



The Spatial Distribution of Meteorological Impacts from Inland Moving Tropical Cyclones

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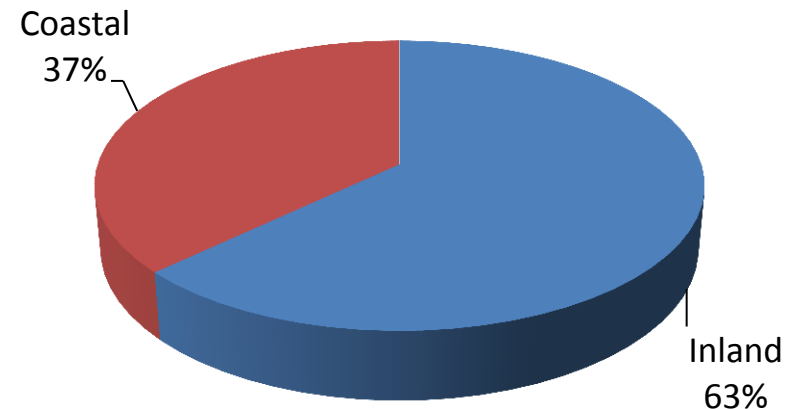
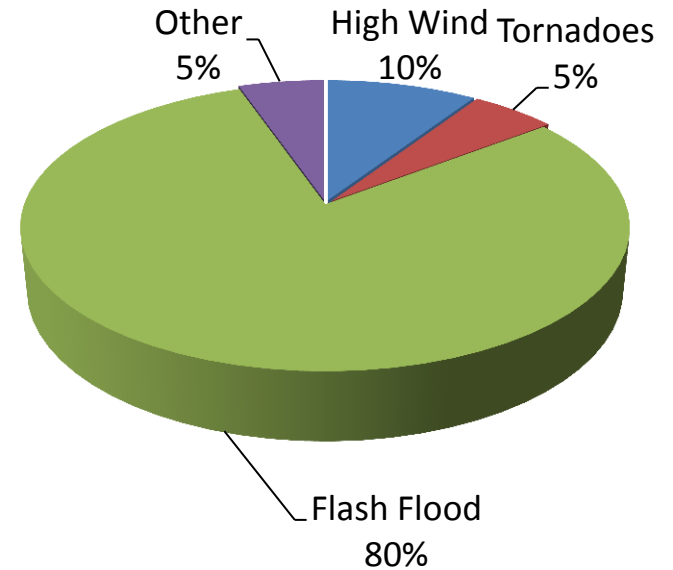
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Background – Societal Impacts

Why are we interested in the meteorological impacts of inland tropical cyclones (TCs)?

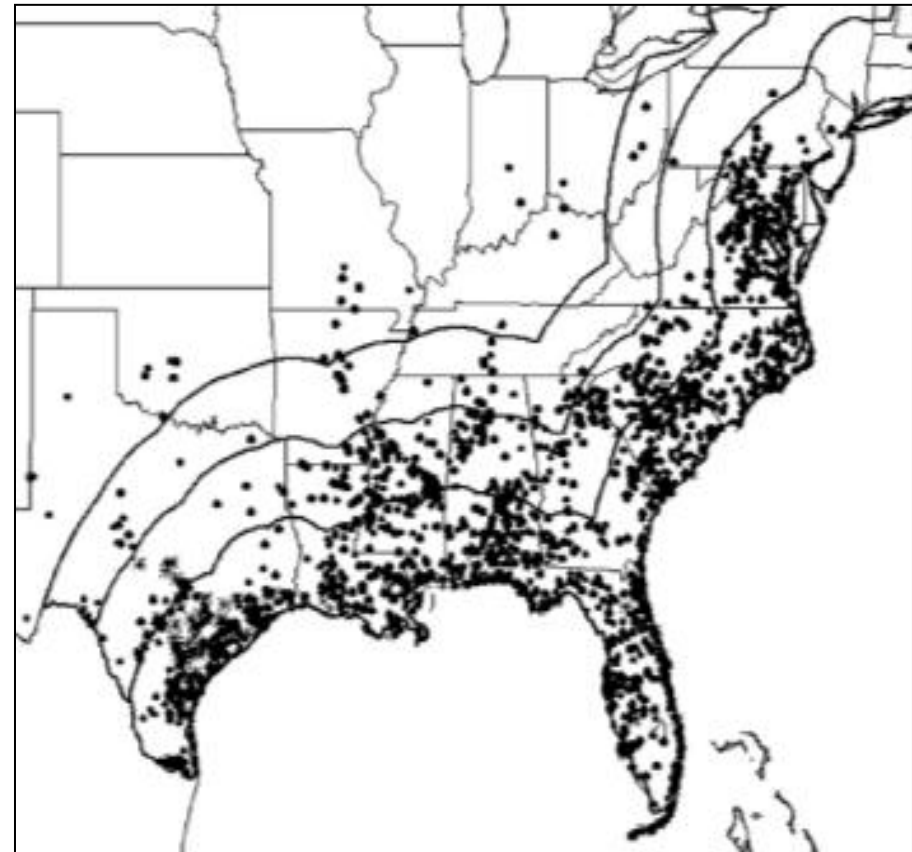
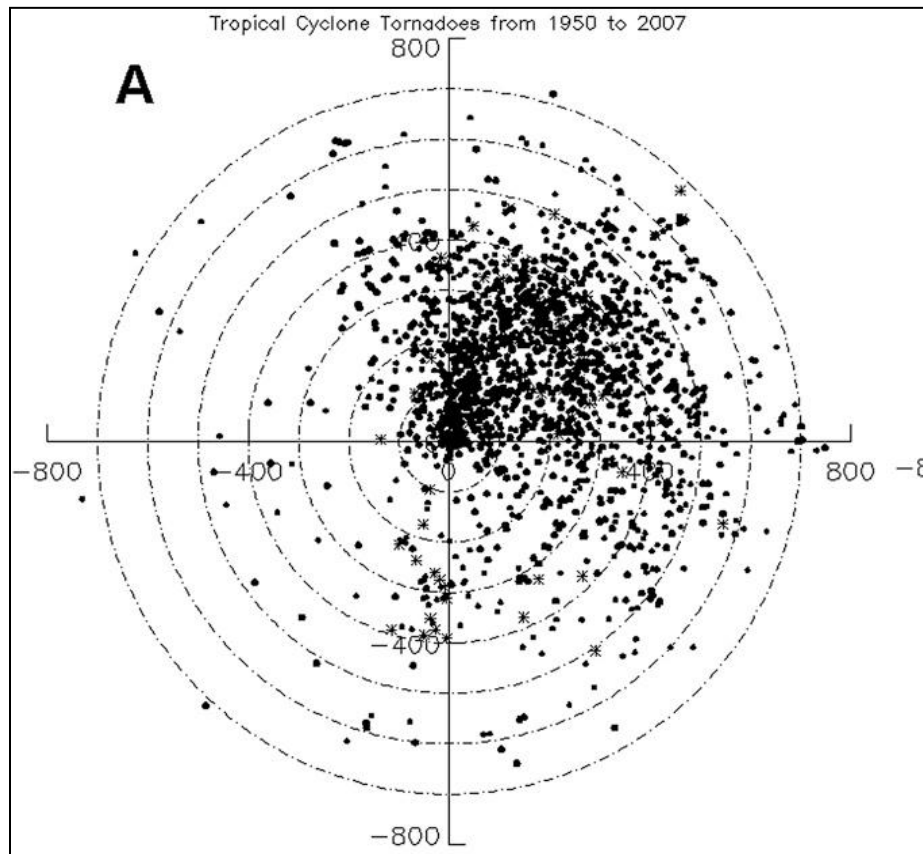
- Prior to the 1970s, 90% of hurricane-related deaths were due to storm surge along the coastline (AMS 1973).
- From 1970 to 1999, 63% of all tropical cyclone related deaths were inland deaths. (Rappaport 2000).



(Data obtained from Rappaport 2000)

Background – Tropical Cyclone (TC) Tornadoes

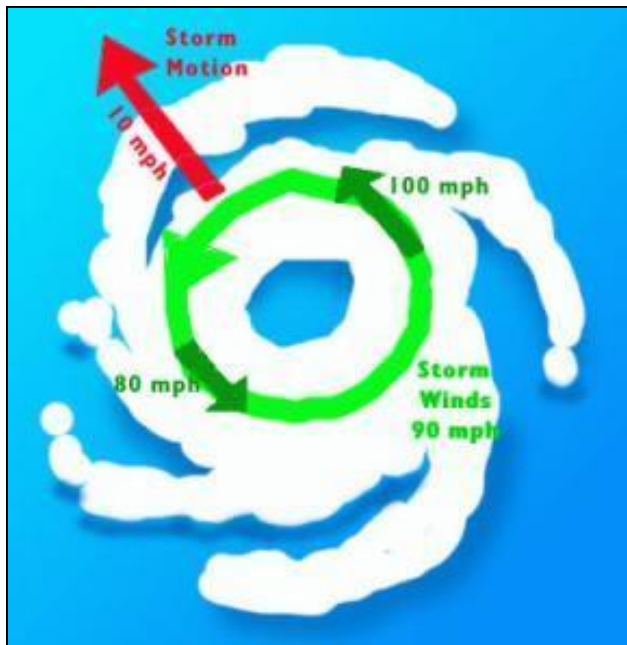
- Two distinct peaks occur in the right forward quadrant (Schultz and Cecil 2009).
- The majority of tornadoes occur close to the coastline (94% within 400 km).



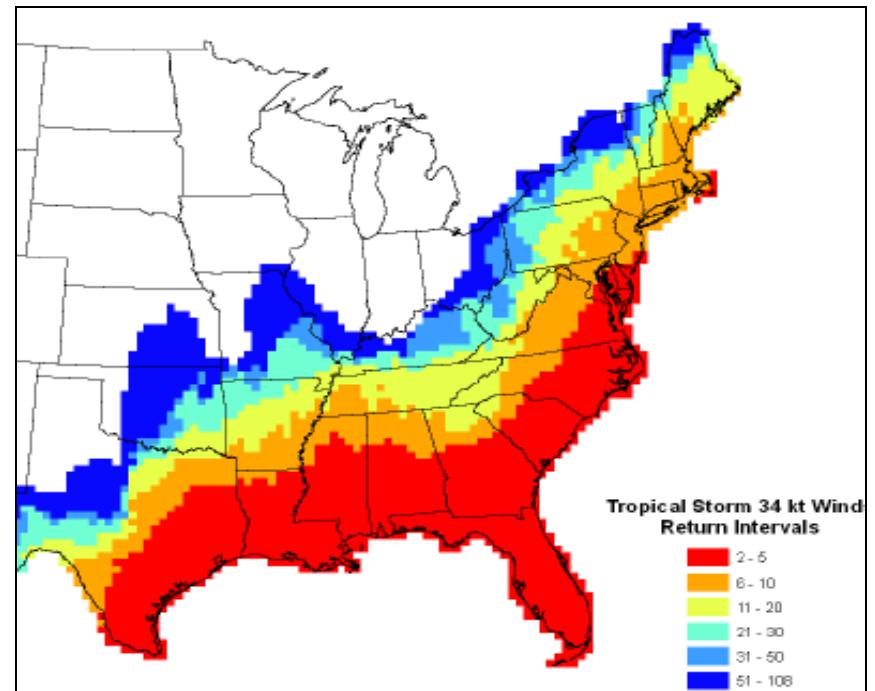
(Schultz and Cecil 2009)

Background - High Winds

- Maximum gust speeds can remain above hurricane force several hundred kilometers inland due to increased turbulence (Powell 1991).
- Significant high winds from TC occur regularly within inland locations (Kruk *et al.* 2010).
 - Return interval of 2 to 6 years.



