



Societal impacts of inland moving tropical cyclones across the southeastern U.S

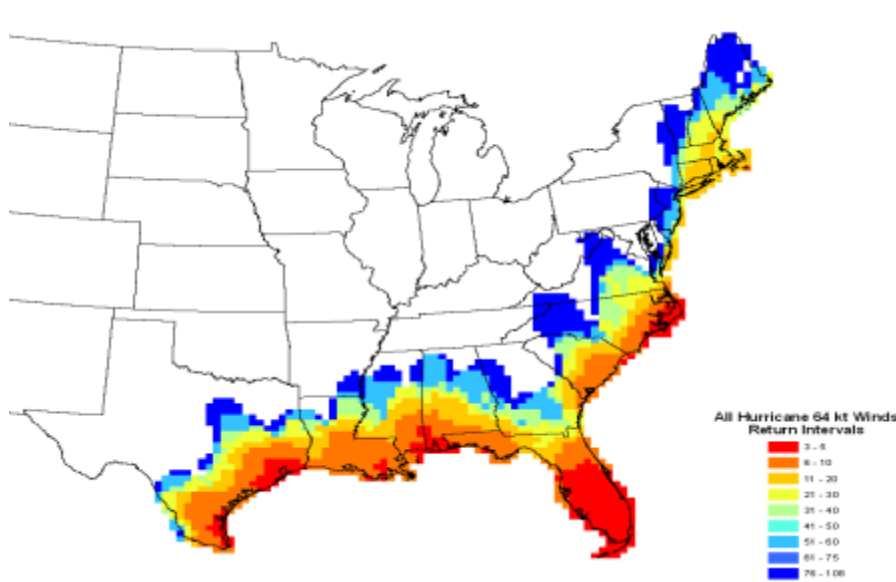
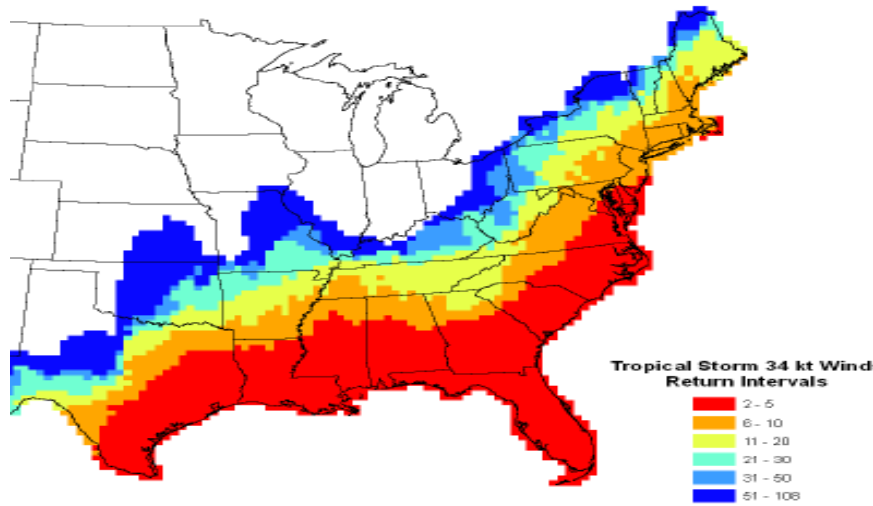
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Outline

- Background
- Description of data sources and methodology
- Preliminary Results
 - Location of Damage relative to cyclone track
 - Societal Impacts of cyclone
- Present and Future Work

