cyclone at landfall
- Gulf or Atlantic coast
- Direction of movement

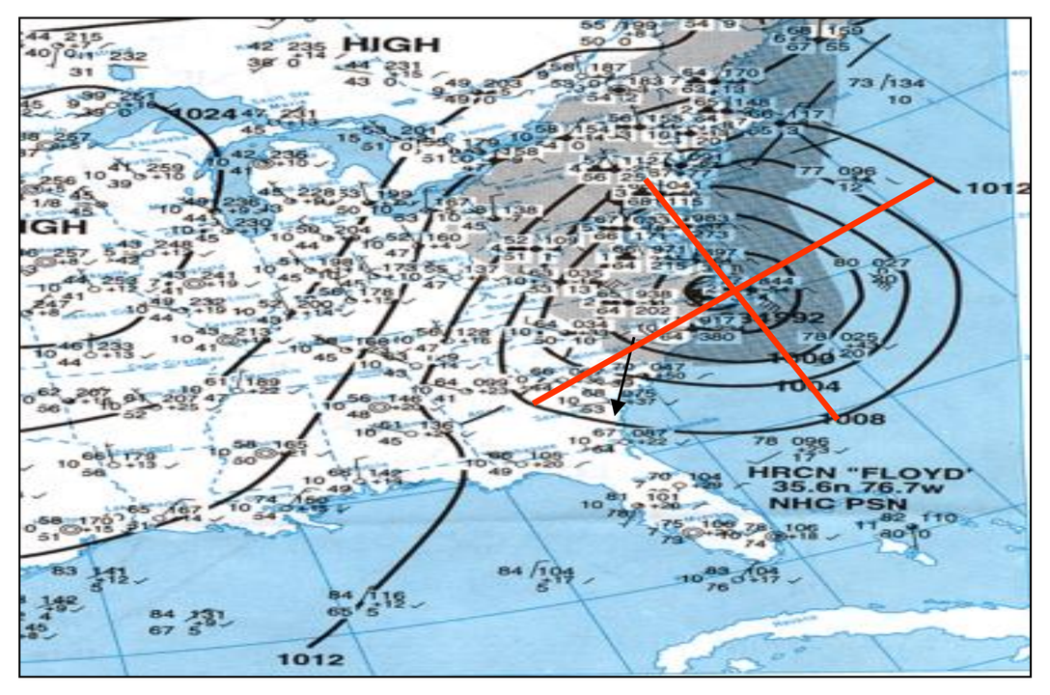
Size of cyclone
- Area inside outermost closed isobar

Cyclone Strength (maximum sustained winds)
- Strength of storm when damage occurred
- Strength of storm at landfall
- High wind maps

Cyclone Speed of movement
- National Hurricane Center's HURDAT database to track hourly locations