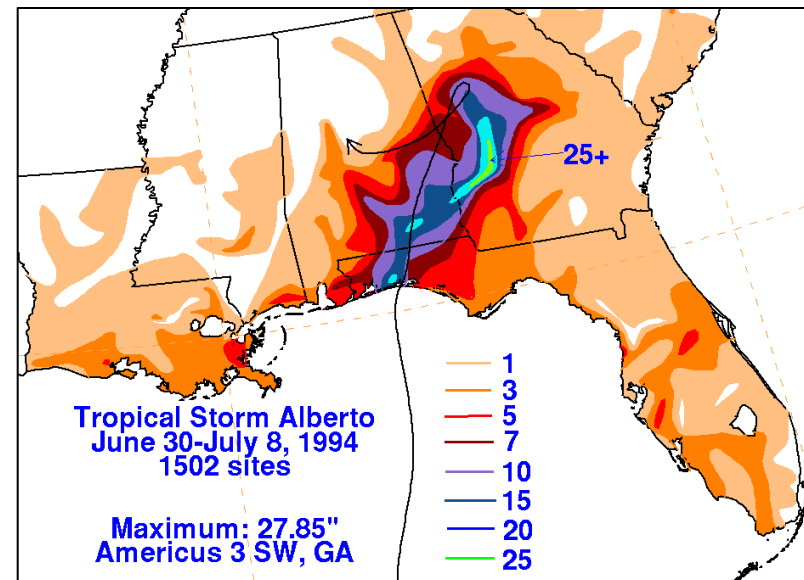
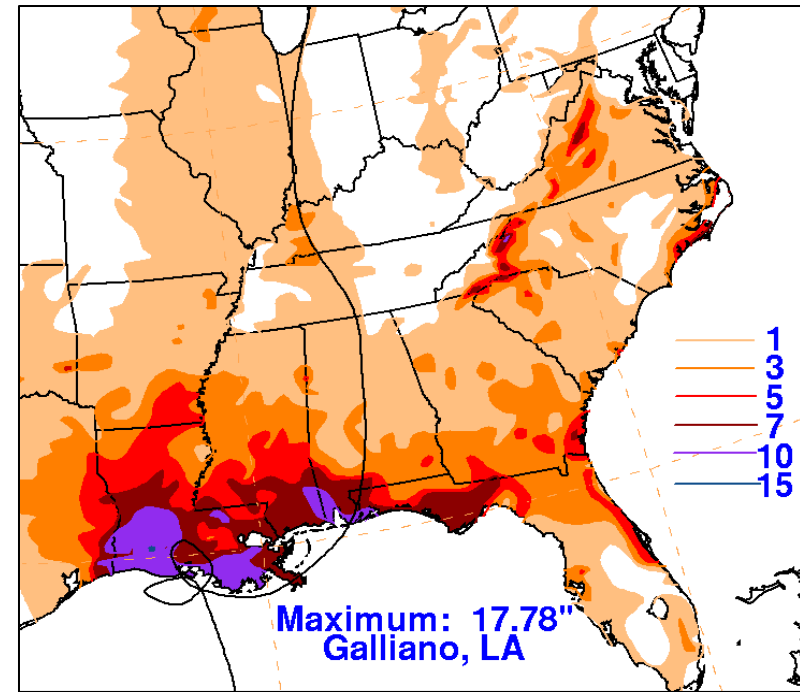
Source: <http://www.aoml.noaa.gov/hrd/tcfaq/D6.html>



Source: Kruk *et al* 2010

Background – Flash Flood

- Spatial pattern of rain is highly variable for each storm.
 - Dependent on size and speed of movement (Konrad *et al.* 2002, Matyas 2007)
- Spatial pattern and intensity of rainfall is also influenced by extratropical transition.
 - Nearly half of TCs from the Atlantic basin undergo extratropical transition (Hart and Evans 2001).



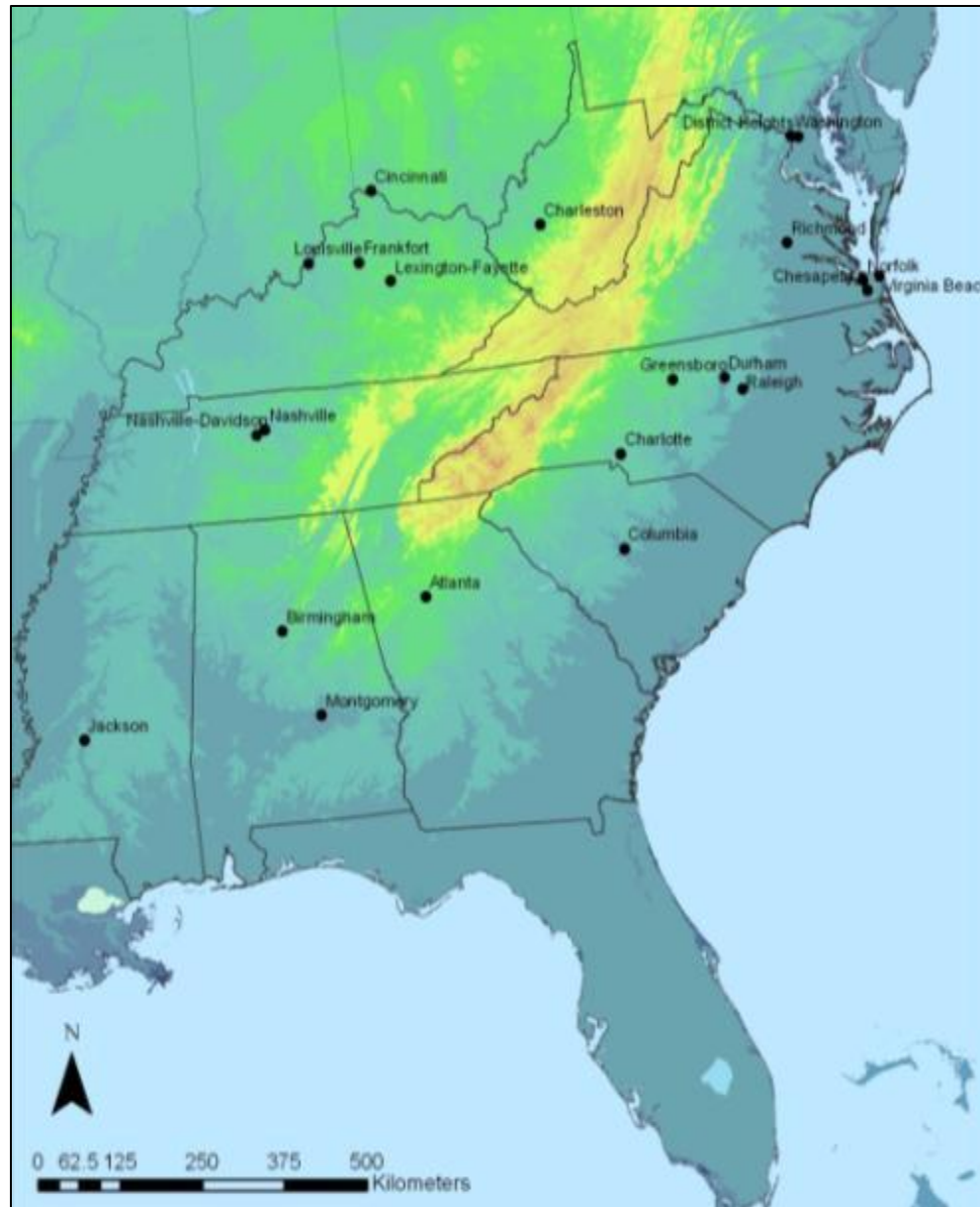
Research Questions

- A.) Where do the meteorological impacts (i.e. flash floods, tornadoes, high winds) occur relative to the tropical cyclone track and it's position?
- B.) Why do particular meteorological impacts depart from what is typical (e.g., outliers)?
- C.) How do tropical cyclone attributes (strength, size, speed of movement) affect the spatial distribution of the meteorological impacts?



Hugo (1989)
Source: NOAA

Study Area



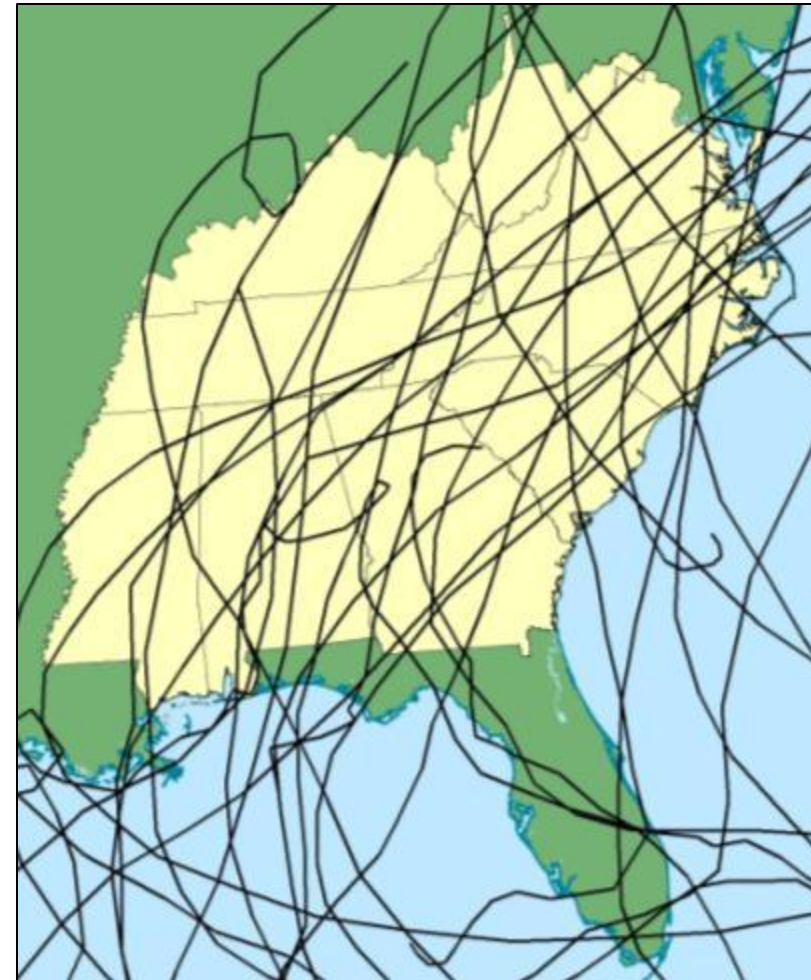
Methodology - Tropical Cyclones

Sources of Data on Tropical Cyclones

- 31 inland tropical cyclones were selected from 1985 – 2008.
- National Hurricane Center's (NHC) HURDAT database

Landfall	TS	Cat 1	Cat 2	Cat 3	Cat 4
Gulf	4	4	0	4	0
Atlantic	0	2	2	1	1
Florida	8	2	1	2	0

Distribution of Tropical Cyclones in the study



Tracks of tropical cyclones examined in the study

Methodology – Impact Sources

Sources of Data on Meteorological Impacts

- Meteorological impacts (e.g. flash flood, high winds and tornadoes) are identified by:
 - Agriculture Damage
 - Infrastructure Damage
 - Environmental Damage
 - Death/Injury
 - Power Outages
 - Cancellations of Event
- NOAA's Storm Events Data
- Urban Newspaper Sources



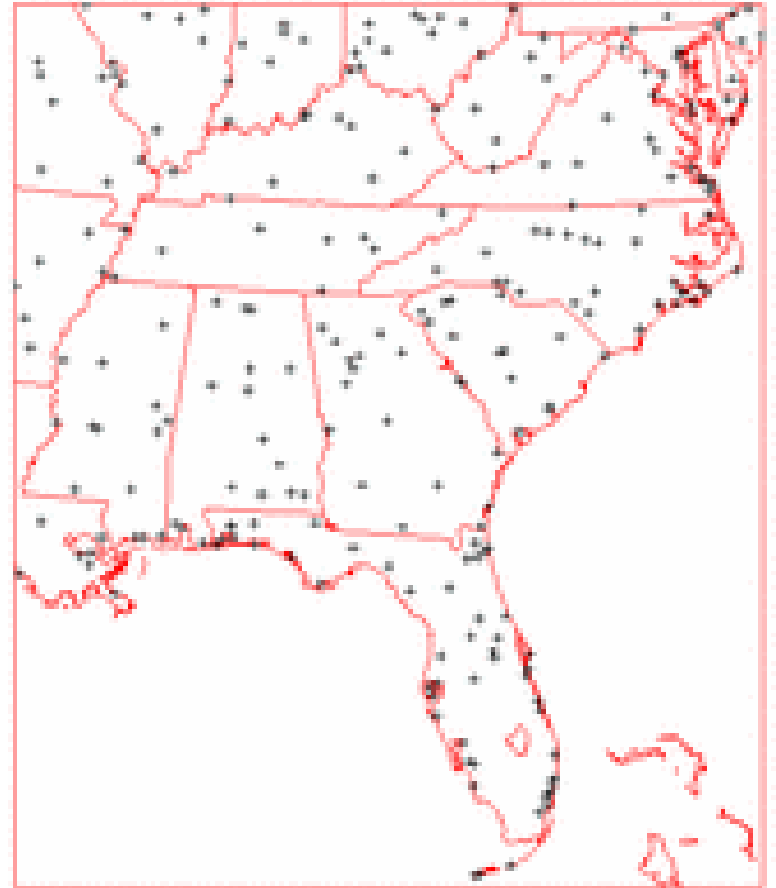
State	Number of Newspapers
Alabama	18
Georgia	11
Kentucky	12
Mississippi	7
North Carolina	45
South Carolina	26
Tennessee	8
Virginia	24
West Virginia	11