Background – High Winds

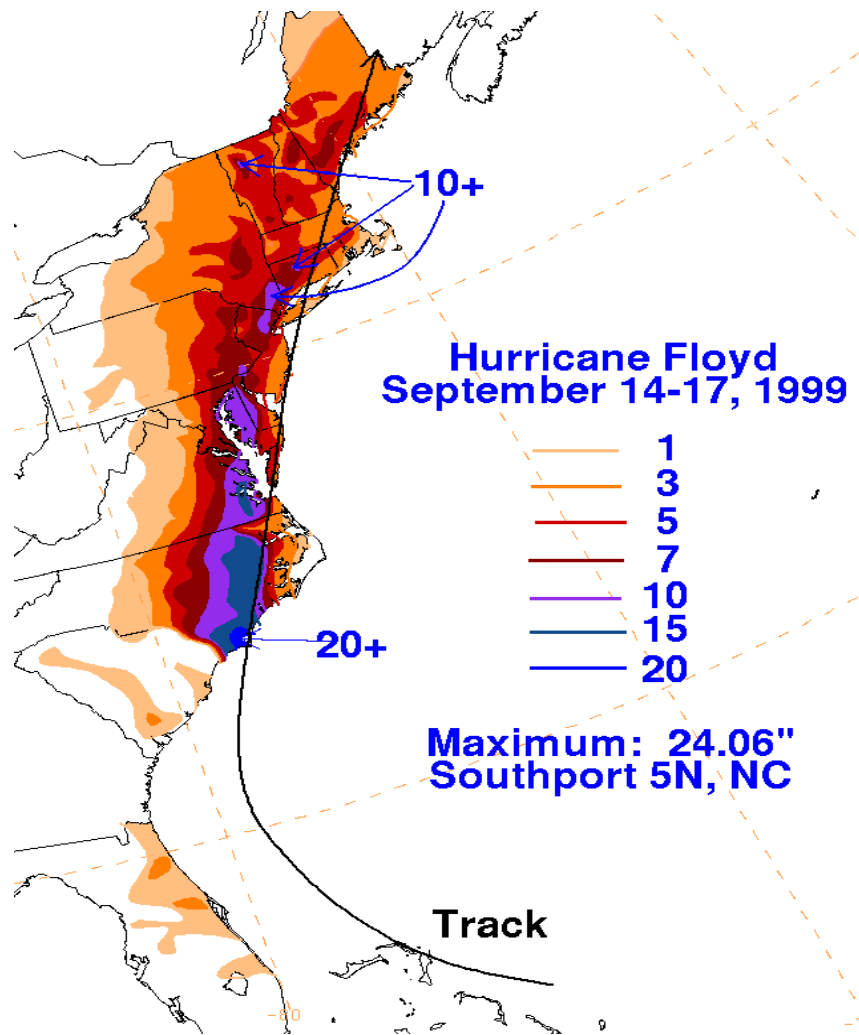


Risk of Inland locations to Atlantic Tropical Cyclones

- Significant high winds from tropical cyclones occur regularly within inland locations
 - Return intervals of 2 –6 years
- Hurricane strength winds occur less often with return intervals in range of 11 years to 100 years
- The most favored areas include Carolinas northeastward through Virginia and into New England.

Return Interval for tropical storm winds greater than 34 kt (top) Return interval for hurricane strength winds greater than 64 kt (bottom) (Kruk et al 2010)

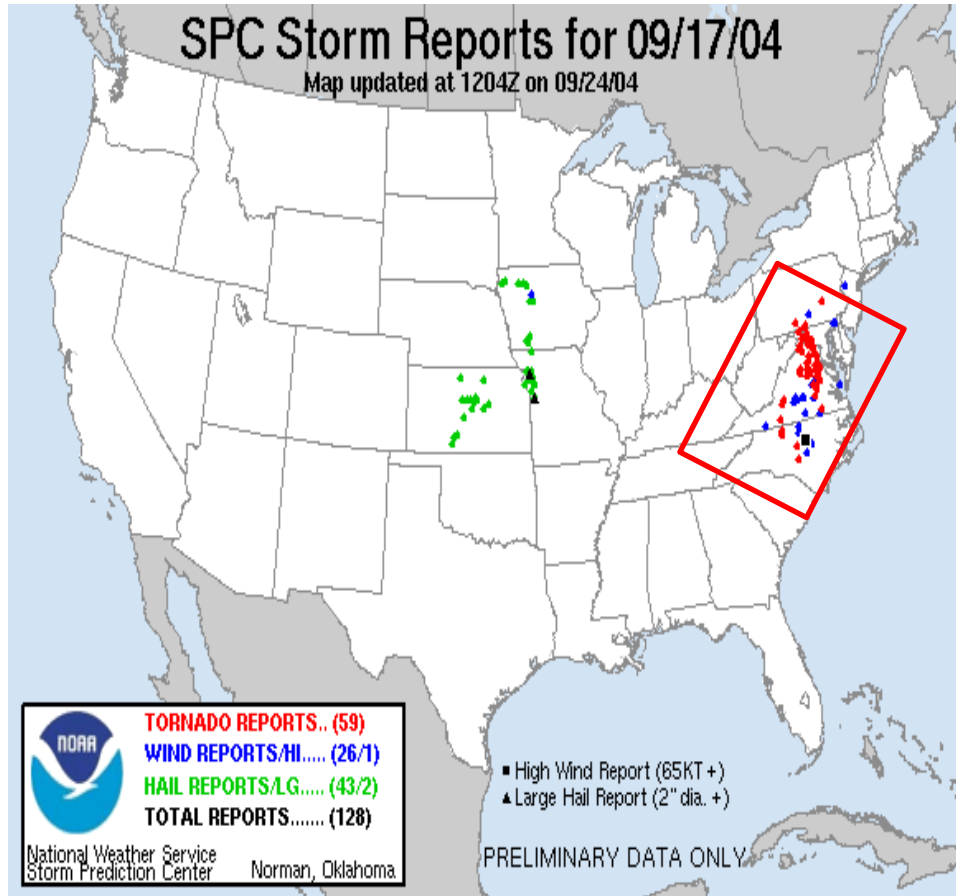
Background – Heavy Precipitation



Risk of Inland locations to Atlantic Tropical Cyclones

- Hurricane Floyd (1999)
- Spatial pattern of rain is highly variable for each storm
 - Dependent on size and speed of movement
- Spatial pattern and intensity of rainfall is also influenced by extratropical transition

Background – Tornadoes



Hurricane spawned Tornadoes during Hurricane Ivan (2004)

Risk of Southeast US to tornadoes associated with tropical cyclones

- Most favorable region of a tropical cyclone for tornadoes is the northern to eastern quadrants.
- Many tornadoes are related to intense, persistent cells within the outer rain bands.
- Hurricane spawned tornadoes account for 10% of all tropical cyclone fatalities
- Hurricane Ivan (2004)
 - Over a 3 day period 119 hurricane spawned tornadoes occurring from Florida to West Virginia

Background - Impacts



*Geographic distribution of tropical cyclones deaths during 1970-1999
(Rappaport 2000)*

Societal Impacts from Tropical Cyclones can extend far Inland

- Of the total inland and coastal deaths, 63% occurred within inland counties.
- Strong wind accounted for approximately 10% of inland deaths.
- Freshwater flood account for 79 % of inland deaths, mostly attributable to driving on flooded roads and child drowning.

Research Question

Where do damaging winds, tornadoes, and floods occur **relative to the track** of an inland moving tropical cyclone and what **attributes** of the tropical cyclone and its **large scale environment** control the occurrence and magnitude of this damage?

