The Clustering of Extreme Weather Events in the Southeast U.S. with Respect to Time And Their Relationship with the Planetary Scale Circulation

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Introduction

A very small portion of weather events are responsible for the vast majority of impacts to human and environmental systems.

These extreme weather events show much unevenness in terms of their occurrence with respect to time. Long periods of quiescent weather are found that are punctuated by short periods in which extreme weather events are clustered.

For some types of extreme weather, such as hurricane landfalls and arctic outbreaks, these temporal clusters show some relationship with anomalous patterns observed in the planetary scale circulation.

In this study, the temporal clustering of 7 types of extreme events are identified over a 58 year period and related to anomalies in the planetary scale and ocean circulation as summarized by circulation and sea surface temperature (SST) indices.

Methodology

Seven types of extreme weather are investigated for the period 1950-2007 across the southeastern U.S (Fig.1). Only weather events with a regional recurrence interval of one year or greater considered in this study.

The intensities of the 7 extreme event types were summed across each season and associated with the mean circulation/ocean index values for that season: **Winter season** (Dec-Feb): heavy snow, ice storms, and Arctic outbreaks; **Spring season** (Mar-May): tornadoes; and **Summer and early Fall season** (Jun-Oct): tropical cyclones, heavy rainfall, heat waves.

Heavy snowfall events and **ice storms** identified from daily summaries of snow totals and hourly precipitation measurements, respectively, at 18 first order stations (Fig. 1). These winter weather events are defined by the occurrence of a contiguous period of precipitation as discerned from Hourly Precipitation Data (HPD). A regional event magnitude was estimated by computing the mean snowfall and freezing rain total across the 18 stations.

Arctic air outbreaks and **heat waves** identified from minimums and maximums, respectively, in the 4-day mean temperature series at each station in the network. Local events with a 1-yr or greater return interval were averaged across the 18 station network to assess the event's regional intensity or magnitude.

Heavy rainfall events identified from maximums in 2-day precipitation totals at each station. Events with a local 1-yr or greater return interval were averaged across the 18 station network to provide a measure of the regional magnitude.

Landfalling tropical cyclones (i.e. tropical storms and hurricanes) were identified across the region from 6-hourly position and intensity information from the National Hurricane Center (NHC). The intensity of each cyclone is assessed from the maximum sustained wind observed at the 6-hr map times around landfall.

Tornadic events identified across the region from severe storm reports obtained from the National Climatic Data Center (NCDC). The magnitude of each event estimated from the number of reported F2 and greater intensity tornadoes. Note that this statistic does not show an observer bias with respect to time.

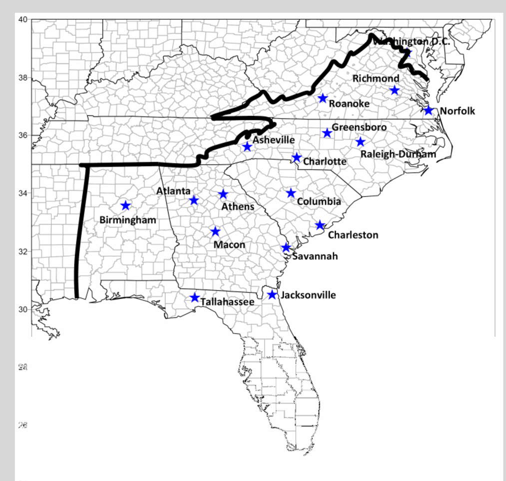

Figure 1. The Southeast United States and locations of the 18 first-order weather stations used in this study.