Total: 162

Methodology - Tropical Cyclones

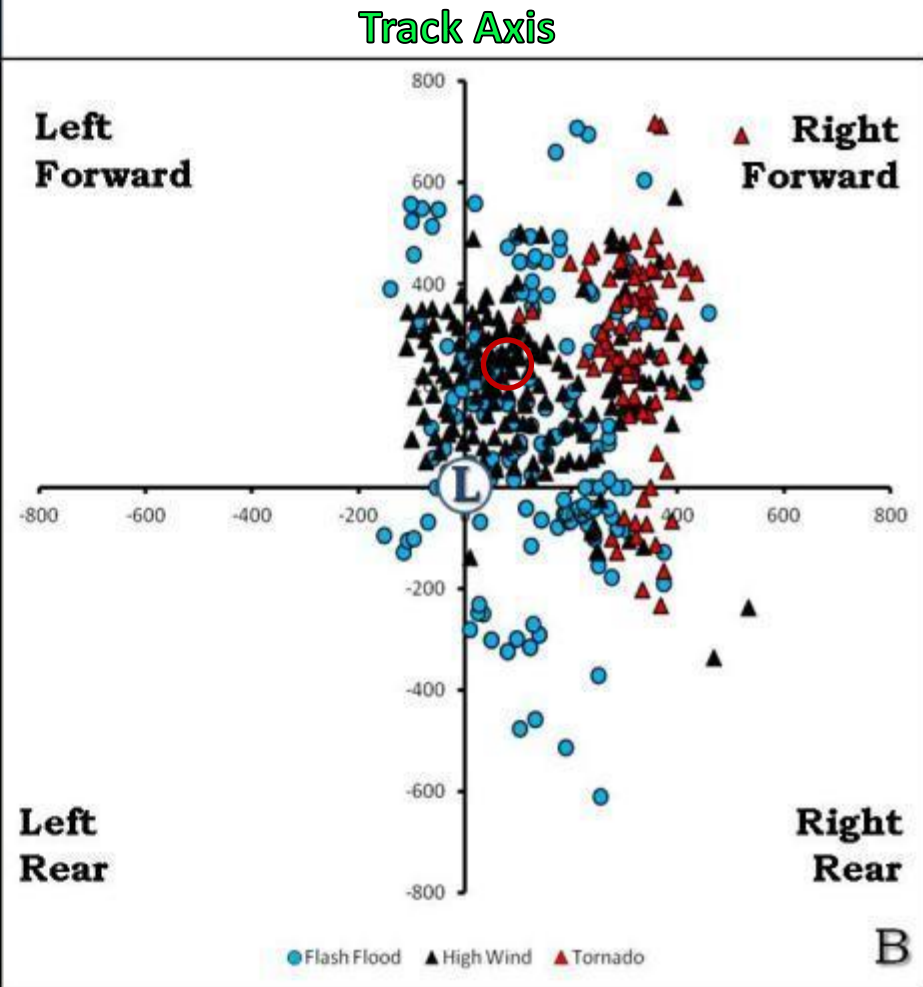
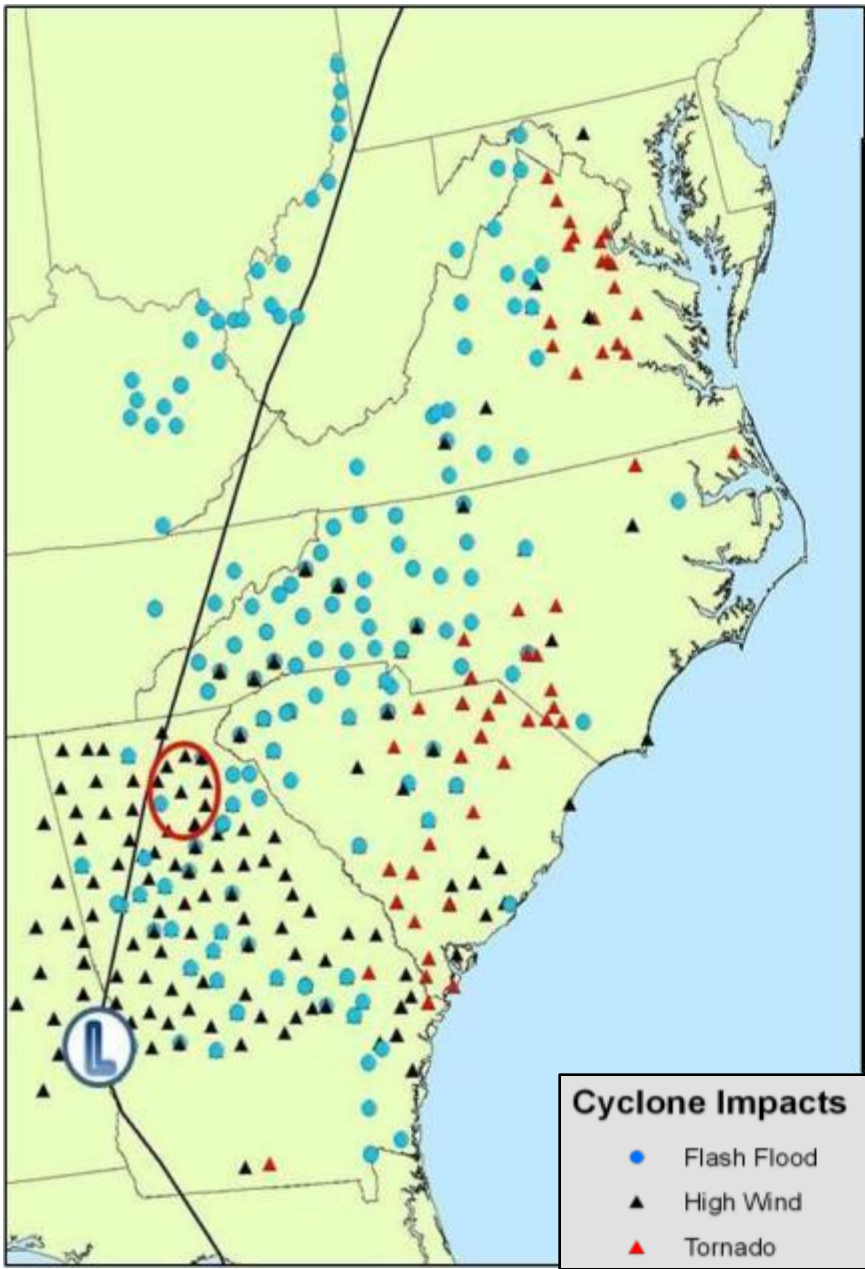
Sources of Data on the occurrence of Meteorological Impacts:

- Meteorological data was needed to determine the timing of societal impact data.
- First order weather stations (i.e. ASOS).



Locations of ASOS stations across the southeastern US Source: ufl.edu

Methodology – Track Following Coordinate System



Hurricane Frances (2004)

Methodology – Measurements

GIS employed to estimate the following:

Size of TC

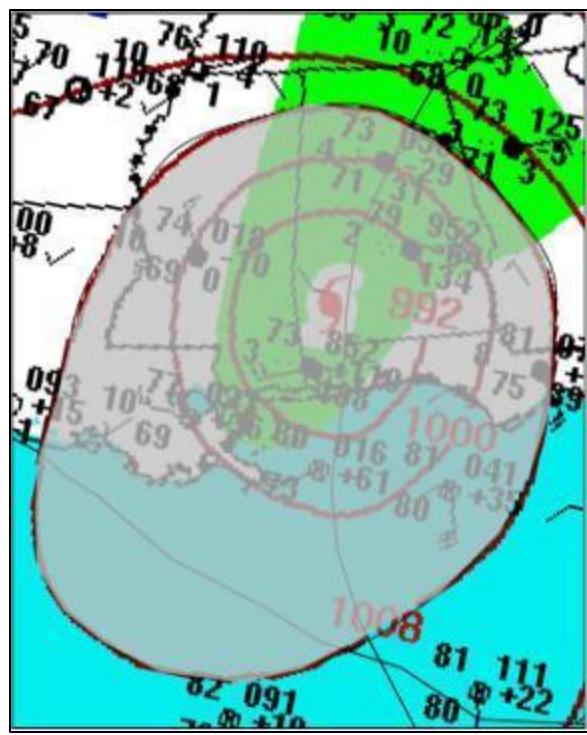
- NOAA daily weather maps at landfall
- Area inside outermost closed isobar (Konrad 2001)

TC Speed of movement

- HURDAT database

TC Strength

- Strength at landfall
- Saffir Simpson Wind Scale



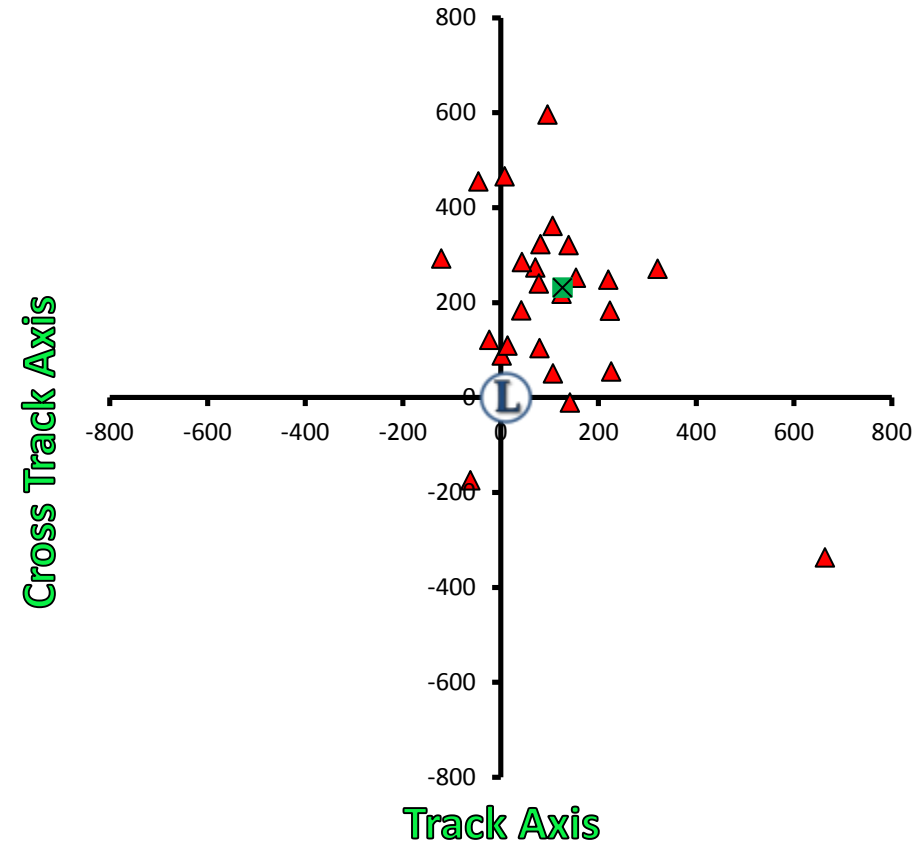
Hurricane Ivan(2004)

Categories	Sustained Winds
Tropical Depression	0-38 mph
Tropical Storm	39-73 mph
Category One Hurricane	74-95 mph
Category Two Hurricane	96-110 mph
Category Three Hurricane	111-130 mph
Category Four Hurricane	131-155 mph
Category Five Hurricane	Greater than 155 mph