-Where do different types of damage occur relative to the tropical cyclone track and location?

-What attributes of the cyclone control the magnitude and nature of the damage inland?



Study Area



Tropical cyclones associated with any societal impacts in the inland portion of the region

Data

Sources of Data on Societal Impacts

- NOAA's Storm Events Data
- Urban Newspaper Sources
 - Raleigh—The News and Observer 01/01/1991--Present
 - Macon—The Macon Telegraph 07/01/1994—Present
 - Columbia—The State 12/01/1987--Present
 - Birmingham—The Birmingham News 04/27/1993—Present
 - Huntsville—Huntsville Times 11/02/1991--Present
 - Atlanta—The Atlanta Journal Constitution 01/01/1985--Present
 - Richmond—The Richmond Times Dispatch 08/19/1985--Present
 - Charlotte—The Charlotte Observer 01/01/1985--Present
 - Greensboro—The News & Record 01/01/1990--Present
 - Spartanburg—The Herald Journal 08/01/1998--Present



Data - Categorization

Impact Categories

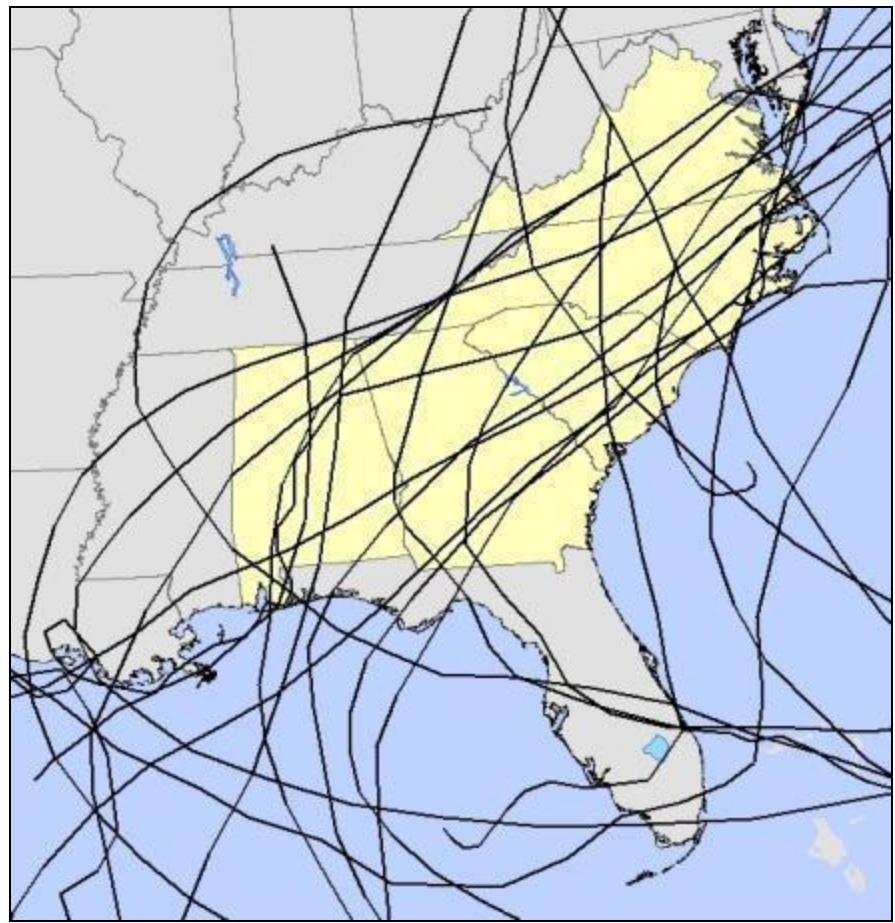
- **Deaths/Injuries**
 - Direct: High Winds, Precipitation events, flooding
 - Indirect: Carbon Monoxide, Repair and Clean Up, Power outages, Other
- **Power outages**
- **Infrastructure Damage**
 - High Winds, Fire/Power outages, Flooding
- **Economic costs/lost**
- **Economic benefits/gains**
- **Cancellations of events**
- **Environmental Damage**
- **Agriculture Impacts**
 - Crop Loses, Crop Gains, Timber lost



Methodology – Tropical Cyclone Tracks

25 inland tropical cyclones were selected from 1985 – 2006

Landfall	TS	Cat 1	Cat 2	Cat 3	Cat 4	Cat 5
Gulf	7	4	0	1	2	0
Atlantic	0	1	1	1	1	0
Florida	2	2	1	1	0	1



25 tropical cyclone tracks within study area

Methodology (continued)

1.) Impact occurrence relative to the track at the time of occurrence

a.) Direction of movement (radial angular measurements)

2.) Impact occurrence relative to cyclone track

a.) Right or Left of Track?

