**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 winds 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 produce significant societal impacts, including 3% 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.

**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 cyclones and their associated meteorological effects shape societal impacts?

**Methodology**

**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

**Spatial Distribution of the Impacts**

- 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.

**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.

**Sources of Data on Societal Impacts**

- NOAA’s Storm Events Data
- Urban Newspaper Sources
  - Raleigh–The News and Observer 01/01/1991
  - Atlanta—the Atlanta Journal Constitution 01/01/1985
  - Fayetteville—The Fayetteville Observer 01/01/1988
  - Columbus—The Columbus Ledger Enquirer 01/01/1988
  - Athens—The Athens Banner 01/01/1999
  - Richmond—The Richmond Times-Dispatch 08/01/1985
  - Norfolk—The Virginian Pilot 01/03/1990
  - Columbia—The Columbia Chronicle 01/01/1991
  - Nashville—The Nashville-Davidson Journal 01/01/1990
  - The Augusta Chronicle 01/01/1994
  - The Roanoke Times 01/03/1990
  - The Herald Journal 08/01/1998
  - The Winston-Salem Journal 01/01/1999
  - The Augusta Chronicle 01/01/1994
  - The Roanoke Times 01/03/1990
  - The Fayetteville Observer 01/01/1988
  - The Herald Journal 08/01/1998
  - The Augusta Chronicle 01/01/1994
  - The Roanoke Times 01/03/1990
  - The Fayetteville Observer 01/01/1988
  - The Herald Journal 08/01/1998

**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.

**References**


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

Maps were constructed from available weather information. Storms, earlier in the study period, such as Dan (1989), 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.

**Societal Impacts of Hurricane Ivan (2004)**

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

Hurricane Ivan (2004) 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 Ivan (2004) (black line).