Saffir Simpson Wind Scale

Selected Results: Tornadoes

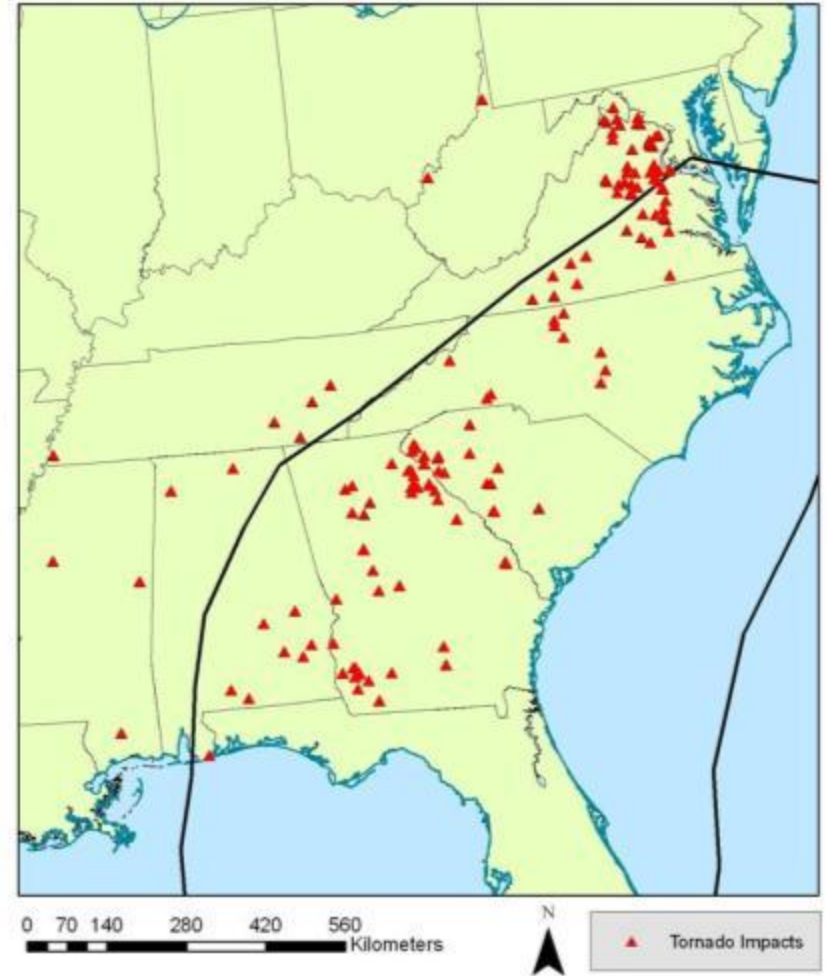
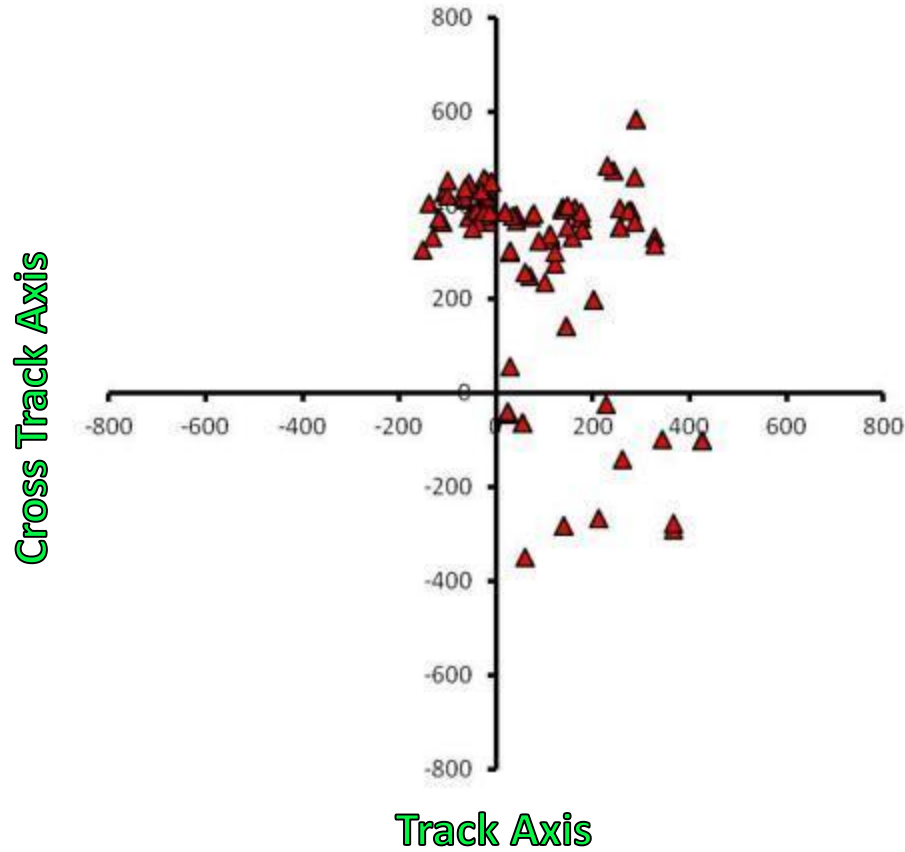
a. Spatial distribution of TC **tornado** centroids



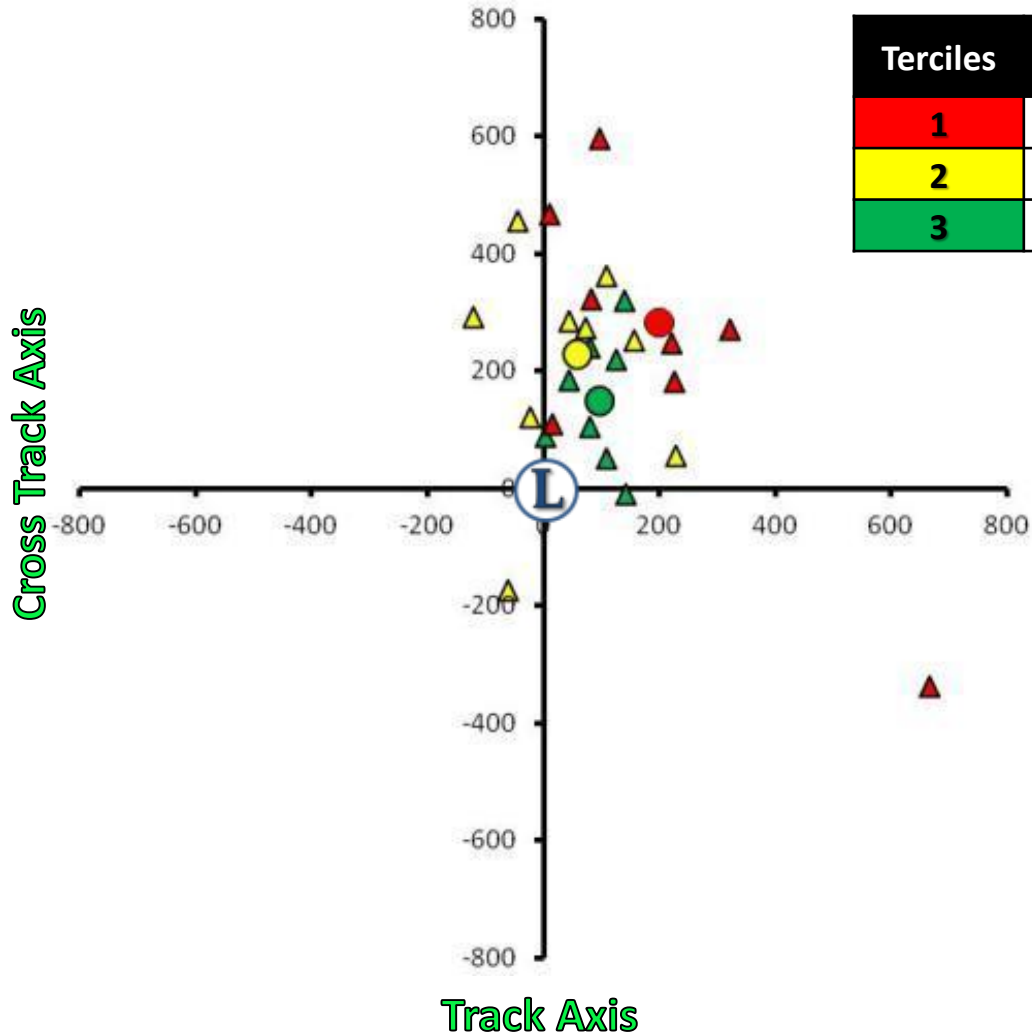
- Centroids are calculated by averaging the x and y coordinates for each impact type (i.e. Flash flood, Tornado, High wind) for each cyclone.

b. Example of Outliers

Ivan (2004)