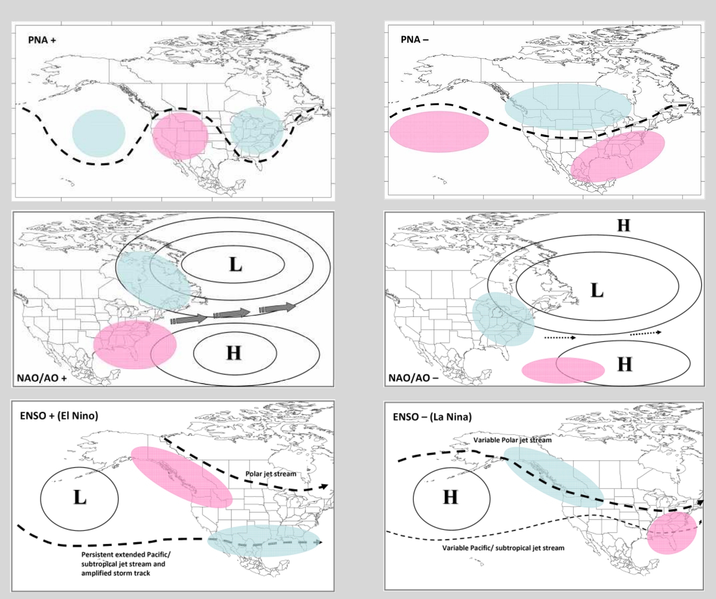

Figure 2. Schematic diagrams illustrating the planetary scale circulation pattern and lower-tropospheric temperature anomalies (cold anomalies shaded blue, warm anomalies shaded red) associated with positive (left panel) and negative (right panel) phases of the Pacific-North American Pattern (top row), the North Atlantic Oscillation and Arctic Oscillation (middle row), and the El Nino-Southern Oscillation (bottom row). Solid (dashed) lines indicate surface (mid-tropospheric) pressure pattern. Arrows indicate the extent of the primary storm track.

Pacific–North American Pattern (PNA). Positive (negative) values of connected with middle tropospheric ridging and troughing across the eastern Pacific /western North America and southeastern North America, respectively.

North Atlantic Oscillation (NAO). Positive (negative) values associated with zonal (meridional) flow across the North Atlantic and ridging (troughing) over the eastern U.S.

Arctic Oscillation (AO). Similar to the NAO. Positive (negative) values are connected with low (high) pressures in the Arctic region and strong zonal (weaker meridional) flow in the mid-latitudes.

El Nino–Southern Oscillation (ENSO). Positive (negative) values associated with El Nino (La Nina) events in the equatorial Pacific. El Nino events are correlated with a stronger than normal subtropical jet stream across the extreme southeastern U.S during the winter along with ridging in the Pacific Northwest. La Ninas are associated with a more variable jet steam that frequently passes north of the southeastern U.S. during the winter.

Pacific Decadal Oscillation (PDO). Positive (negative) values are tied to below (above) normal SSTs in the North Pacific and middle tropospheric ridging (troughing) across northwestern North America during the winter - i.e. PNA positive (negative) pattern.

Atlantic Multi-Decadal Oscillation (AMO). Positive (negative) values are tied to above (below) normal SSTs across the North Atlantic Ocean.