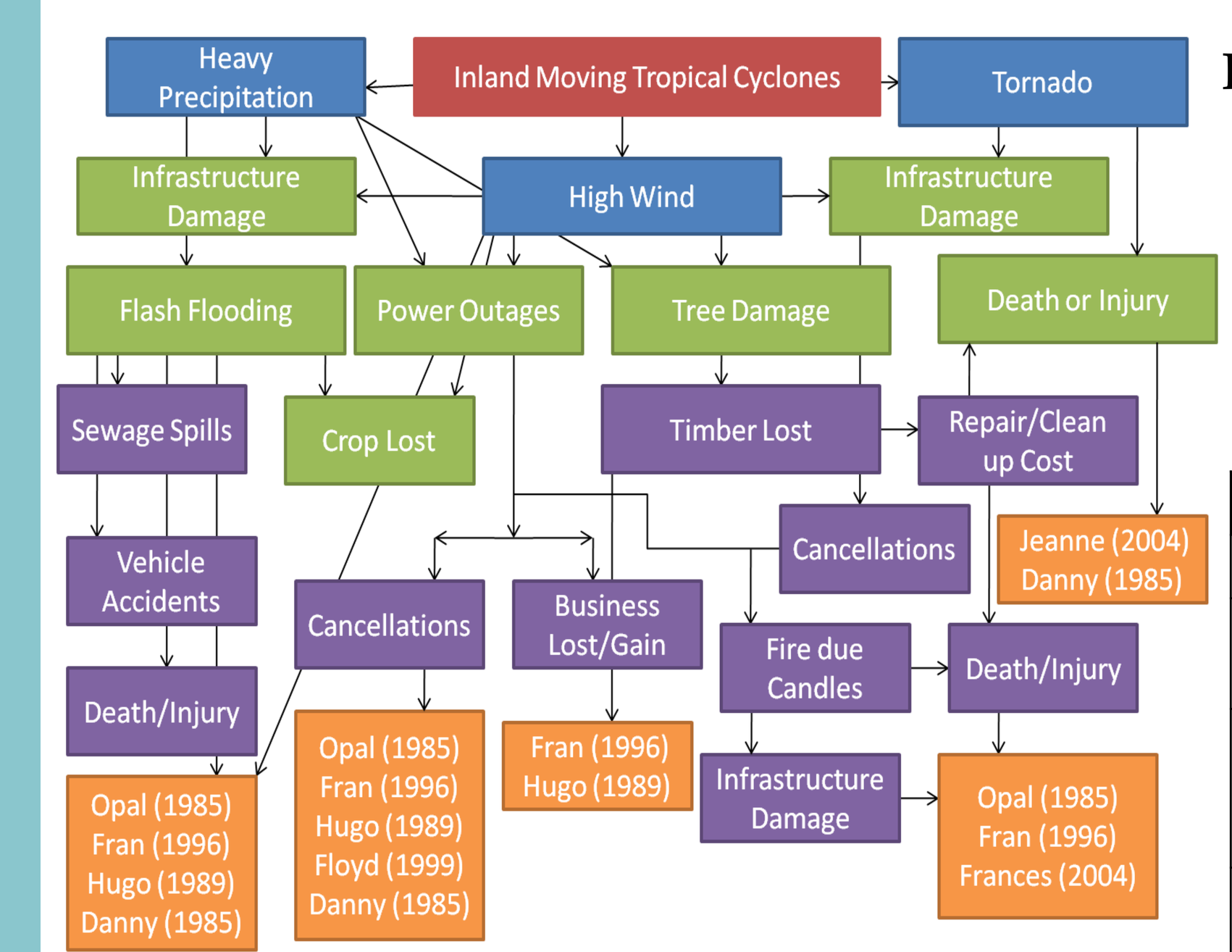


Measurements of Impacts relative to cyclone track of Hurricane Earl (1998)



Measurements of the outermost isobar of Hurricane Floyd (1999)

Societal Impacts of Inland Moving Tropical Cyclones



Impacts are extremely interconnected.

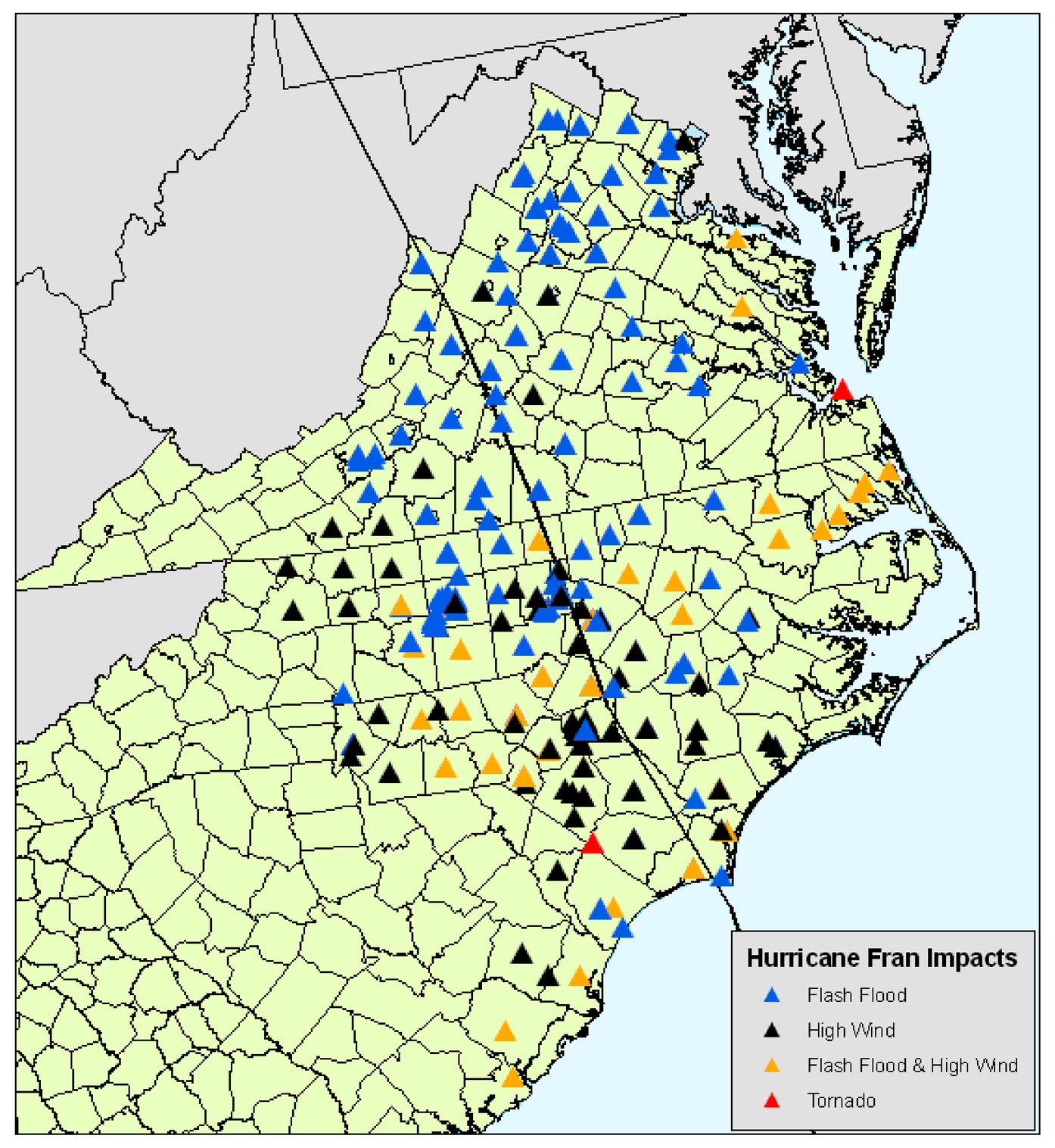
Impacts, such as power outages, can have widespread effects, including indirect deaths from fire or carbon monoxide poisoning, missed public school days and spoiled food.