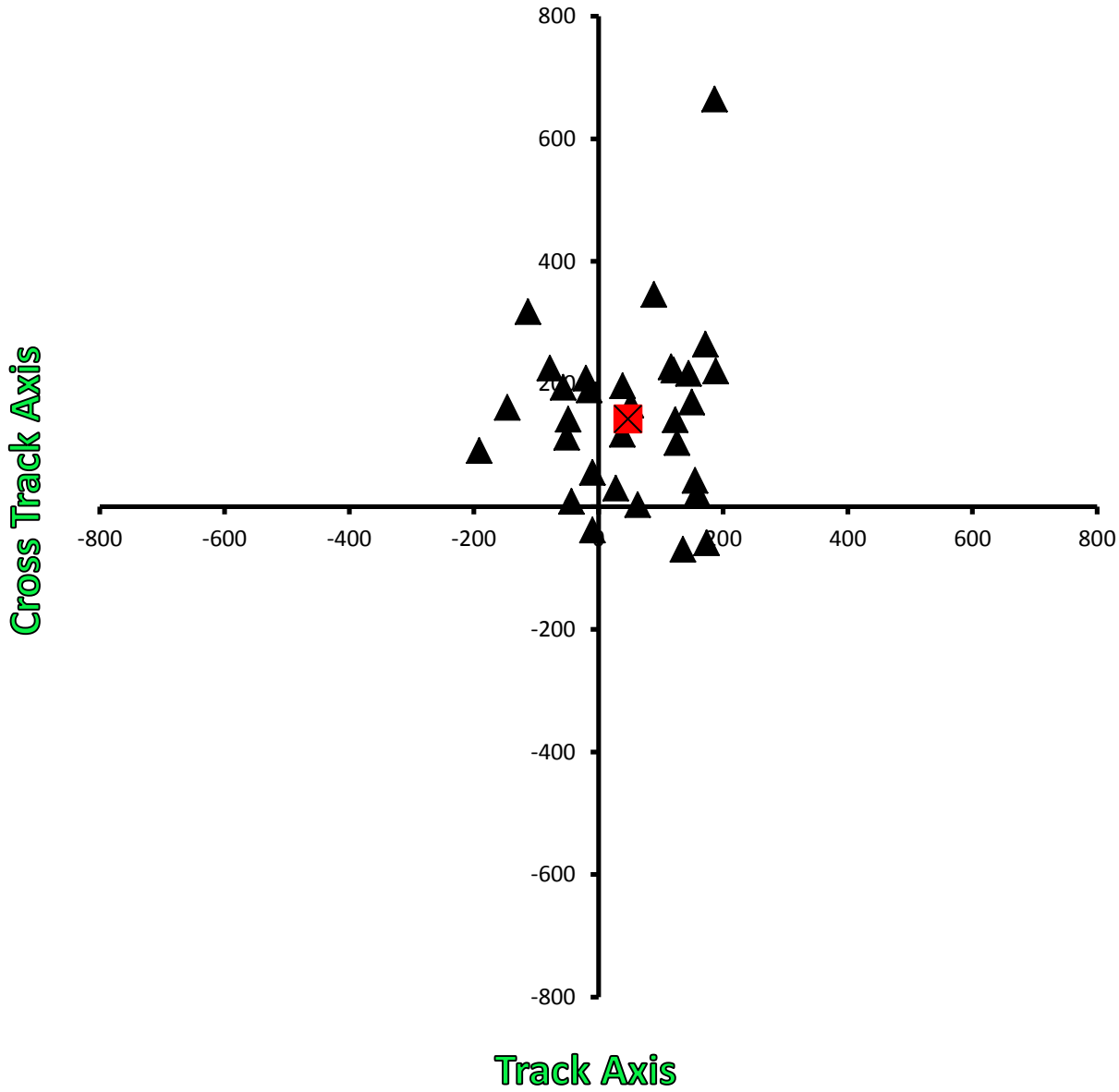


c. TC size vs. tornado centroids



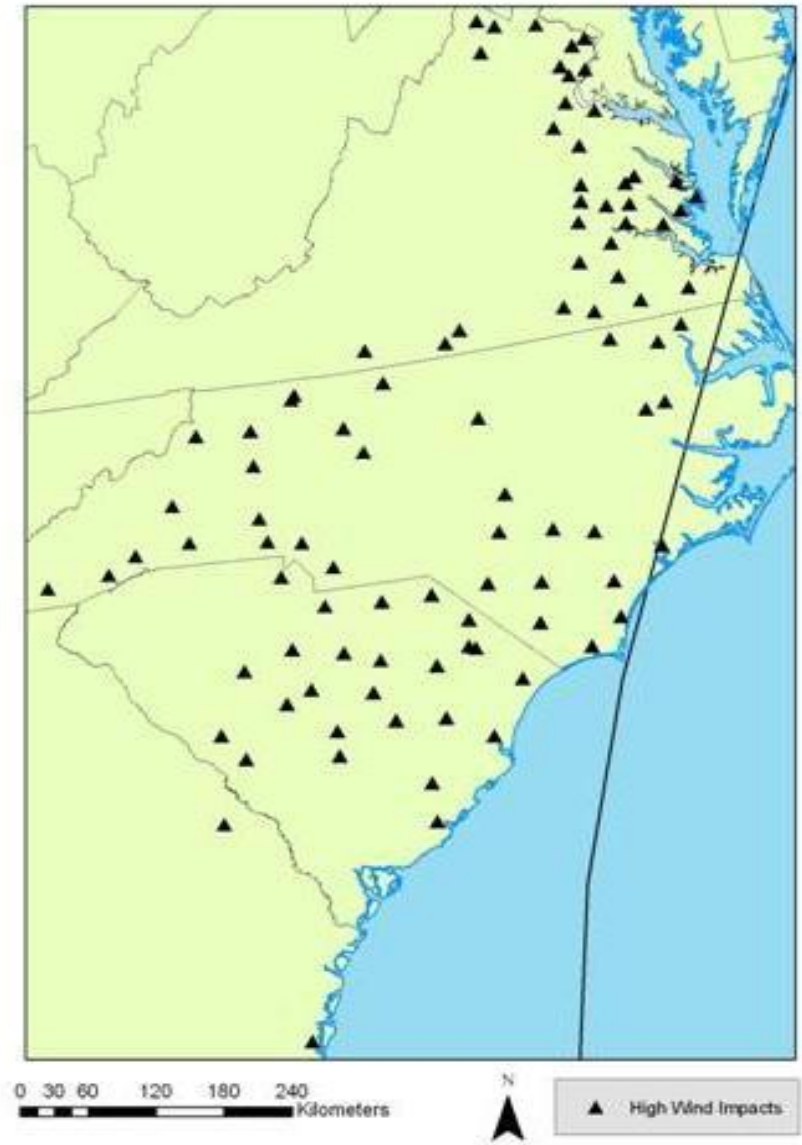
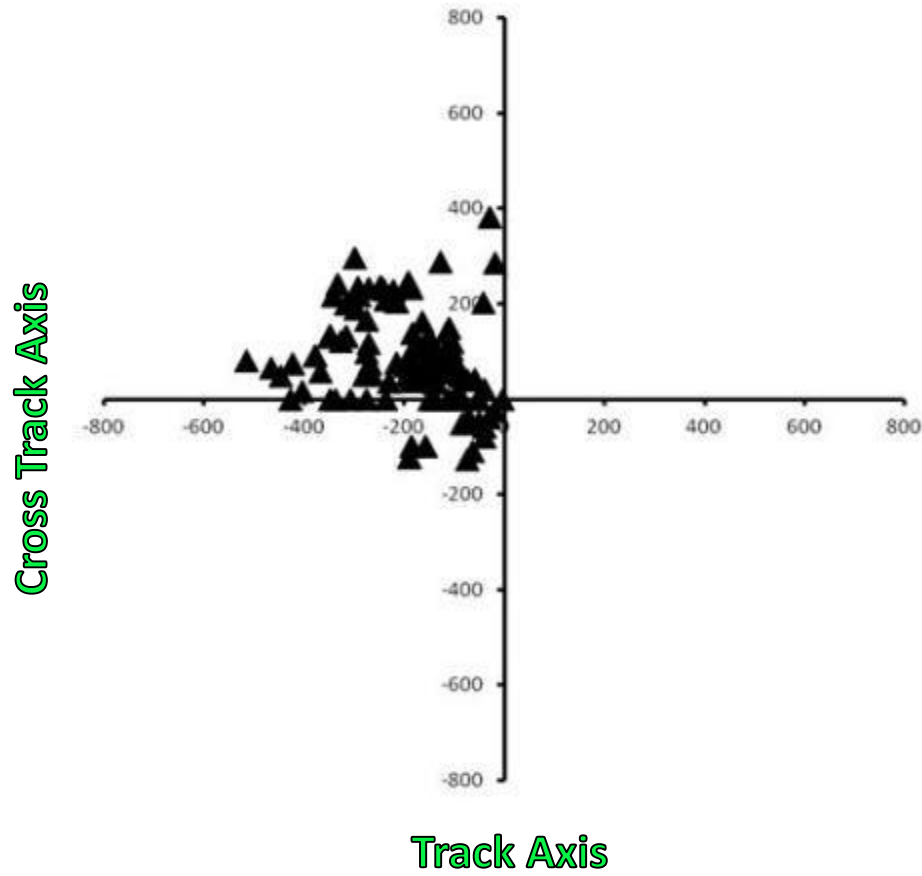
Selected Results: High Wind

a. Spatial distribution of TC high wind centroids



b. Example of Outliers

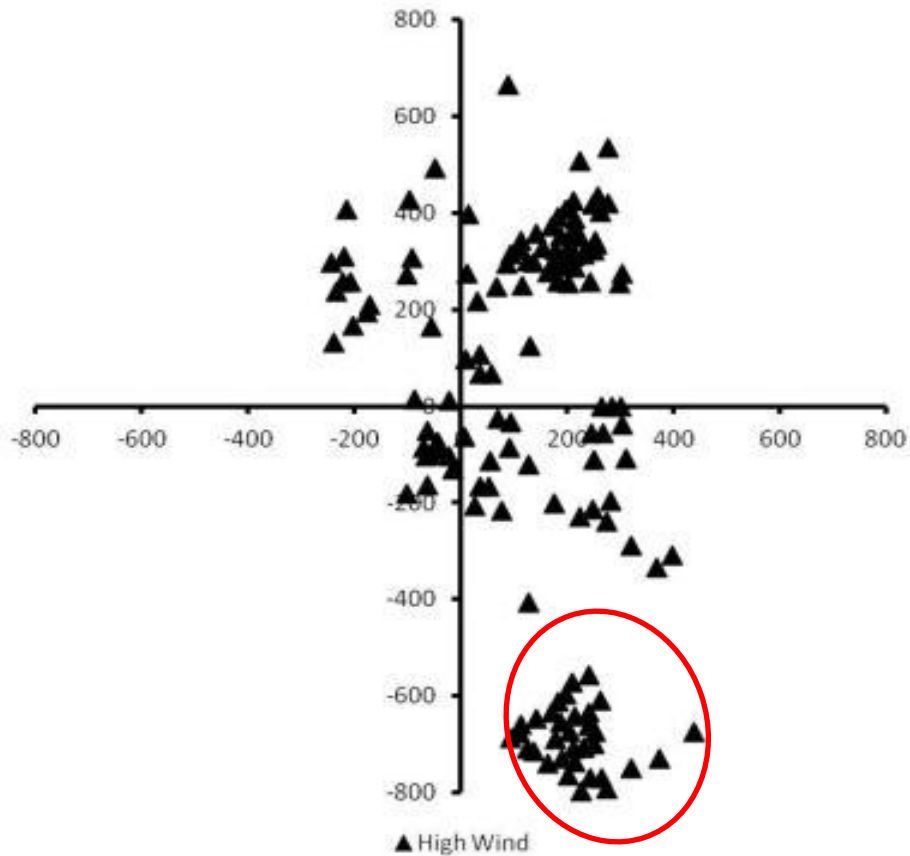
Floyd (1999)



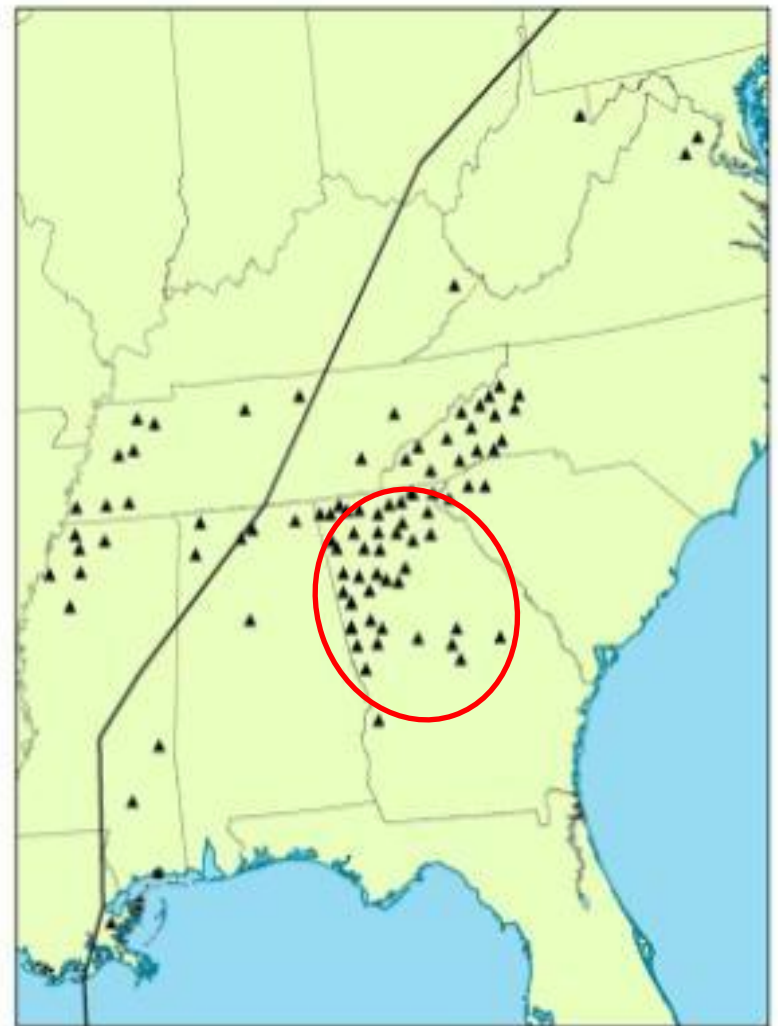
b. Example of Outliers

Isidore (2002)