Winter Season Circulation and Weather Extremes

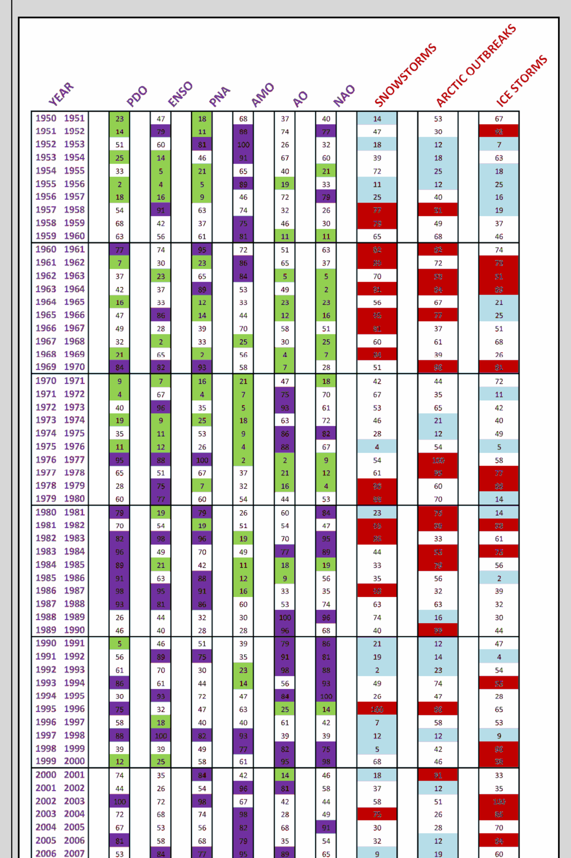

Figure 3. Comparison of the winter season patterns in the circulation & SST indices with the seasonal intensities of heavy snowfall, ice storms, and Arctic outbreaks. The mean seasonal index values and extreme weather intensities are presented as percentiles. Seasons displaying high (top quartile) and low (bottom quartile) mean values in the circulation & SST index are highlighted with violet and green, respectively. Likewise, seasons with a high and low extreme weather intensity are highlighted with red and light blue, respectively.

- **Pacific Decadal Oscillation (PDO)** flips from a preponderance of low seasonal values prior to 1976 (green) to high values (violet) after 1976. The abrupt shift in the PDO pattern correlates with the following changes:
  - Change in **El Nino-Southern Oscillation (ENSO)** from frequent La Ninas (negative ENSO) prior to 1976 to more frequent and intense El Ninos (positive ENSO) after 1976
  - Change in the **Pacific-North American Pattern (PNA)** from a frequent PNA negative pattern with zonal flow across the U.S. to a frequent PNA positive pattern with a ridge across northwest North America and a trough across eastern North America
- The highly-correlated **North Atlantic Oscillation (NAO)** and **Arctic Oscillation (AO)** flip from a regime with frequent negative values (green) to one with positive values (violet) beginning in the 1980s
- The **Atlantic Multi-Decadal Oscillation (AMO)** flips from a warm pattern (violet) prior to 1962 to a cool pattern (green) that persists into the 1990s. From the mid-1990s onward, an exceptionally warm pattern persists.
- **Snowstorms** and **arctic outbreaks** both exhibit two temporal periods of high activity: late 1950s-late 1960s and late1970s-mid 1980s (red). Both of these temporal clusters coincide with the frequent occurrence of negative NAO and AO circulations (purple).
- **Ice storms** show a similar clustering, but not as pronounced. More significantly, 6 of the 14 winters between 1994-2007 are associated with exceptional ice storm intensities. This may be tied physically to positive AMO anomalies (e.g., warmer/moister Atlantic air advected over shallow cold wedge east of the Appalachians), which dominate over much of this period.

Summer and Fall Season Circulation and Extremes

- **Landfalling tropical cyclones** show two distinct decadal periods of high intensity along the Southeast coast: 1950s and mid-1990s to mid-2000s, both of which correspond with exceptionally positive AMO values (i.e., warmer Atlantic SSTs that support more tropical cyclone activity). Only one exceptional year occurred between 1968 and 1995, a period in which exceptionally negative values of the AMO were common. Only a slight association is identified between ENSO and tropical cyclone activity.
- **Heavy rainfall** displays a more even secular distribution with the greatest clustering between 1985-1995 (6 of 11 years display a high magnitude). Six of the 15 exceptional heavy rain years were also exceptional with respect to tropical cyclone intensity. There is no clear connection identified with any particular circulation index. This may be related to the fact that a range of synoptic scenarios and associated planetary scale circulations can produce exceptional rainfall.
- **Heat waves** show a marked increase in their seasonal magnitude from 1977-2007. However, they are strongly clustered during the beginning of this period (1977-1988: 8 out of 11 summers), which coincides with anomalously high PDO values (green). In contrast, nearly half of the summers between 1958-1976 showed an exceptionally low occurrence of heat waves (light blue). This period can be associated with a preponderance of exceptionally low PDO values.