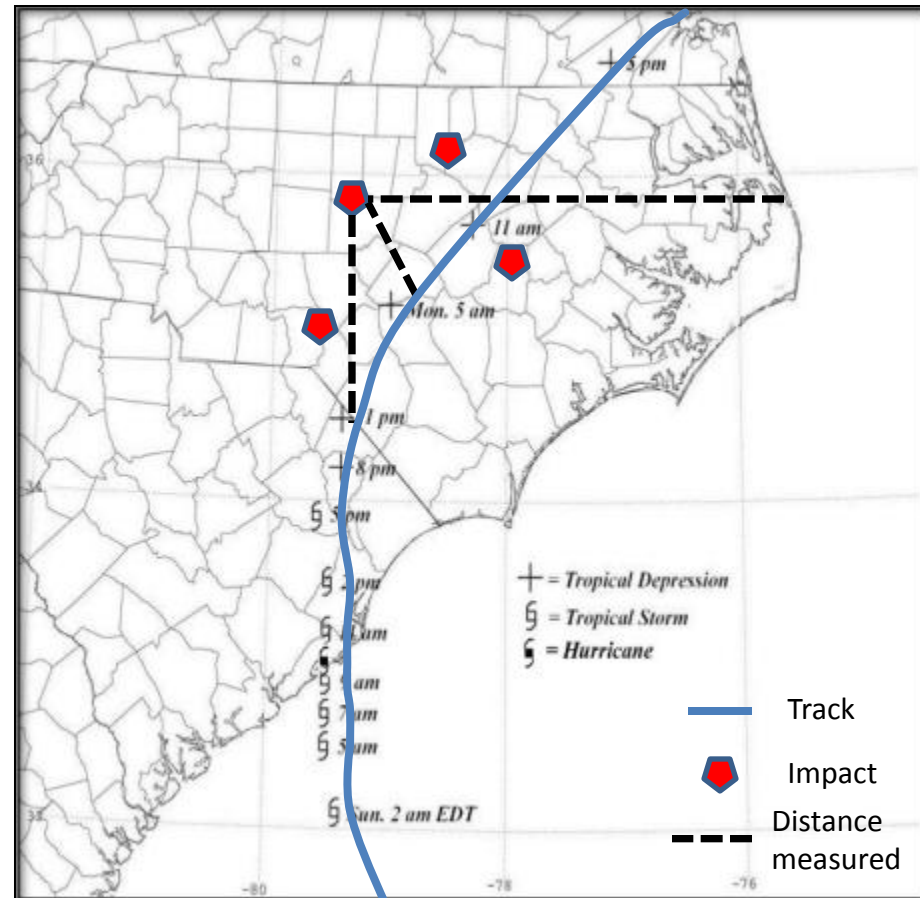
b.) Direct Distance from impact to track (km)

3.) Distance from Coastline to Impact

4.) Impact location relative to the cyclone at landfall

a.) Gulf or Atlantic coast

b.) Direction of movement (radial angular measurements)

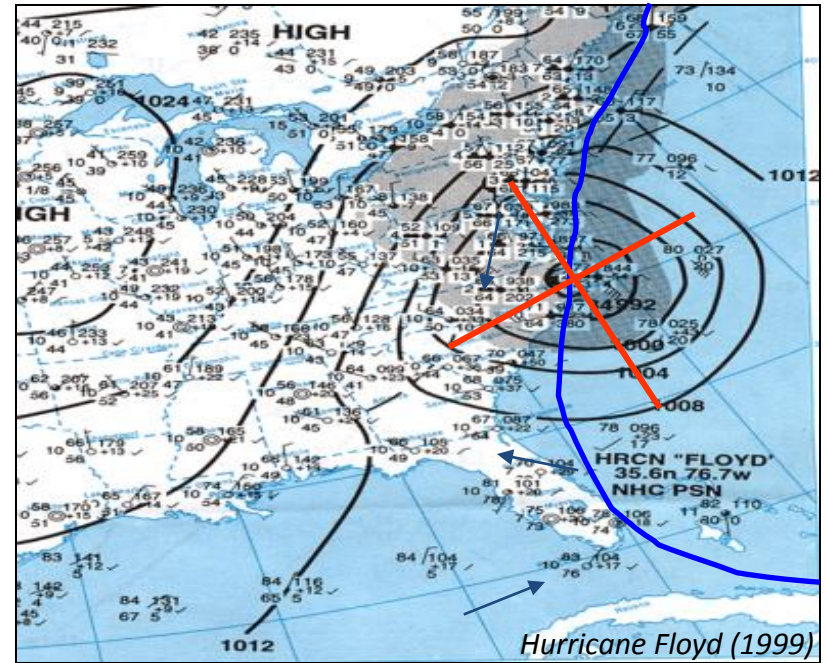


Hurricane Gaston (2004)

Methodology (continued)

5.) Size of cyclone

- a.) Area inside outermost closed isobar -See Konrad et al (2001)