Cross Track Axis



Track Axis

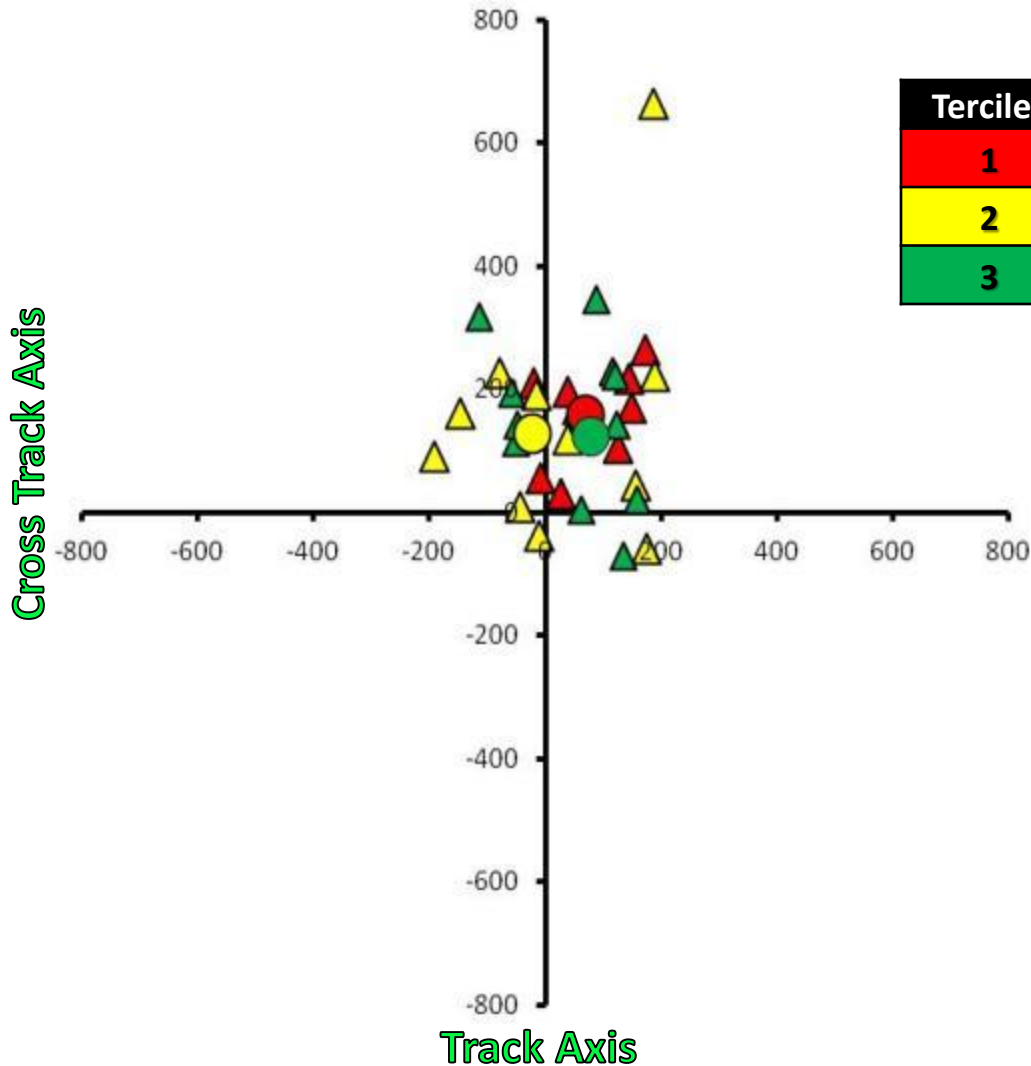


0 60 120 240 360 480 Kilometers



▲ High Wind Impacts

c. TC intensity vs. high wind centroids

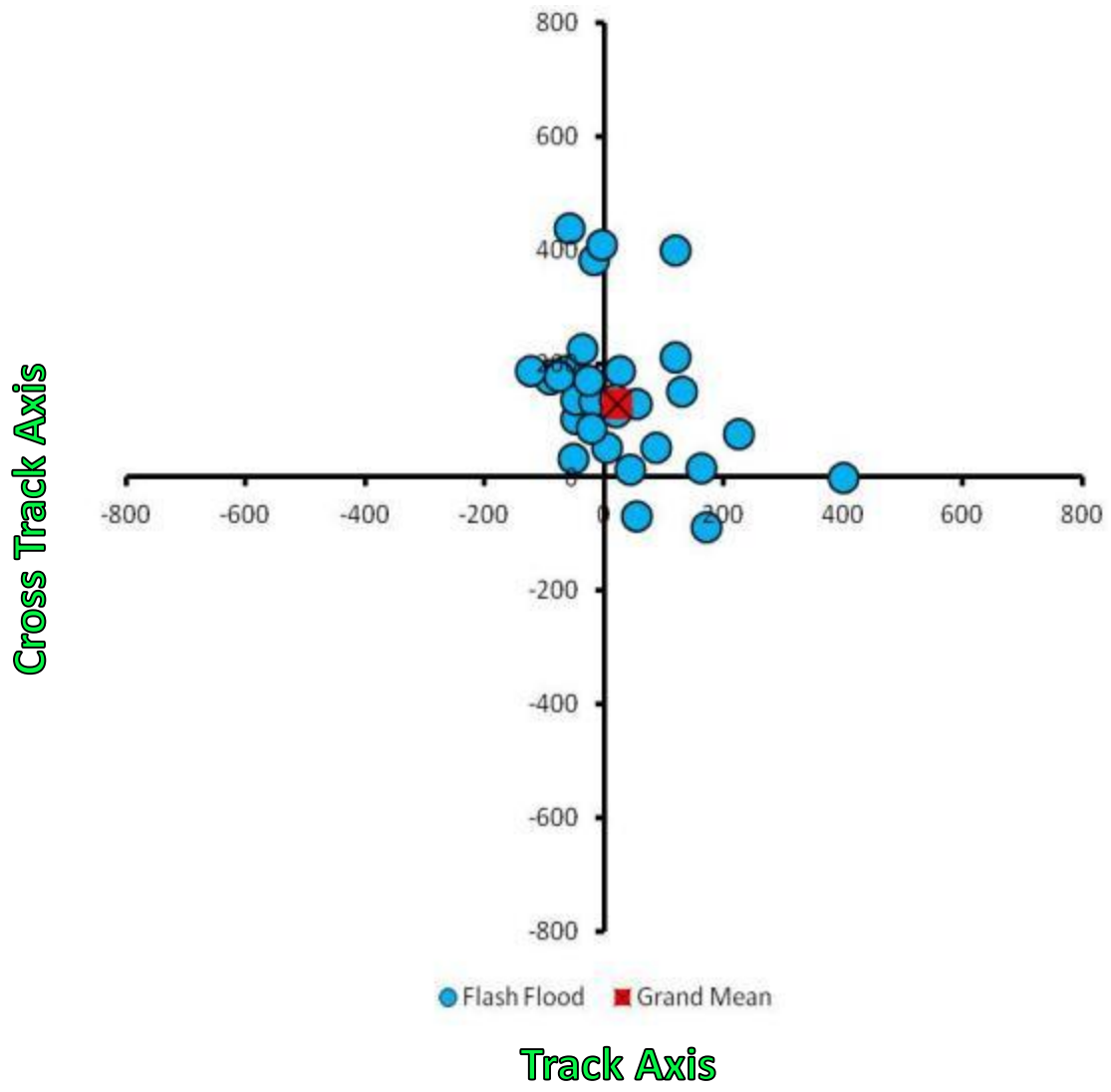


Terciles	Size (Square kilometers)	Spatial Dispersion
1	Category 3 and 4	141
2	Category 1 and 2	229
3	Tropical Storm	137

- TC intensity displayed a strong correlation with the number of high wind impacts ($r=0.563$, $p\text{-value} < 0.01$)

Selected Results: Flash Floods

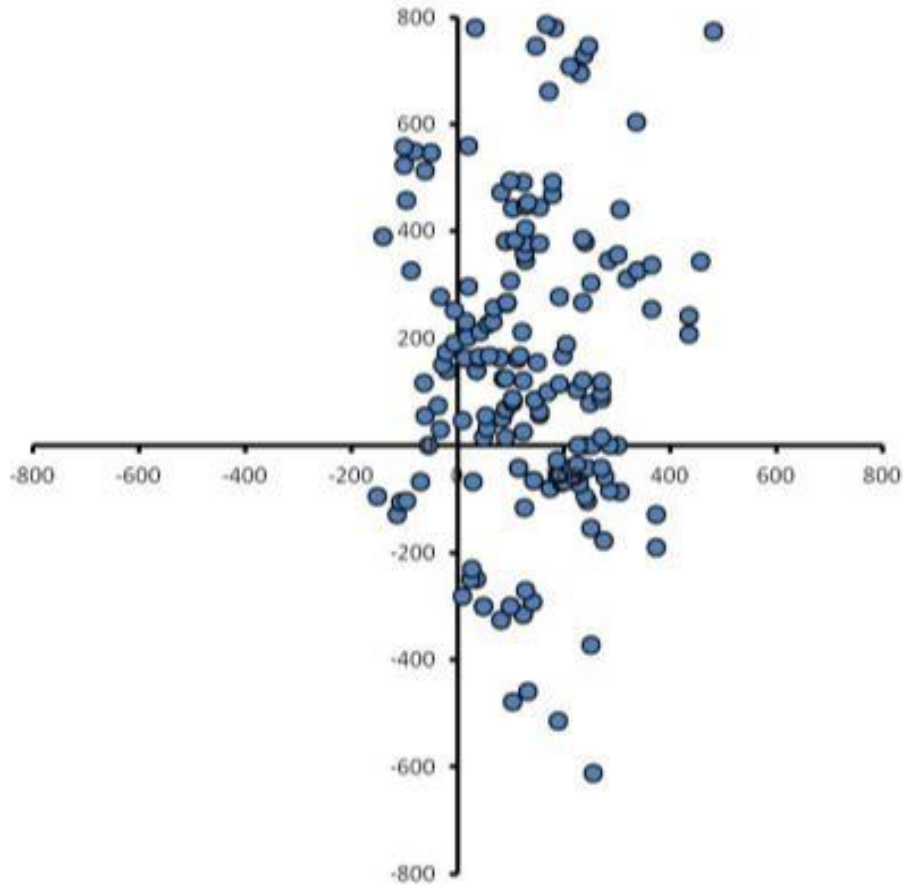
a. Spatial distribution of TC flash flood centroids



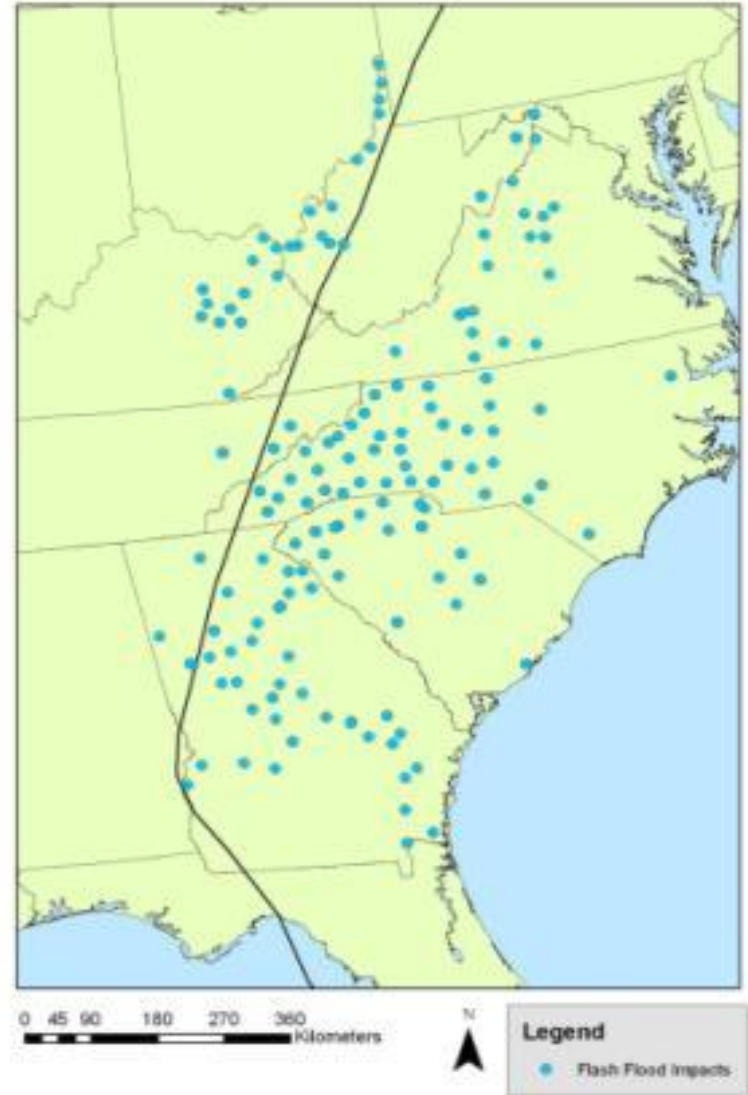
b. Example of Outliers

Frances (2004)