Inland tropical cyclones cause extensive damage and economic lost. However, certain sectors benefit from such storms. Notable examples include Fran (1996), Kate (1985), Hugo (1989),Opal (1995), Frances (2004), Katrina (2005)

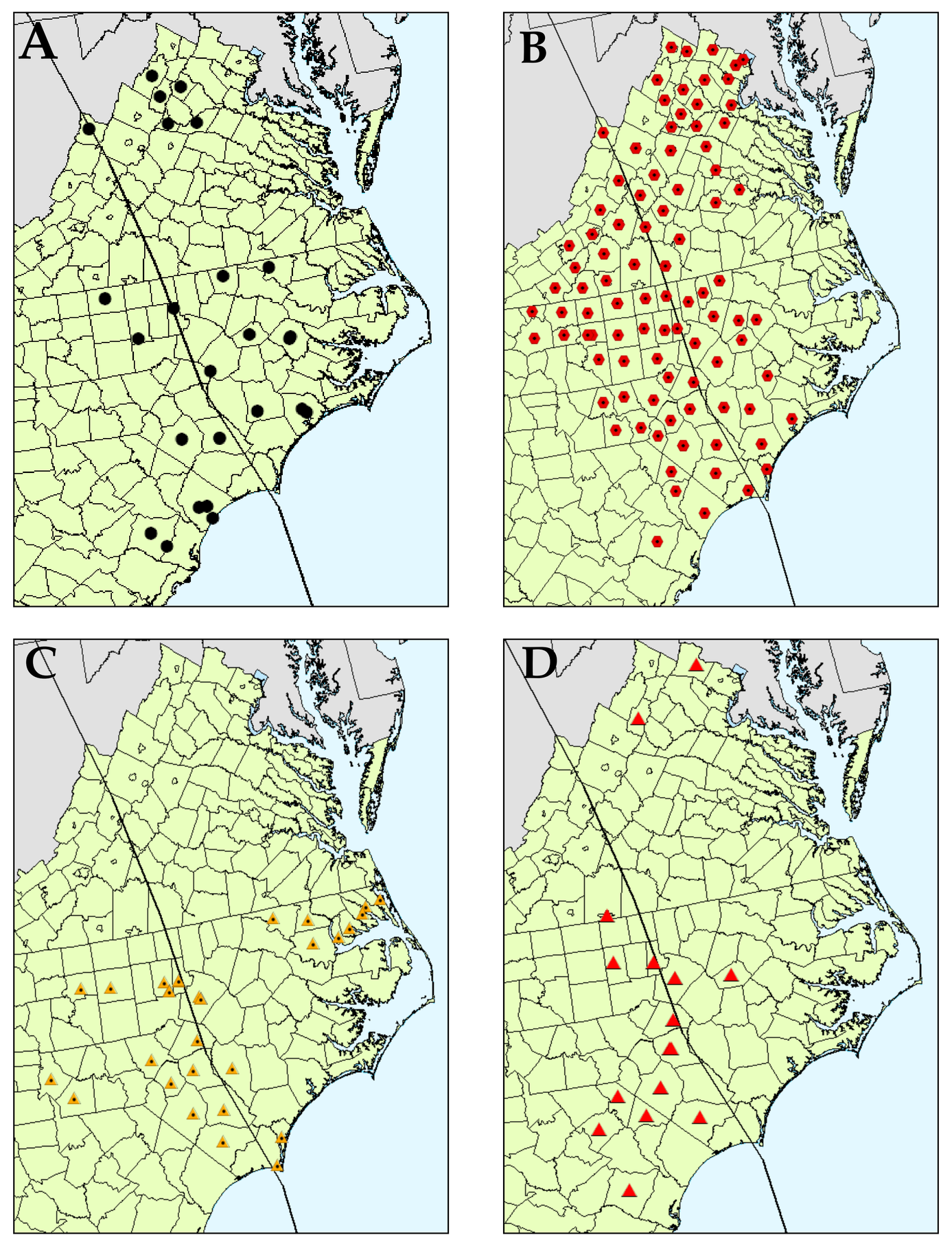
Economic Benefits	Economic Losses
Auto repair companies	Timber lost
Significant precipitation for crops	Crop or agriculture lost
Increased hotel occupancy with coastal evacuations or people without electricity	Loss of species habitat with significant tree destruction
Restaurants and local businesses (with electricity)	Infrastructure damage due to flooding, fire, tornado or wind
Tree and landscaping companies	Loss of business due to widespread power outages
Roofing companies	Sewage spills
Hardware or Grocery Stores	Transportation problems with flooded or down trees
Fishing reports	Increased bug activity