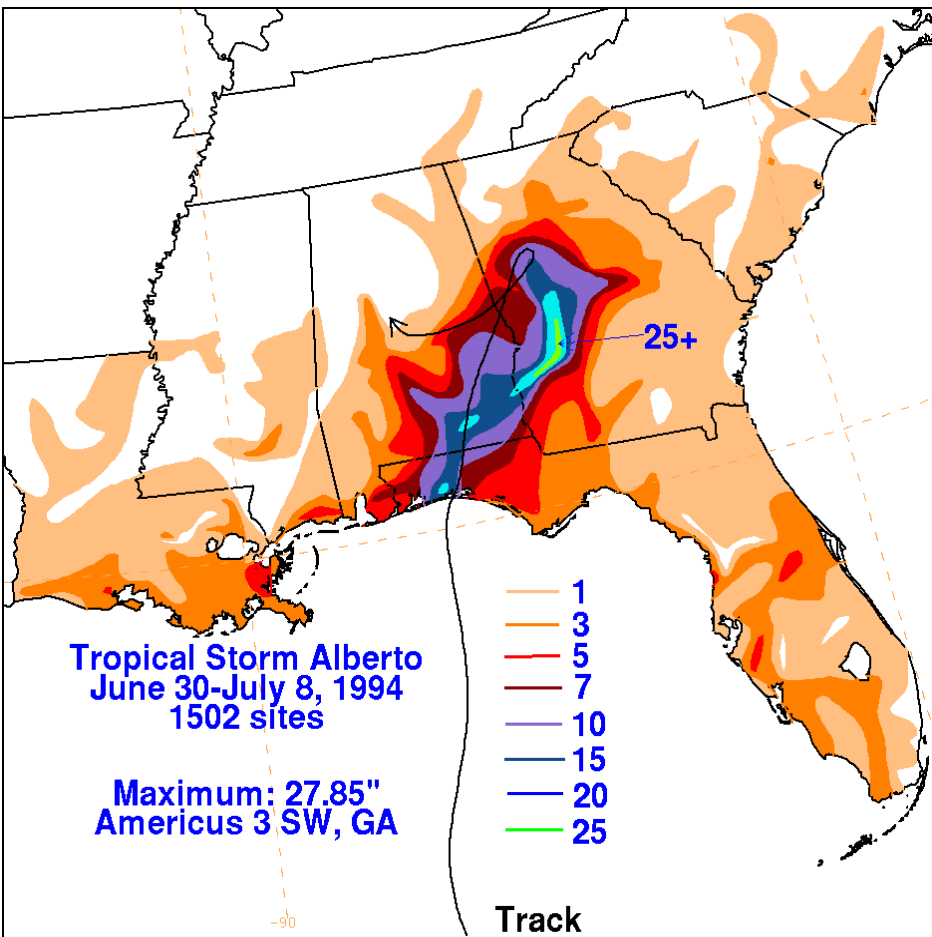
6.) Cyclone Strength (maximum sustained winds)

- a.) Strength at hour in which each damage report made
- b.) Strength at landfall



Methodology (continued)

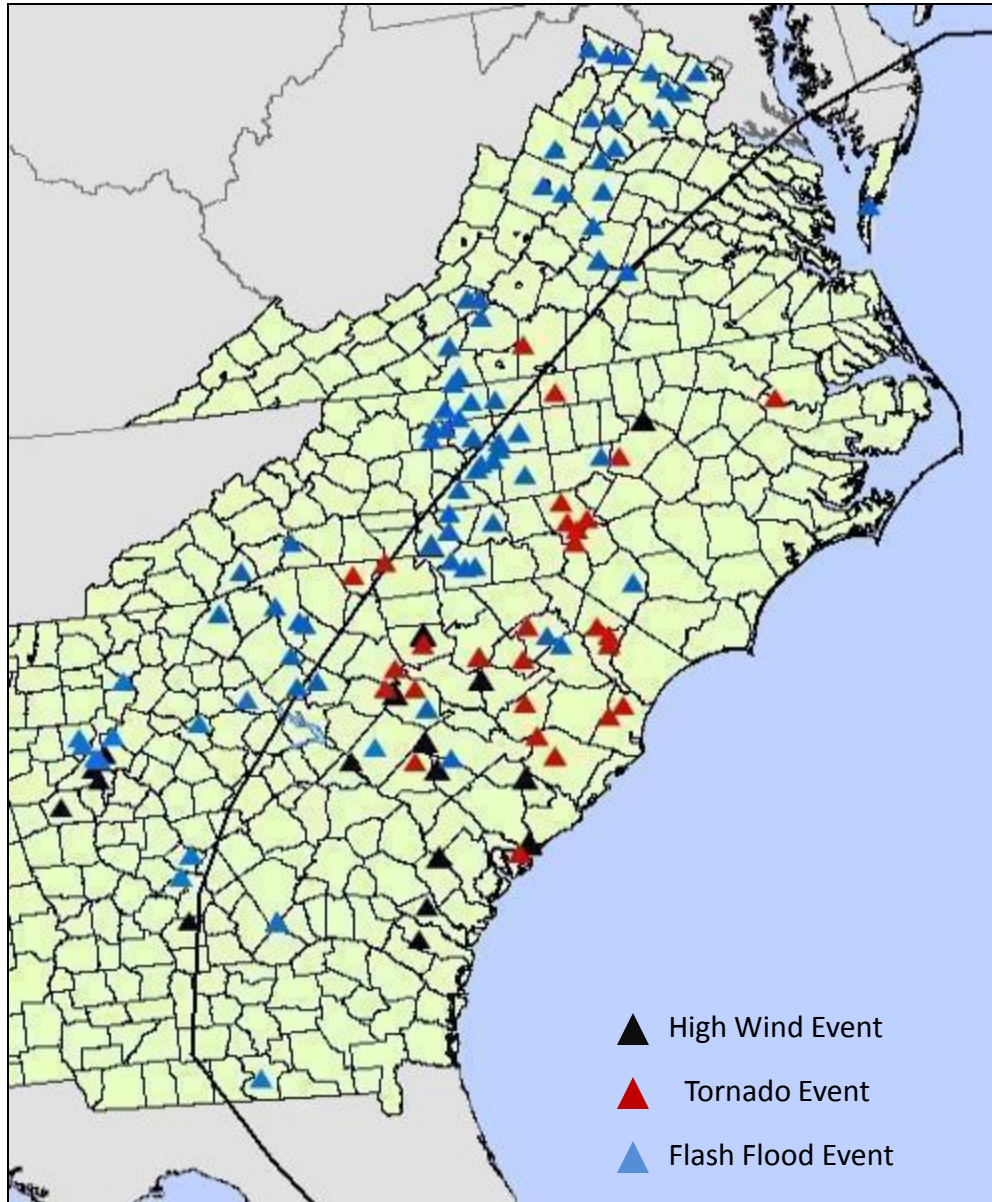
7.) Cyclone Speed of movement a.) NHC HURDAT database