Cross Track Axis

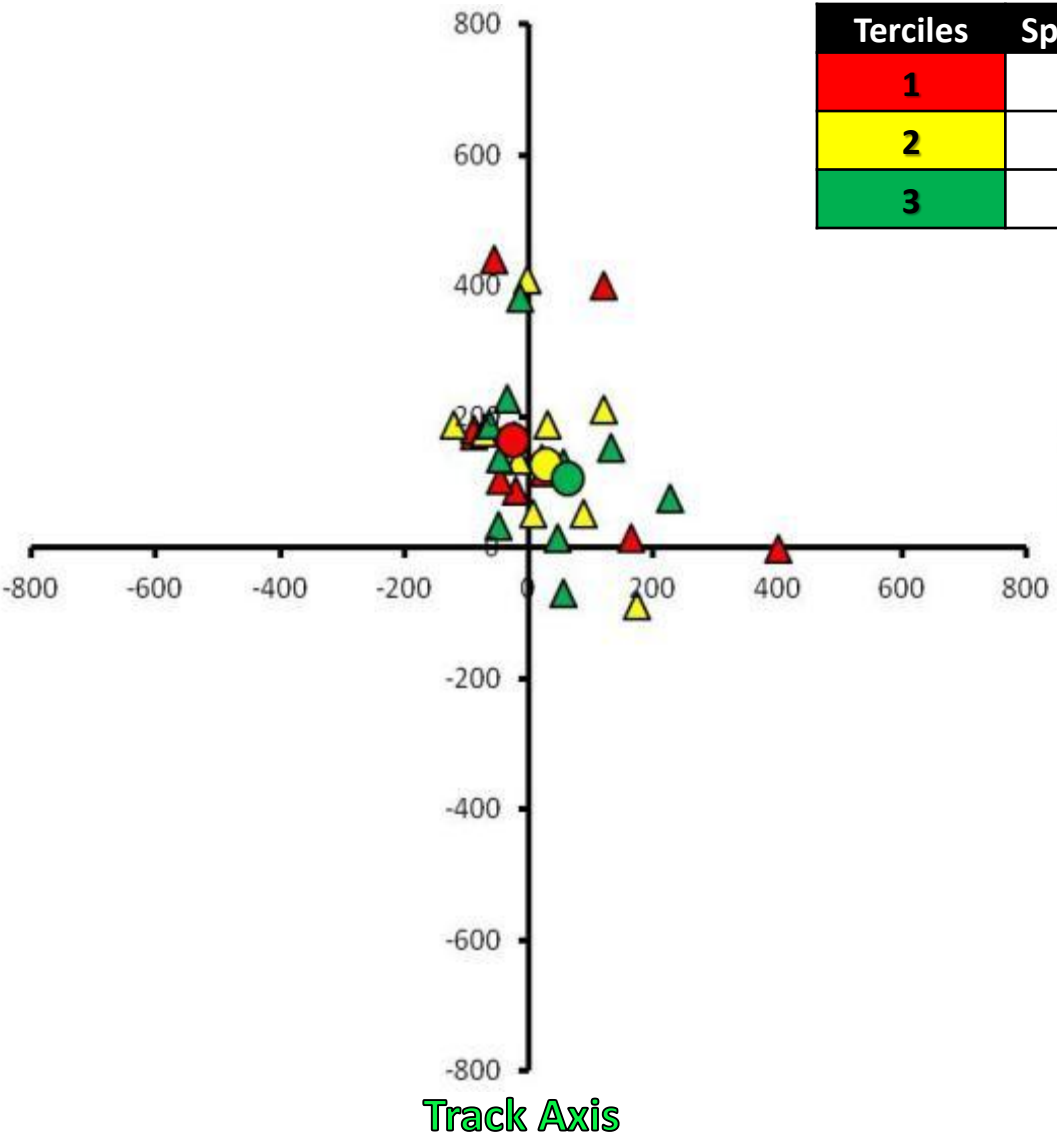


Track Axis



c. TC speed of movement vs. flash flood centroids

Cross Track Axis

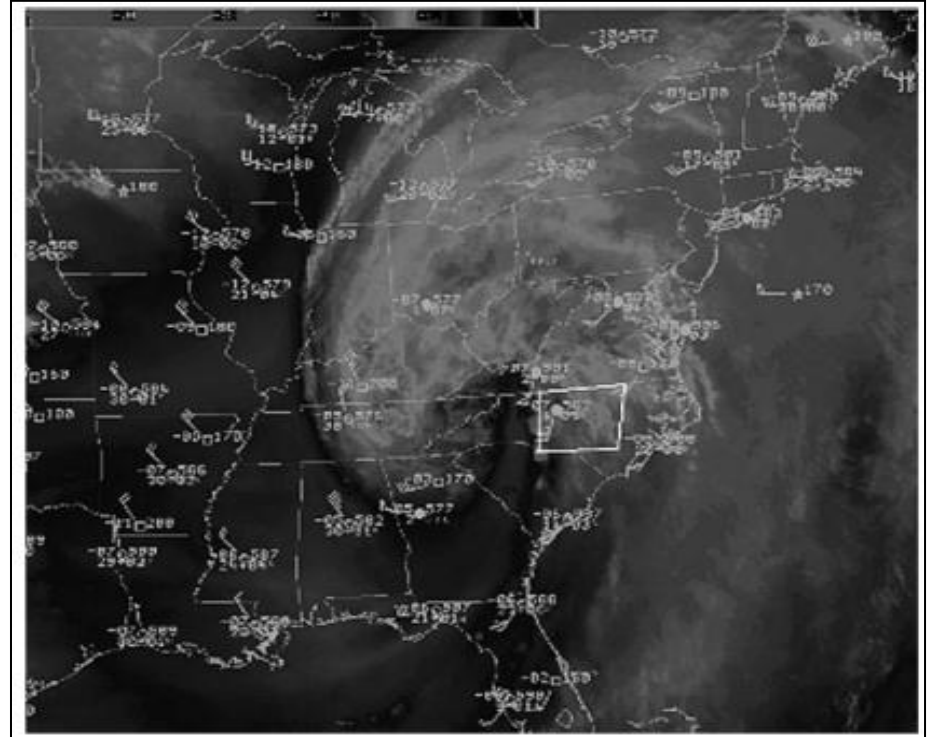


Terciles	Speed of movement (mph)	Spatial Dispersion
1	19 to 40	158
2	12 to 18.9	201
3	2.2 to 11.9	203

Conclusions

Tornadoes

- The majority of tornadoes occurred in the right forward quadrant.
- Nearly one-third of tornado occurred outside the right forward quadrant:
 - Mid-Latitude Features
- Tornadoes in Larger TCs



(Schneider and Sharp 2007)

Conclusions

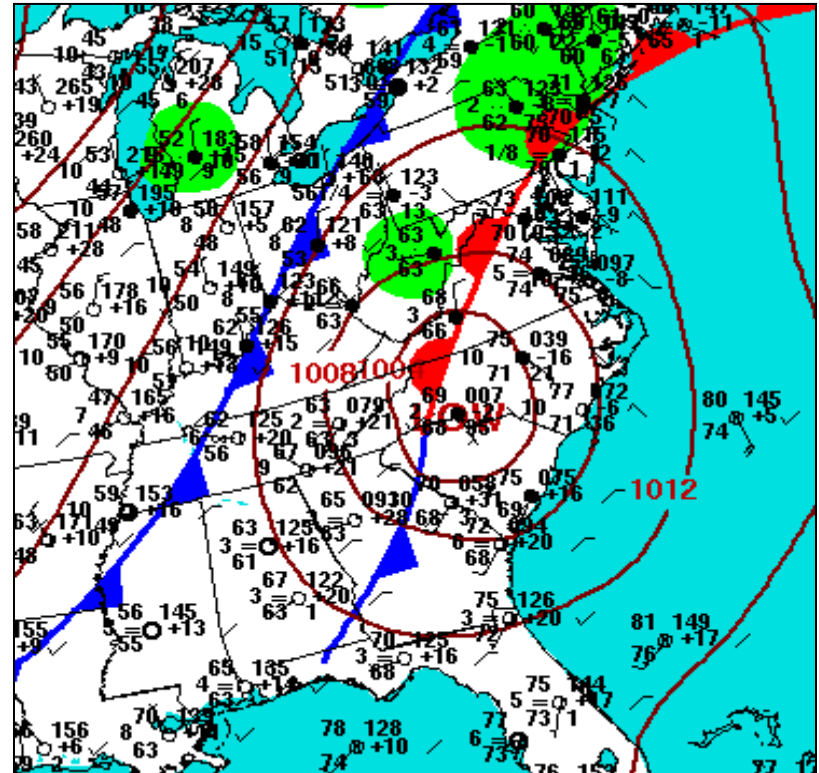
High Winds

- A strong preference for the right forward quadrant.
- Outliers may result from:
 - Spiral band outflow winds
 - Topographic influences
- Higher intensity TCs



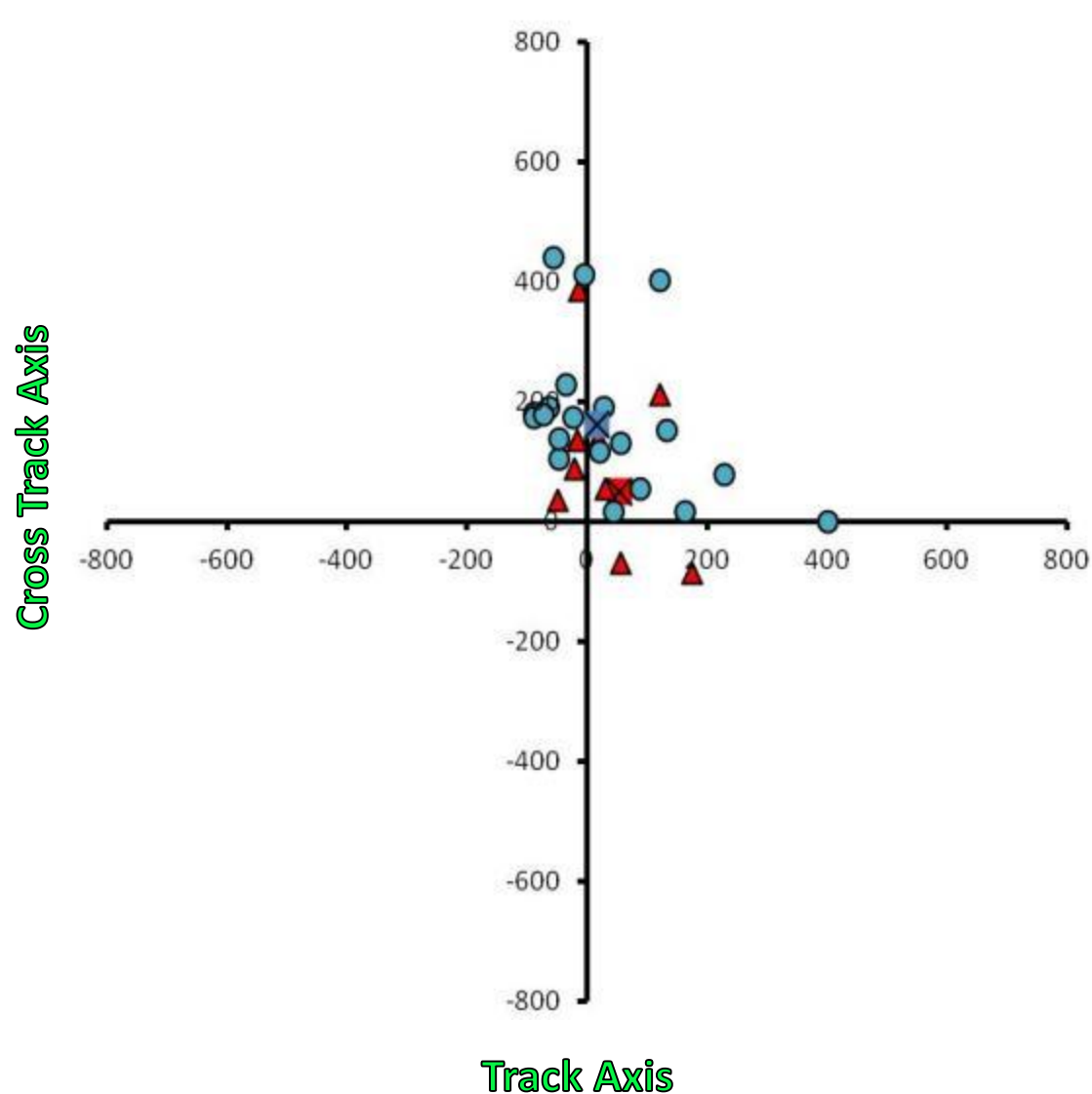
Flash Floods

- More TC centroids occurring in the left forward quadrants
- Faster moving TCs had flash flood impacts over a much smaller area



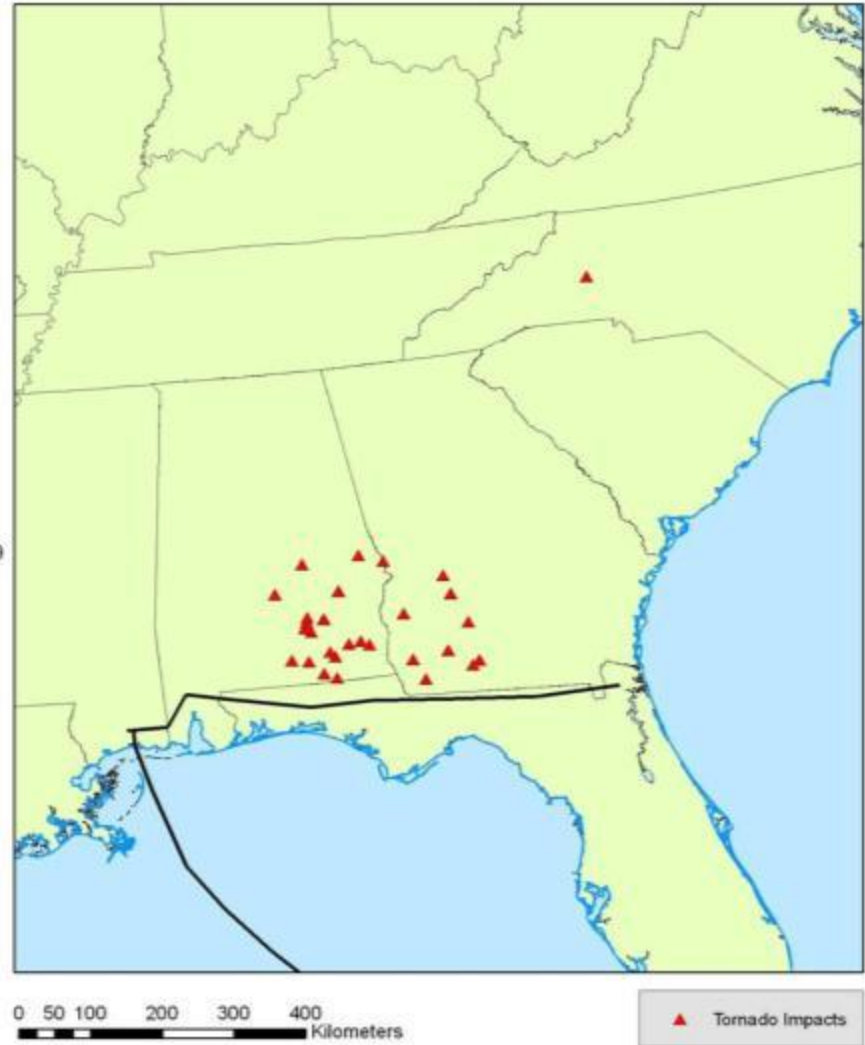
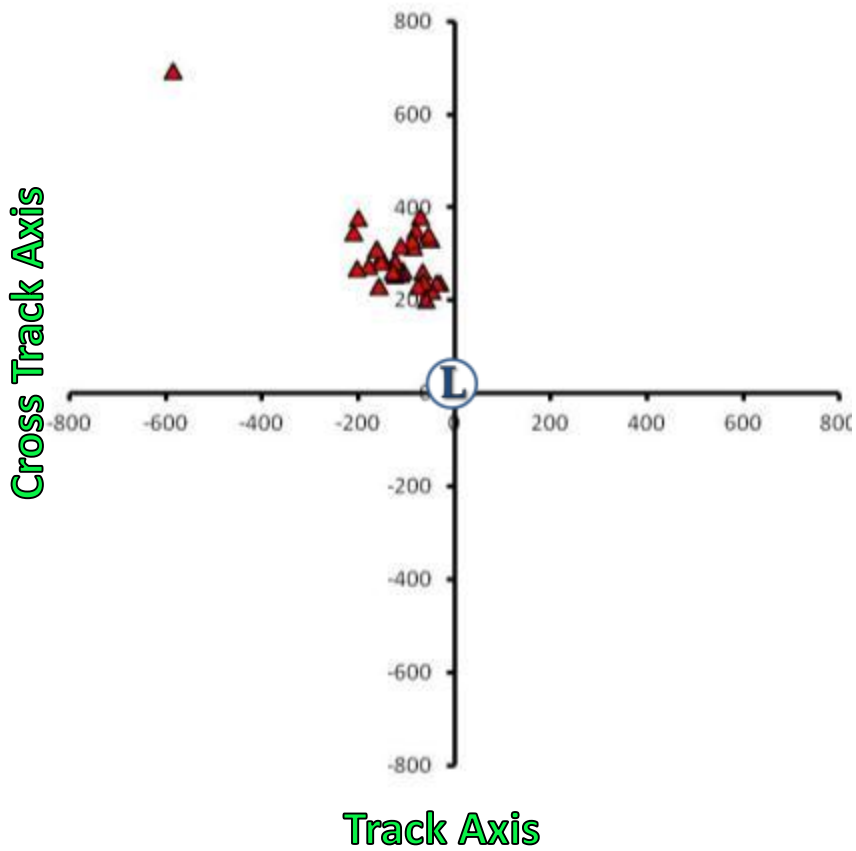
Questions?