Table 2: Economic losses and benefits of tropical cyclones for inland communities

Societal Impacts of Hurricane Fran (1996)



The distribution of high wind or flash flood or tornado impacts (triangles) relative to the track of Hurricane Fran (1996)

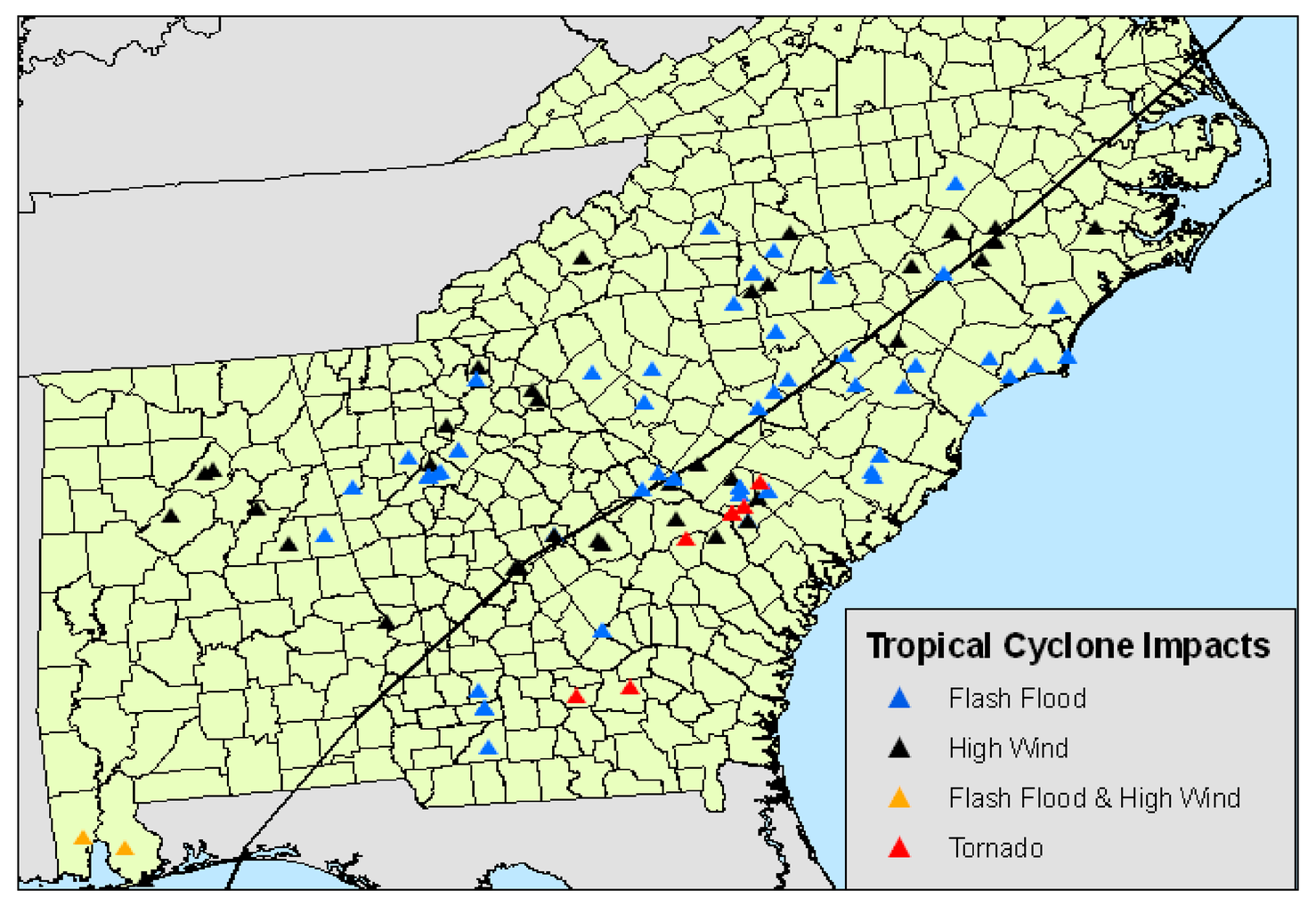


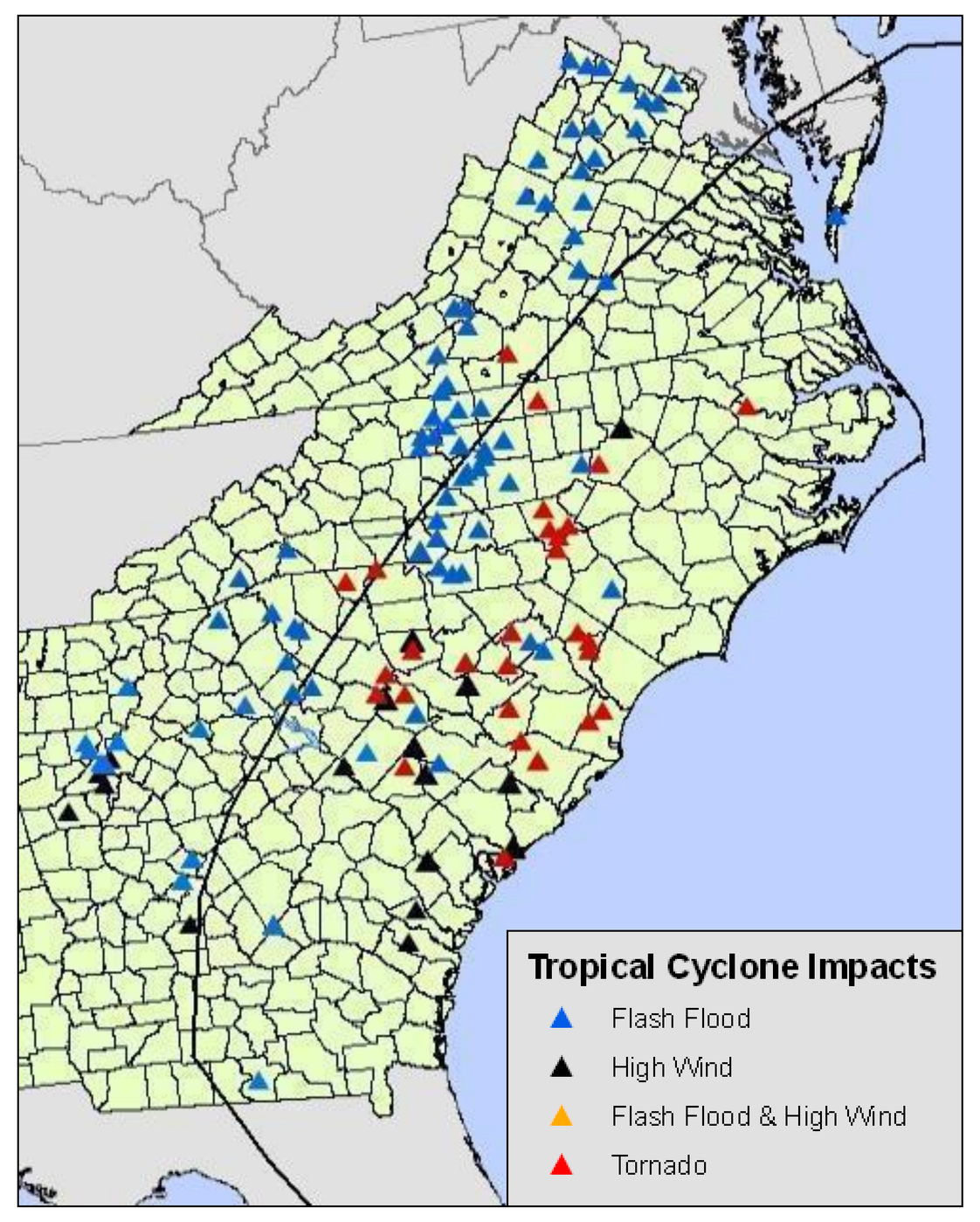
Impacts for Hurricane Fran (1996) categorized as Indirect or Direct Deaths (A) Agriculture (B) Power Outages (C) and Injuries (D)

