Relating Clustered Convective Events To Land-Surface Features in Mississippi

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Introduction

It is well recognized that the development of quasi-steady supercell storms has been linked to the ingestion and tilting of horizontal vorticity into the updraft region of a storm. Typically these circulations are generated and sustained through a vertically sheared atmosphere. Until recently, with the exception of dynamic processes that create horizontal rolls (i.e. thunderstorm outflow, sea-breezes, etc…) these horizontal rolls were considered to exist randomly across the landscape. However, recent studies (Brown and Arnold, 1998, Koch and Ray, 1997) suggest that these circulations may form as a result of surface and boundary layer processes that are confined to recognizable locations. These locations were all associated with a vegetation or soil type transition zone. For example Koch and Ray, 1997 found a region of enhanced convection associated along the Sand Hills and Piedmont regions of North Carolina. In addition Brown and Arnold, 1998 found clusters of convective activity along a sharp vegetation transition in east-central Illinois. An understanding of the regions favorable to, and processes involved in the generation of local horizontal vorticity and the local destabilization of the Planetary Boundary Layer (PBL) should lead to more reliable forecasting of deep convective development and intensification.

This study attempts to identify regions within the state of Mississippi that are statistically more favorable for the generation of free convection. It is anticipated that through the identification of preferential convective regions, further research may capture the processes associated with land-surface-atmosphere interactions. Therefore, no attempt will be made to discern the meso-, local-, or storm-scale processes involved in the modification of the PBL. Instead generalizations and potential land-surface-atmosphere linkages will be discussed.

Background

During periods of weak synoptic flow, surface cover type and/or soil heterogeneity can lead to the development of thermally induced circulations known as Non-Classical Mesoscale Circulations (NCMCs) (Segal and Arritt, 1992) across the surface boundaries (Garrett, 1982; Mahfouf et al., 1987; Segal and Arritt, 1992). The idea that surface heterogeneity may be linked to convective activity is not new. Black (1963) and Black and Tarmy (1963) proposed the idea of building asphalt islands in order to generate thermal updrafts that could potentially trigger convective rain showers in North Africa. However, considering the negative environmental impacts the plan was never initiated. Rabin et al. (1990) showed that the location of convective clouds, under weak synoptic forcing, is determined by the relative positions of dry and moist areas. Rabin defined moist land areas are those in which the Bowen ratio (sensible heat/latent heat) is less than one. Ookouchi et al. (1984) determined that large contrasts in soil moisture, and therefore large differences in sensible and latent heat partitioning, along relatively flat terrain was capable of producing thermally direct circulations equivalent in magnitude to that of a sea-breeze. Regions of increased soil moisture are expected to increase evapotranspiration rates leading to larger latent heat values and the development of thermal gradients and baroclinic circulations. Arnold, (1994), Koch and Ray, (1996), and Brown, (2003) suggest that the development of mesoscale circulations via differential heating may contribute to regions of enhanced severe weather. Koch and Ray, (1996) found that when preexisting convection intersects a mesoscale thermal boundary there is a strong likelihood that the convection will increase in intensity. Arnold, (1994) has linked a tornado corridor in southwest Indiana to a soil type boundary in the same region, and Brown, (2003) noted that a soil type discontinuity in eastern North Carolina was related to a marked increase in tornadic activity as compared to nearby homogeneous locations.

Data and Methods

Land Surface Information

The objective of this study is to identify surface discontinuities that have the potential to significantly contribute in the production of local scale circulations via differential heating. The state of Mississippi was chosen for this study because of the large homogeneous surface cover (agriculture and forest) and widely varying soil type regions with relatively sharp surface change boundaries. Geological formation data (Figure 1.) were extracted from the Mississippi Automated Resources Information System (MARIS) and placed into an ArcView GIS database. This database will allow for spatial comparison between surface features and atmospheric events.