c. Frontal interactions vs. flash flood centroids



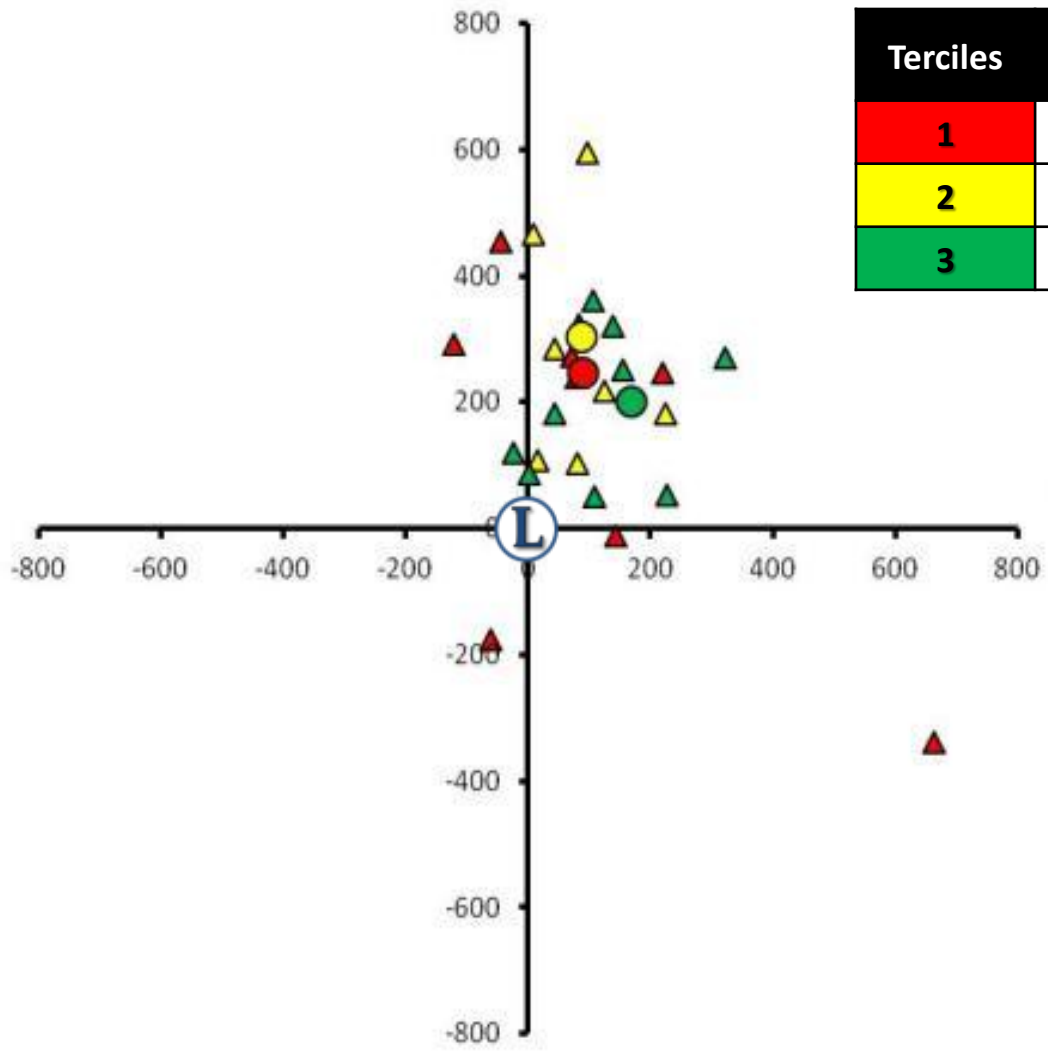
b. Example of Outliers

Georges 1998



c. TC speed of movement vs. tornado centroids

Cross Track Axis



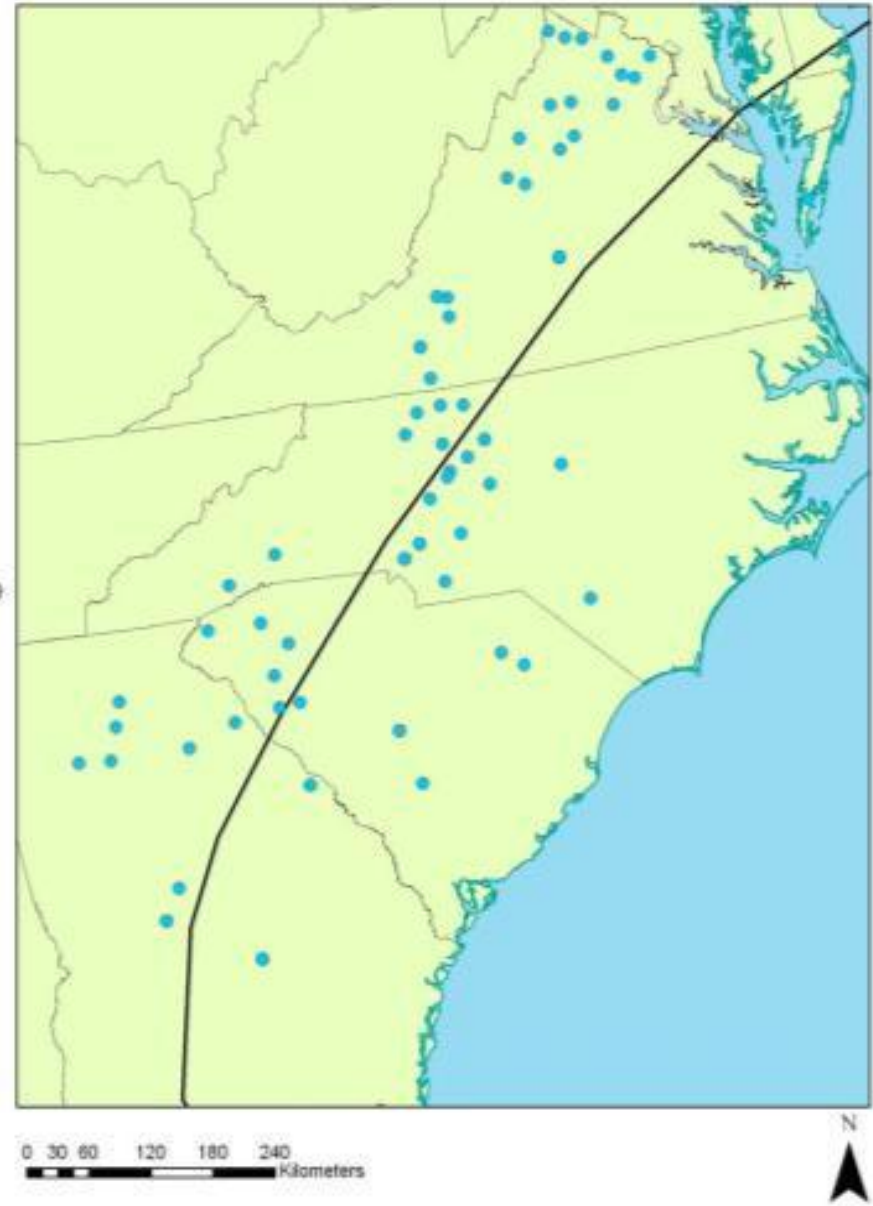
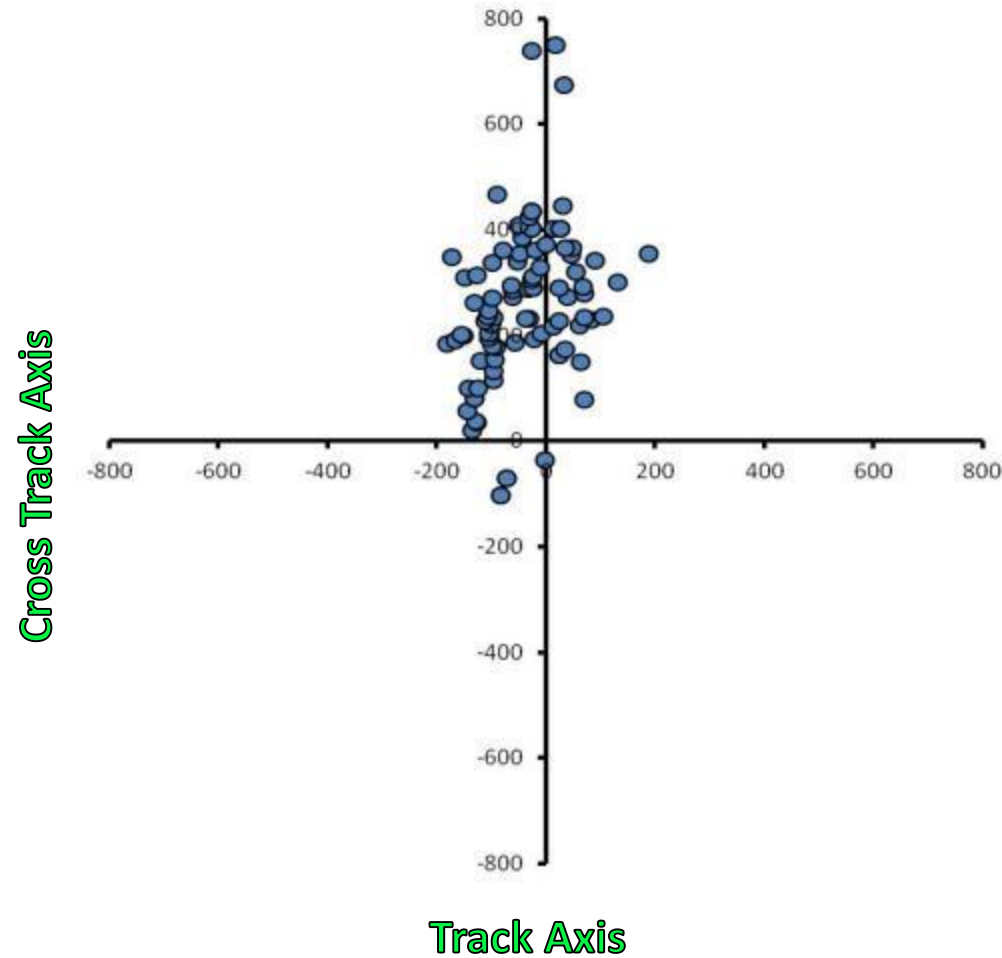
Terciles	Speed of Movement (mph)	Spatial Dispersion
1	19 to 40	324
2	12 to 18.9	301
3	2.2 to 11.9	229

- The TC speed of movement was negative correlated with tornado counts ($r = -0.398$, $p\text{-value} < 0.05$)

Track Axis

b. Example of Outliers

Jeanne (2004)



Nearly, 66% of Jeanne's flash flood impacts were located left of the TC track.

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