Spatial Distribution of the Impacts

Weaker Cyclones, like **Helene (2000),** have a more sporadic pattern of impacts relative to stronger cyclones, such as **Jeanne (2004).**

Tropical Storm Helene (2000)



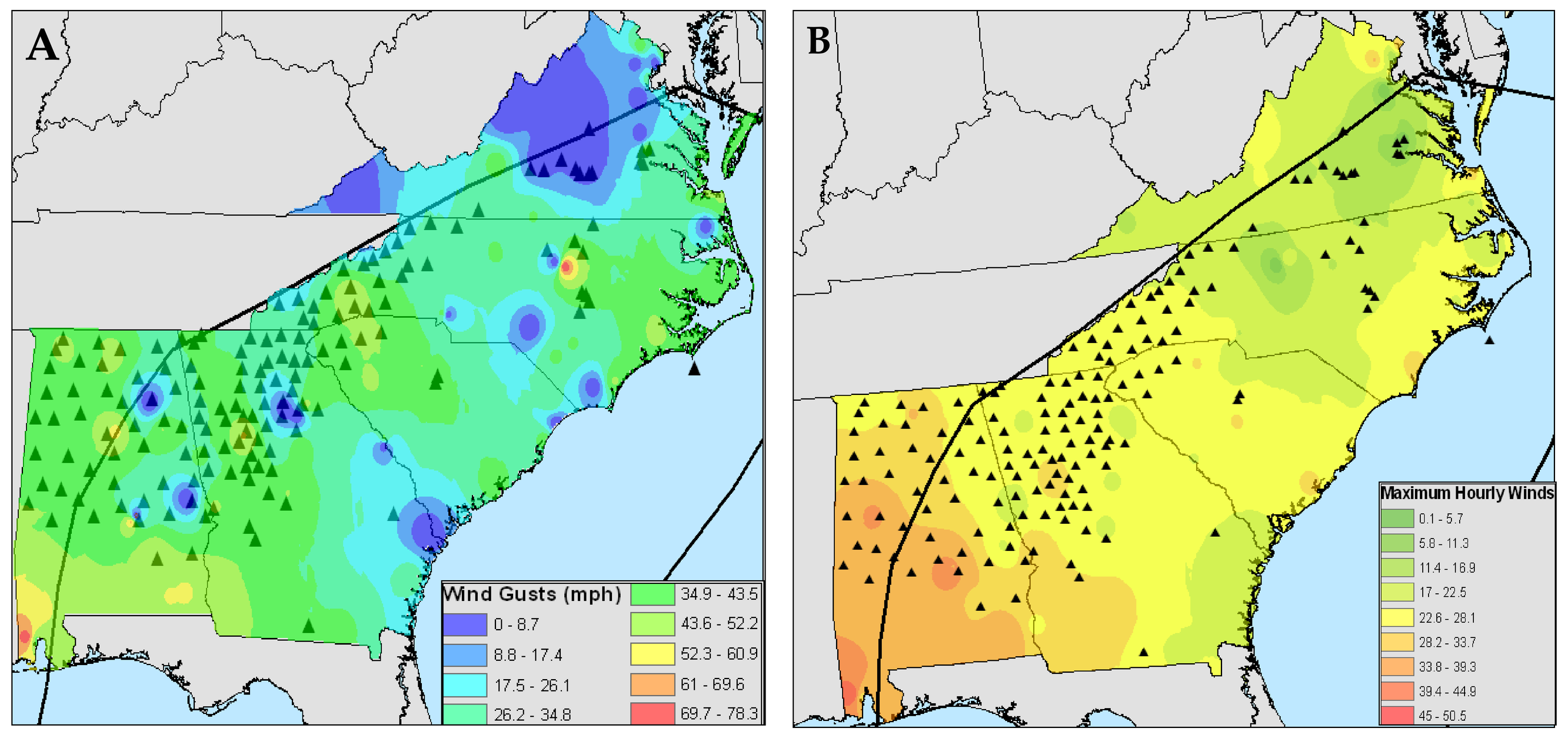


Hurricane Jeanne (2004)

- **Tornadoes** are concentrated in the right forward quadrant.
- High winds observed in stronger storms, such as **Hurricane Jeanne (2004),** and are also concentrated in the right forward quadrant.
- **Heaviest Precipitation** generally occurs along the cyclone track but may spread across the left forward quadrant when the cyclone is undergoing extra tropical transition.