First Convection Data

First convection is defined as the first cumulus convection identified using Geostationary Operational Environmental Satellite (GOES) visible imagery during a study day. The period of study for this portion of the project includes the summer months of June, July and August, 1990 – 1994. These months are associated with a distinct absence of synoptic forcing features and instead are dominated by differential heating. Given the relatively early planting season in Mississippi it is anticipated that agricultural vegetation will have reached a maximum leaf-area index and with adequate soil moisture will be transpiring at a high rate throughout these months. Individual study days were chosen if: for a 24 hour period there were no synoptic scale frontal boundaries located within 300 kilometers of Mississippi; 500mb wind speeds above and upstream of Mississippi were less than 15 knots; and surface winds were less than 10 knots. These criteria were developed to help ensure that convection was related to local scale surface destabilization and not synoptically forced. Forty-four days met these criteria.

The identification of first convection was achieved employing a methodology similar to Brown and Arnold, (1998) in which the location of the initial convection is corrected for solar angle and satellite nadir. These corrections insure a spatially representative first convective cloud climatology. Visual imagery was chosen over Infrared imagery due to its finer spatial resolution. No attempt is made to discern cloud heights. In fact, given that the anticipated convective initiation process is differential surface heating, the majority of the identified clouds may be confined to the Planetary Boundary Layer.

Historical Tornado Data

Tornado data was extracted from the Historical Severe Weather Report Database provided by the Storm Prediction Center, for the state of Mississippi, 1950-2000. These data provided the initial location (given in latitude and longitude coordinates) for all recorded tornadoes within the study region. While these data provide a good summary of tornado events within the study region, there are limitations to their use. It is well known that the reporting of severe weather events is subject to considerable spatial and temporal bias (Changnon, 1977; Kelly and Schaefer 1985; Doswell and Burgess, 1988). These potential biases are less of a concern for tornado data, relative to severe wind or hail reports, specifically because tornadoes can often be identified by the damage inflicted even when visual confirmation at the time of the event is unavailable. This is not to suggest that weak tornadoes might not be excluded from the data set even during daylight hours. Weak and short-lived tornadoes can be difficult to identify, especially by the untrained public. Nevertheless, there are clearly more reports of severe weather from densely populated urban areas than from sparsely populated rural areas. For this reason the raw tornado data were adjusted for a potential population bias. This adjustment removed all weak (F0 and F1) tornadoes, which were found to occur within 5 miles of population center with 10,000 or more residences (as defined by the 2000 census).

Spatial Testing of First Convection and Historical Tornadoes

Quadrant testing and density analysis (Barber, 1988) were used to determine if the first convection and tornado data were spatially clustered. The Quadrant test utilized a 50km grid cell to determine if the spatial distribution of events was significantly non-uniform or non-random. The density analysis used a finer grid cell (10km) in order to better locate individual regions of clustering.

Results

First Convection

Due to the complexity yet relatively subtle differences in nearby soils, physiographic regions (Figure 2.) of Mississippi were used to describe the surface of Mississippi. Physiographic regions encompass the underlying geology (including soil types) and topography. Table 1. indicates the general soil classification and topography of each physiographic region within Mississippi.

An examination of the temporal distribution of the 209 first convection events (Figure 3.) shows a temporal peak of events between 18z and 19z, with the majority of occurrences in the early or mid-afternoon hours. This finding is similar to Rabin et al., (1990) and is not surprising given the weak synoptic conditions and time necessary for ascending parcels to adequately mix the PBL eventually reaching the convective condensation level (CCL). The temporal clustering of events in the early and mid-afternoon suggests that synoptic scale forcing has been successfully eliminated from the data.

An inspection of the spatial distribution of the first convection events suggests that a many of the events occur near physiographic boundaries (Figure 4.). In fact, nearly one-third of the events are found within 5 miles and nearly one-half of the events are within 10 miles of a physiographic boundary. Quadrant and Nearest Neighbor tests indicate that the clustering is statistically different from a random distribution at $p= 0.005$. A density analysis of the first convective data indicates regions of mesoscale clustering (solid line) with embedded regions of sub-cluster centroids (i.e. local scale clusters) (Figure 5.). The clustered regions encompass 25.8% of the total study area and 67.0% of all first convective events.