Tropical Storm Alberto (1994)

<http://www.hpc.ncep.noaa.gov>

Preliminary Results – Hurricane Jeanne



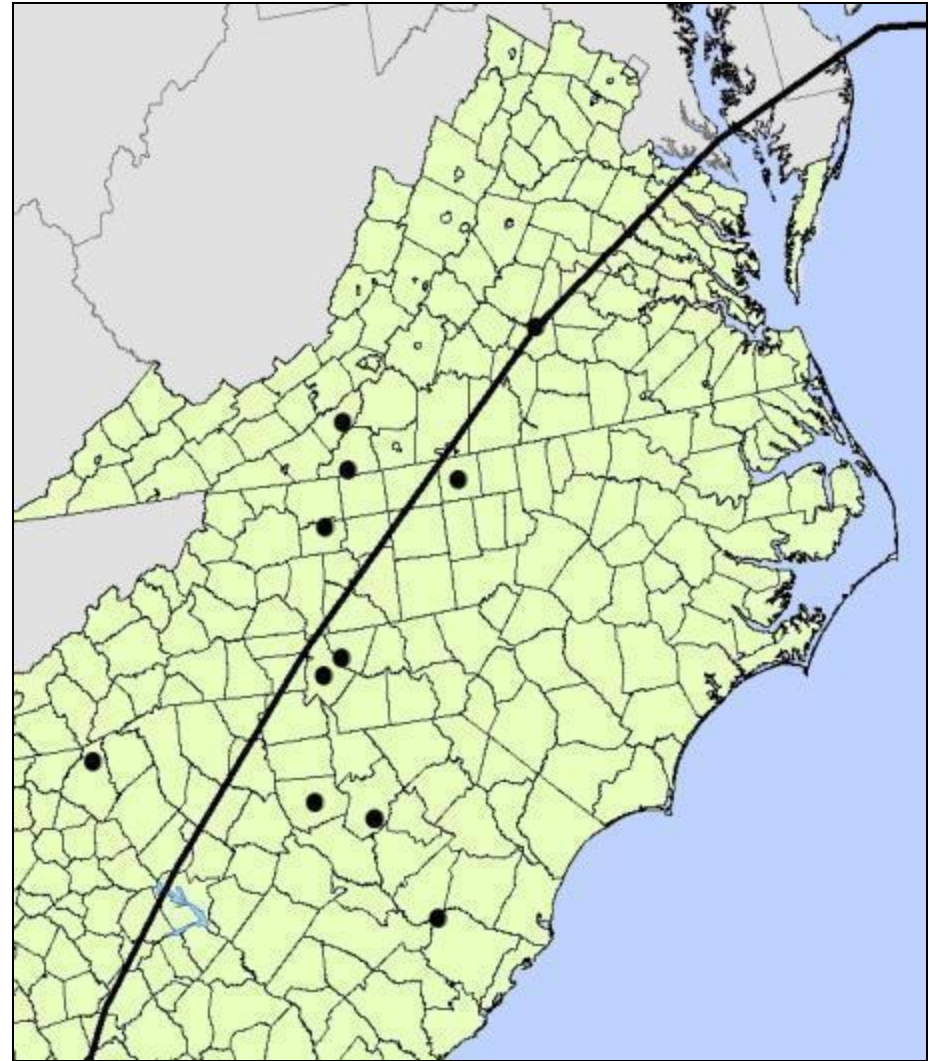
Graphical Representation of Hurricane Jeanne's (2004) societal impacts (divided into high wind, tornado and flash flood events)

- Tornado and high wind events occur earlier in storm track
 - Right side track
- Flash Flood events occur later in storm track
 - Both right and left side of track