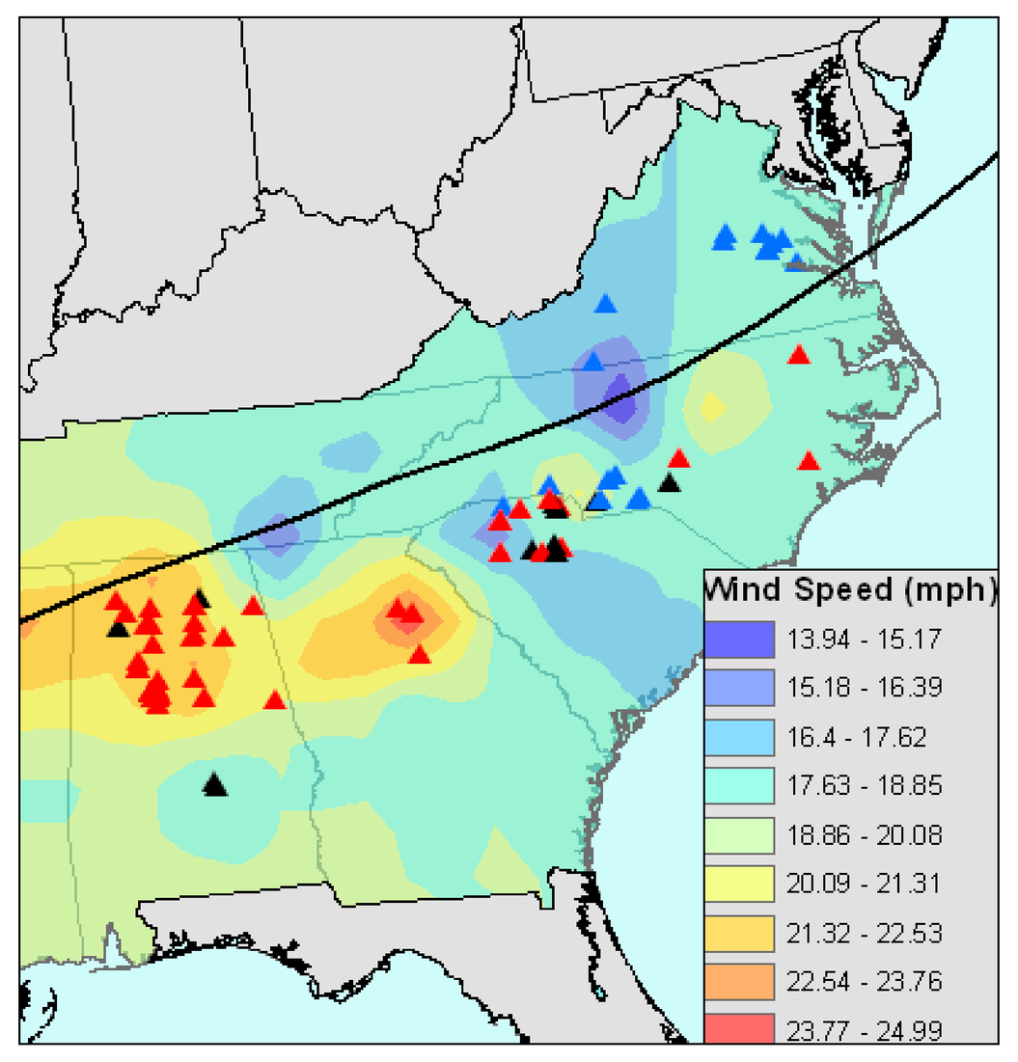
High Wind Maps

Peak sustained winds and wind gusts were mapped for each tropical cyclone and classified into 4 categories: Core winds (strong sustained winds near the track), peripheral winds (weaker winds either farther inland or a greater distance from the track), convective outflow winds from spiral bands, and winds influenced by topographic funneling .