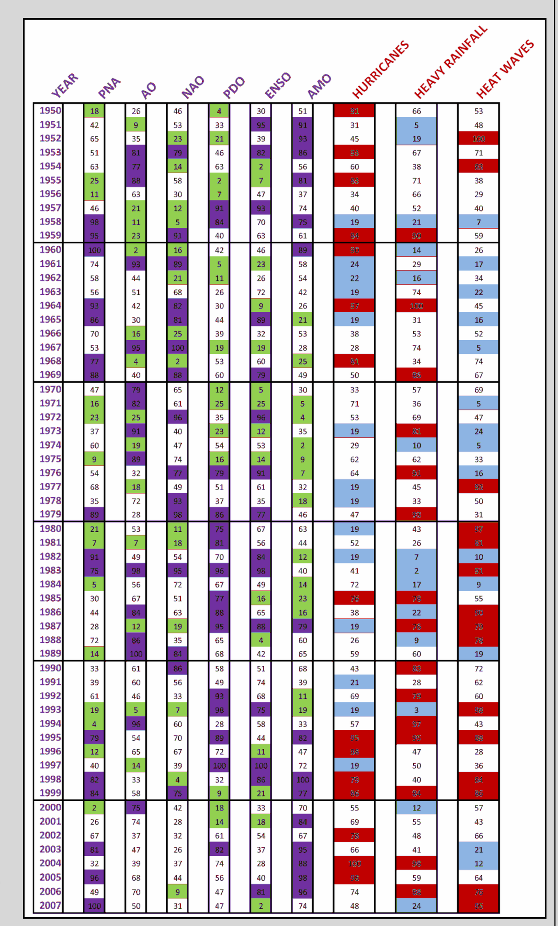

Figure 4. Comparison of the summer and early fall patterns in the circulation & SST indices with the seasonal intensities of tropical cyclones, heavy rainfall and heat waves. The mean seasonal index values and extreme weather intensities are presented as percentiles. Seasons displaying high (top quartile) and low (bottom quartile) mean values in the circulation & SST index are highlighted with violet and light green, respectively. Likewise, seasons with a high and low extreme weather intensity are highlighted with red and light blue, respectively.

Spring Season Circulation and Tornadoes

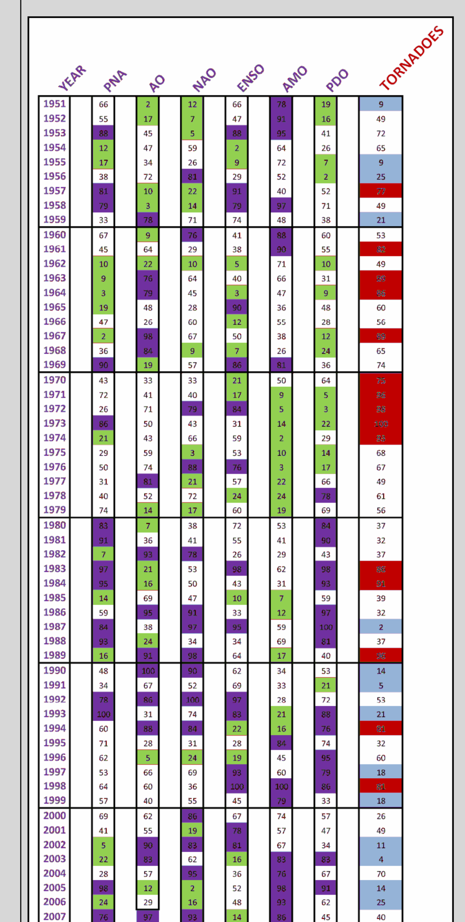

Figure 5. Comparison of the secular patterns in the circulation & SST indices with annual tornado intensities (i.e. number of F2 and greater tornado frequencies). The mean seasonal index values and the tornado intensities are presented as percentiles. Seasons displaying high (top quartile) and low (bottom quartile) mean values in a given circulation &SST index are highlighted with purple and light green, respectively. Likewise, seasons with a high and low numbers of F2 and greater tornadoes are highlighted with red and light blue, respectively.

- **Tornadoes** show much temporal clustering from 1961-1974 (9 out of 15 seasons were exceptional), with every season from 1970-1974 exceptional.
- This coincides with a period in which many seasons show exceptionally low PDO values (troughing across western North America).
- Interestingly, 6 of the last 10 spring seasons display an exceptionally low number of tornadoes (F2 strength and greater) with no apparent connection to the PDO.