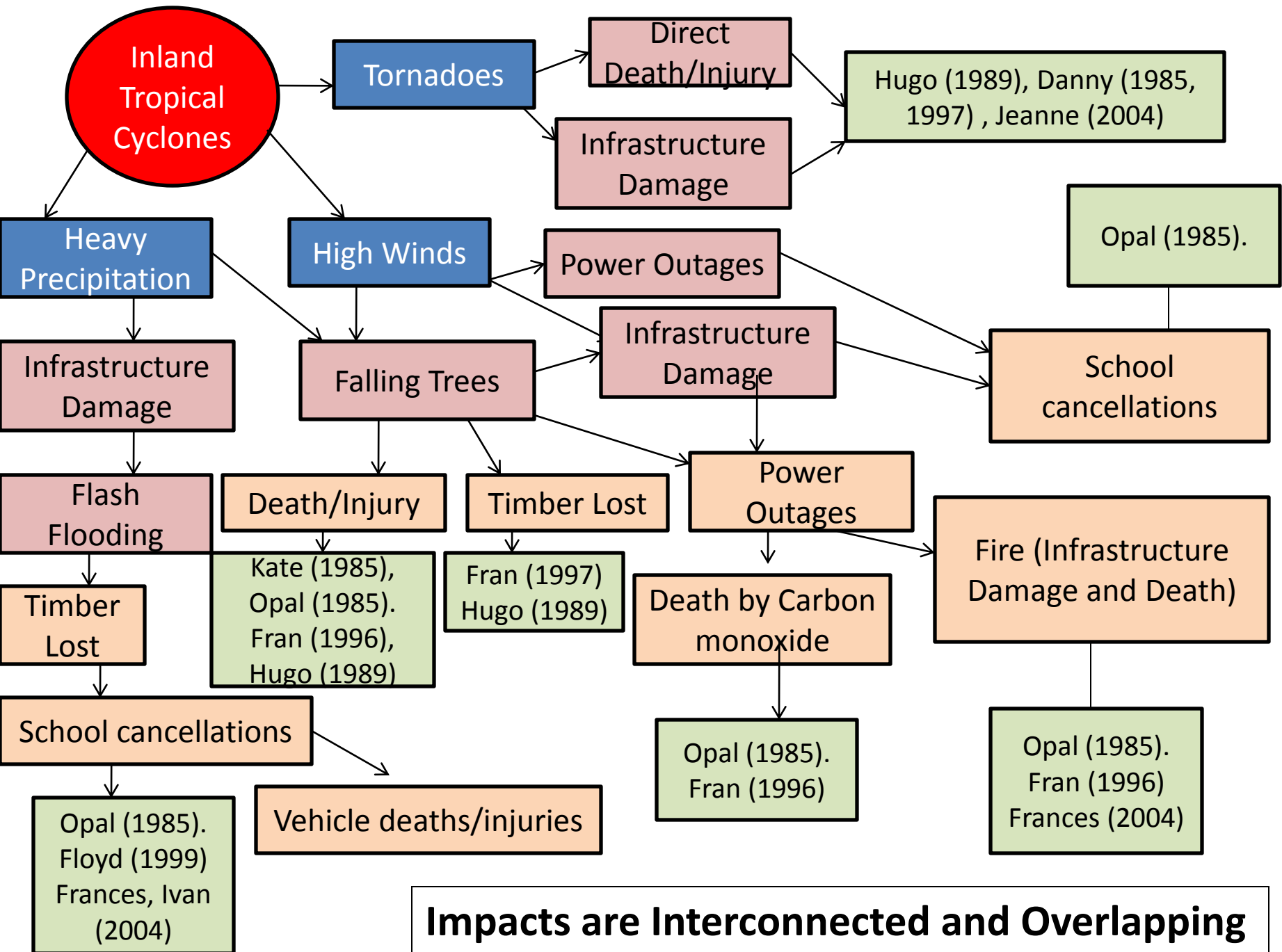
Preliminary Results – Hurricane Jeanne

Deaths and Injuries associated with Jeanne:

- 15 tornado injuries and 1 tornado death in SC
 - Fairfield and Clarendon County
- 2 heavy precipitation death in SC
 - Vehicle death on rain soaked road
- 5 flooding injuries in NC
 - Father and son boating accident on Rocky River near Harrisburg, NC
 - Vehicle injury on flooded roads
- 1 tornado injury in Callands, VA
- 2 heavy precipitation death in VA
 - Mud slide while woman sleeping in mobile home
 - Drowning in flash flood near Stuart, VA



Hurricane Jeanne's newspaper and storm events reported deaths and injuries



Impacts are Interconnected and Overlapping

Economic Benefits

- **Increased Hotel Occupancy**
 - Katie (1985), Hugo (1989), Opal (1995), Frances (2004), Katrina (2005)
- **Tree cutting companies, auto body repair businesses and roofing firms**
 - Hugo (1989), Allison (1995), Frances (2004)
- **Grocery & Hardware stores**
 - Hugo (1989), Frances (2004)
- **Fishing Reports**
 - Andrew (1992), Fran (1997), Bob (1985)



Environmental Damage

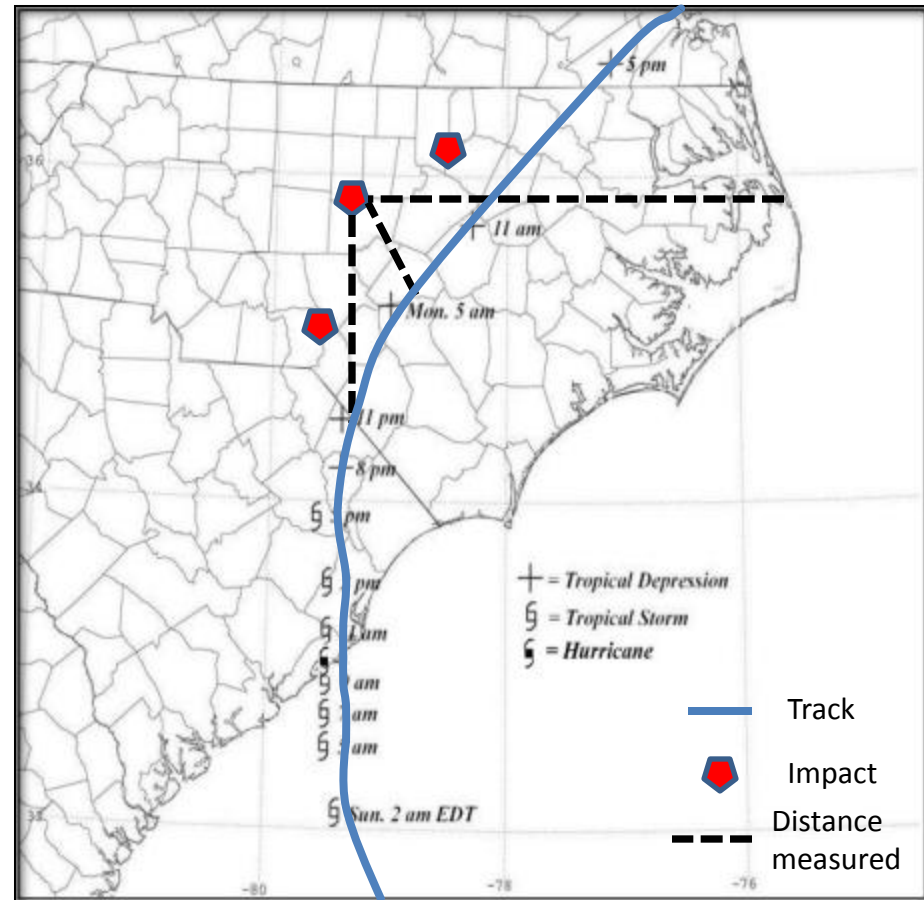
Overwhelming majority of environmental damage due to Heavy Precipitation events