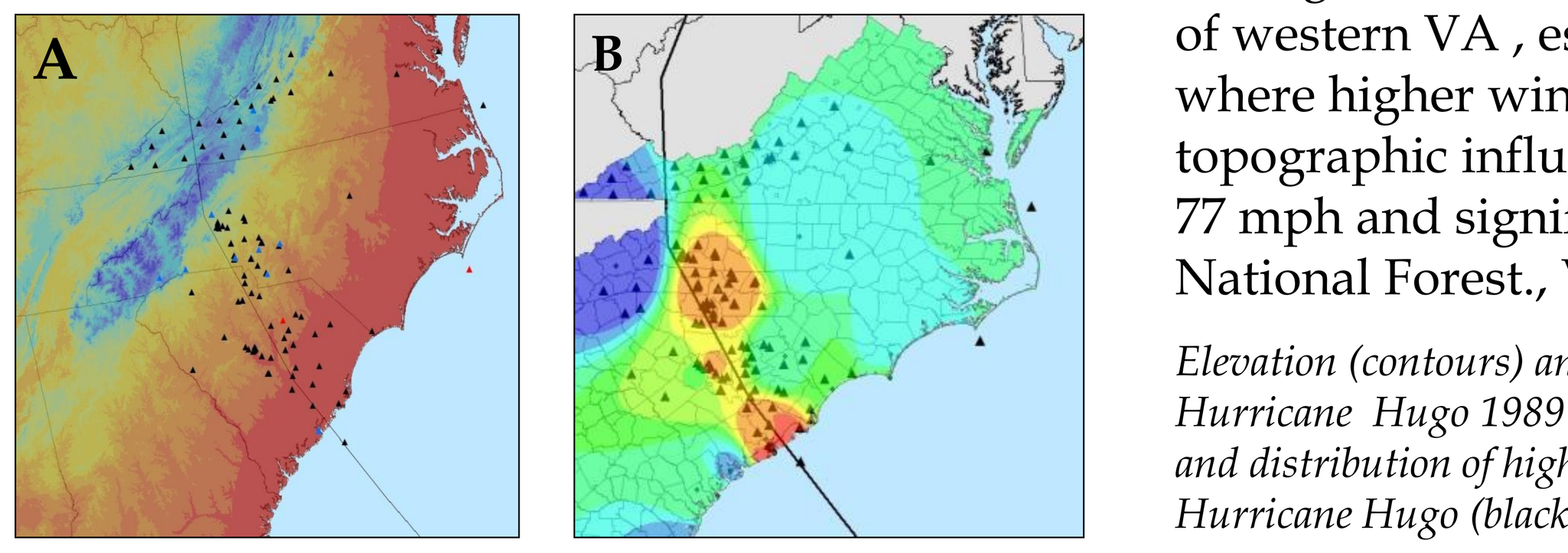
Peak wind speeds (A) or winds at the top of the hour (B) (contours) and distribution of high wind (triangles) relative to the track of Hurricane Ivan (black line).

Hurricane Ivan (2004) created significant spiral band convective outflow winds (79.4 mph) in the Raleigh, NC area causing unexpected damage to airplanes, roofs, and trees.



Maximum Winds at the top of the hour and the distribution of impacts (triangles) relative to the track of Hurricane Danny (1985)

Maps were constructed from available weather information. Storms, earlier in the study period, such as **Danny (1985),** have limited data, with winds only available at the top of the hour. More recent storms have data available for both peak wind gusts and maximum hourly wind data. Both variables were constructed to illustrate relationships between wind, impacts and the cyclone track.



Hurricane Hugo (1989) produced widespread wind damage along it's entire track. Wind damage was observed across a broad area of the of western VA , especially the higher elevations, where higher winds aloft coupled with topographic influences caused wind gusts up to 77 mph and significant timber lost in Jefferson National Forest., VA.

Elevation (contours) and associated wind impacts from Hurricane Hugo 1989 (A) and peak wind speeds (B) (contours) and distribution of high wind (triangles) relative to the track of Hurricane Hugo (black line).

References:

Kruk, M. C., Gibney, E. J., Levinson, D. H., & Squires, M. (2010). A climatology of inland winds from tropical cyclones for the eastern united states. *Journal of Applied Meteorology & Climatology, 49*(7), 1538-1547. doi:10.1175/2010JAMC2389.1

Rappaport, E. N. (2000). Loss of life in the united states associated with recent Atlantic tropical cyclones. *Bulletin of the American Meteorological Society, 81*(9), 2065. Retrieved fromhttps://auth.lib.unc.edu/ezproxy_auth.php?url=http://search.ebscohost.com/login.aspx?direct=true&db=aph&AN=3736823&site=ehost-live&scope=site