The high density clustering of first convective events along the Gulf of Mexico coast (FC-1) is not surprising given the vast contrast in surfaces and subsequent generation of a sea-breeze front. Of the remaining five clustered regions, two are co-located with changing physiographic regions. The second cluster of note is the north-south oriented cluster in the northeast portion of the state (FC-2). This clustered region is just east of, and parallels the Blackland physiographic region. Similarly a west-east oriented cluster in the east-central portion of the state (FC-3) is located just south and parallel to another region of Blacklands. The majority of the raw convective events in these two clusters are located over the more sandy soils of the Upper- and Lower-Coastal Plain. This suggests that differential heating between the sandy Coastal-Plain regions and more clay dominant Blacklands is resulting in a local destabilization of the atmosphere. It is, therefore, likely that the differing soil-order characteristics, especially surface tension and porosity (Mahfouf et al., 1987), have an effect on the evaporative flux and ultimately the partitioning of sensible (QH) and latent (QE) energy. Segal and Arritt (1992) show that the generation and strength of Non-Classical Mesoscale Circulations is directly proportional to the strength of soil moisture characteristics. A fourth cluster oriented southwest-northeast in the west-central portion of the state (FC-4) is located near the transition from the sandy-loam Delta to the silty-loam / loess region of the Natchez formation. This transition region is also associated with an abrupt elevation increase (moving from the west (Mississippi floodplain) to the east) and there is therefore less certainty in first convective forcing mechanisms.

Historical Tornadoes

Cluster testing and density analysis were applied to the 979 tornado events (Figure 6.). Similar to the first convection data, a statistically significant ($p=0.031$) clustered pattern was indicated (Figure 7). Visually the tornado clusters are not as distinguishable relative to the first convection clustering. This is likely a result of the larger data set and overlapping point locations. Individual data points included in a cluster where examined to ensure that a single or a few multiple tornado outbreaks were not the cause of the clustering. Eliminating temporally similar data points did not change the outcome of the cluster analysis.

In an attempt to further identify potential population biases a visual comparison between the cluster locations and tornado frequency normalized by county size and population was made (Figures 7 and 8). It appears that the clusters are in regions where there is a high frequency of population normalized tornadoes suggesting these data are not biased.

The five clustered regions identified (Figure 7) encompass 17.6% of the study area and are found to contain 35.8% of all tornado events. Similar to the first convective data (FC-1), the highest density tornado cluster is located in extreme southern Mississippi (T-1). However, compared to FC-1 the tornado clustering in this region is shifted westward and is positioned near the St. Louis Bay. Three of the remaining four tornado clusters (T-2, T-3, and T-4) are near and parallel to Blackland regions. The last of the tornado clusters (T-5) is similar to FC-4 in that it is located along the southern extent of the transition region from the Mississippi floodplain to the silty-loam of the Natchez formation.

Summary / Concluding Remarks

No attempt was made to ascertain the exact processes responsible for the location of the first convection or tornado events. However, there is compelling visual and statistical evidence that during periods of weak synoptic flow, mesoscale surface features aid in the local destabilization of the PBL. The locations of the statistically significant first convection clusters suggest that uplift is enhanced over regions of sandy soils thereby potentially advecting PBL moisture from nearby regions dominated by clay soils.