- **Sewage Spills**
 - Fran (1996), Danny (1997), Frances (2004), Ivan (2004), Jeanne (2004)
- **Increased bug activity**
 - Hugo (1989), Allison (1995), Jeanne (2004)
- **Re-examination of Earthen Dams**
 - Allison (1995)
- **Wind Damage causes environmental damage with tree destruction**
 - Hugo (1989)



Current Work

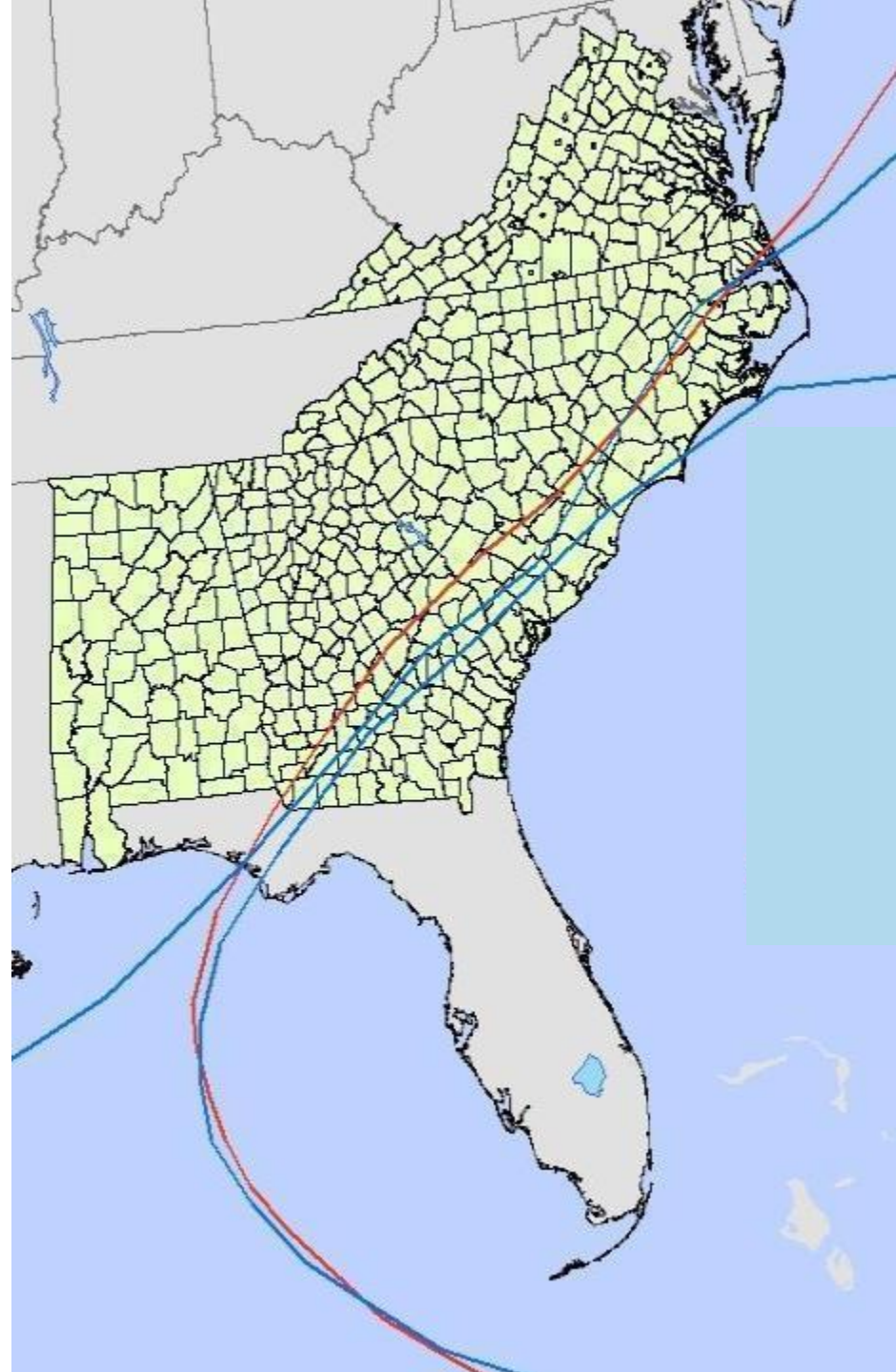
- Geo-coding location of societal impacts into GIS
- Distance and angular measurements for tropical cyclones
- Cyclone Size, speed of movement and extra-tropical features identification for storms



Future Work

Apply results of this study to tropical cyclones over a much longer historical period to estimate the recurrence intervals for different types of damage across the region.

- **Past storm:** San Agapito (1851) – red
 - North and South Carolina reported strong winds that destroyed crops
 - Described as the worst storm in 30 years (cat 4)
- **Present storm:** Earl (1998) & Katie (1985) – blue
 - Earl – cat 2
 - Katie – cat 3



Questions?