Summary

- No long term trend is revealed in the aggregate intensity/frequency of extreme events across the southeastern U.S.
- The greatest temporal clustering of extreme weather occurred between 1959-1970 (6 out of the 12 years in the top quartile) with a high frequency of snowstorms, arctic outbreaks, and tornadoes.
- A secondary maximum in extreme weather occurred between 1994-1999 (4 out of 6 years in the top quartile) with a high frequency of heavy rainfall, hurricanes, and heat waves.
- Much of the 1950s showed a relative lack of extreme weather (4 out of 8 years in the bottom quartile) with very few major ice storms, arctic outbreaks, tornadoes, and heavy rainfall events.
- The 2000s have been relatively quiescent with respect to extreme weather (only 1 out of 7 years in the top quartile). Ice storms and hurricanes have been most prolific, but there has been a lack of arctic outbreaks, snowstorms, and F2 and greater tornadic events.

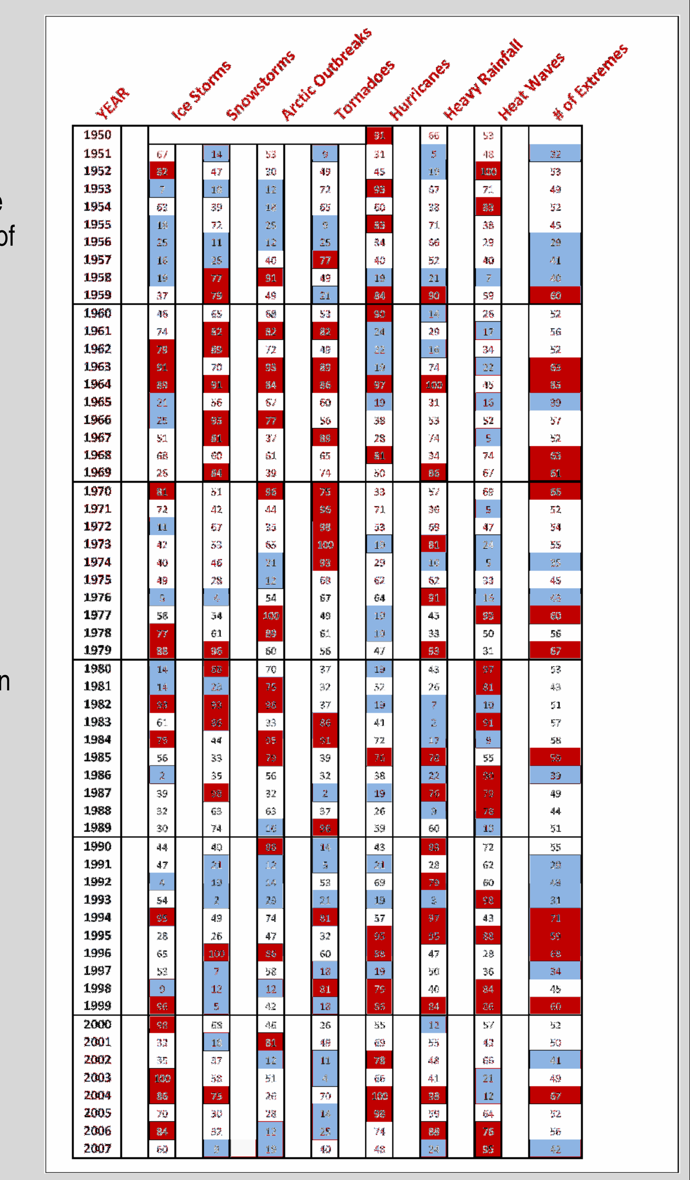

Figure 6. Summary of the secular patterns of extreme weather across the Southeast. Annual extreme weather intensities are presented as percentiles with exceptional years colorized (top and bottom quartiles highlighted with red and light blue, respectively). The extreme weather intensity provides an overall annual measure of the number and intensity of extreme weather occurrences across the Southeast. It is determined by calculating the mean intensity across the seven different types of extreme weather for each year.