Similar to the findings of Changnon, 1962; Arnold, 1994; and Brown and Arnold, 1998, the variation in sensible and latent heat partitioning across surface/soil boundaries may also be partially responsible for the clustering of tornado events. A study in Colorado, conducted by Wilson and Schreiber (1986) found that 79% of storms with radar reflectivities greater than 30 dBZ were associated with a surface convergence boundary. More recently Markowski et al., (1998) found that 70% of the tornadoes observed during project VORTEX were associated with pre-existing low-level boundaries. Clearly the ability to locate these quasi-stationarly boundaries (i.e. vegetation, soil type, soil moisture, etc…) would greatly enhance severe weather nowcasting and forecasting. Future research in Mississippi should give special attention to the regions of statistically significant cluster overlap (Figure 9). It is in these regions that land-surface-atmosphere processes may be most pronounced during synoptically benign and active periods.

However, it must be noted that many of Mississippi’s tornado events occur during the late fall or early winter season. In addition a considerable number of the tornado events are nocturnal. Therefore it is likely not appropriate to suggest that mesoscale differential surface heating plays a significant role in the location of these events. Instead, it may be more useful to compare a subset of warm season daytime tornadoes to the first convective locations.

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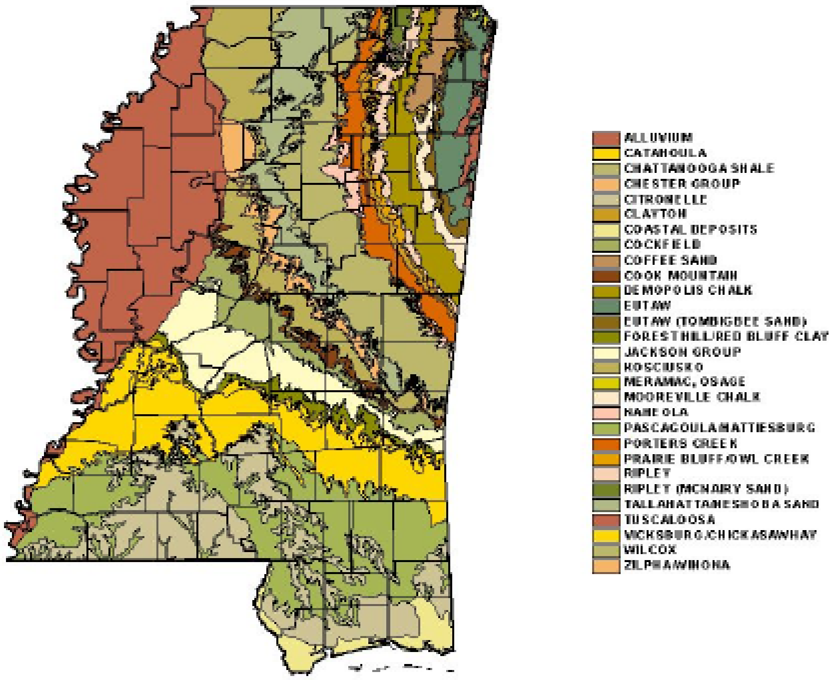

Figure 1. Geologic Formations of Mississippi.

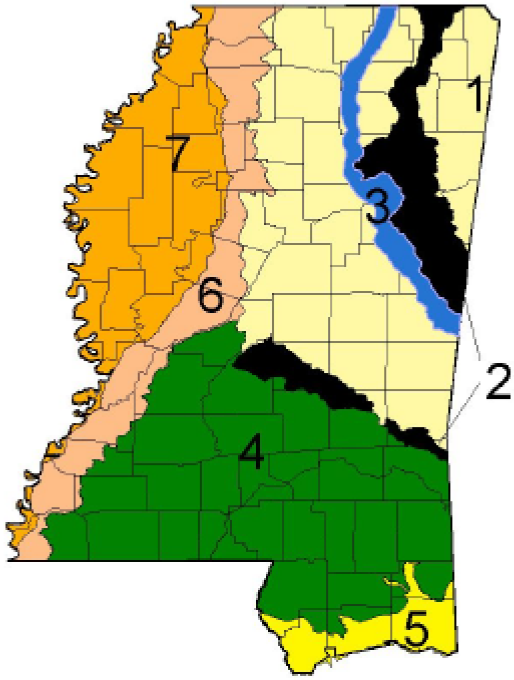

Figure 2. Physiographic Regions of Mississippi.

Table 1. General Description of Physiographic Regions.

	Region	General Soil Characteristics	General Topography
1	Upper Coastal Plain	Sandy Loam w/clay	Deep cut valleys
2	Blacklands	Clay	Broad prarie plains
3	Interior Flatwoods	Clay	Lack of relief
4	Lower Coastal Plain / Pine Belt (south)	Sandy Loam	Rolling hills with broad valleys
5	Coastal Flatwoods	Sand	Flat plain
6	Natchez Formation	Silty Clay Loam	Steep cliff slopes
7	Delta	Sandy Loam	Flat plain

From: Cooperative Extension Service, Mississippi State University.

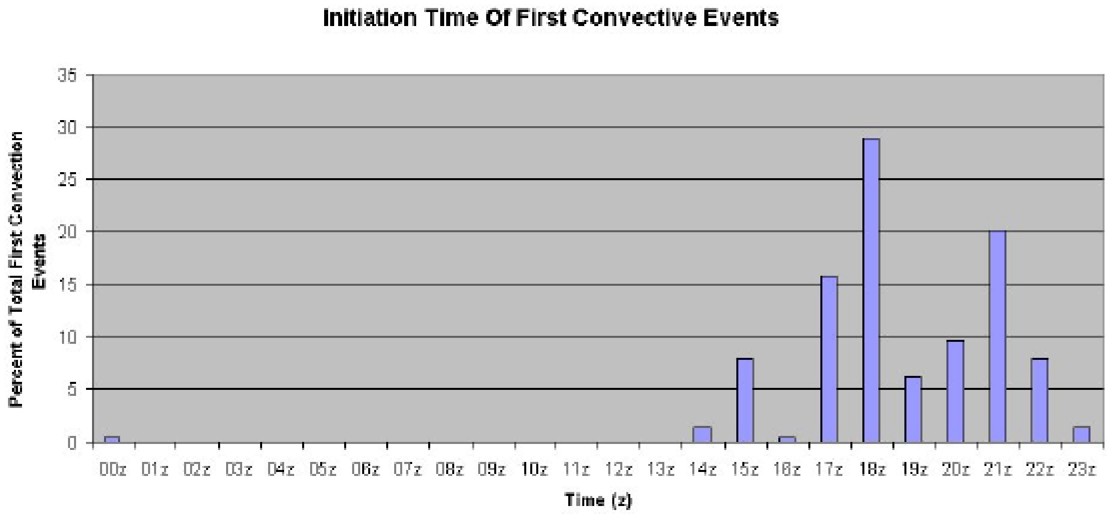

Figure 3. Temporal Distribution of First Convective Events (1990 - 1994).

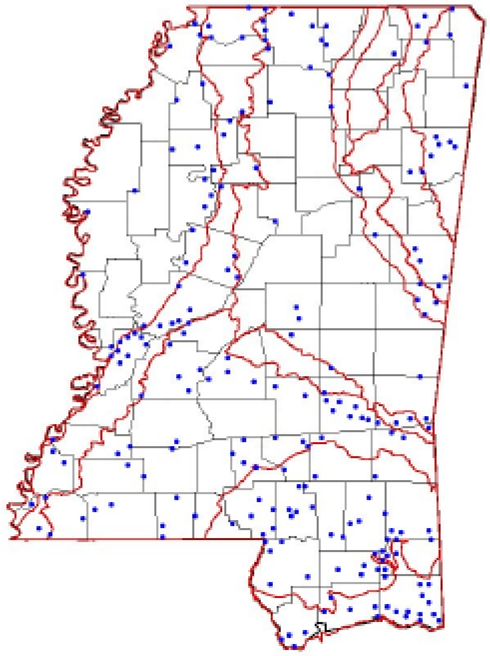

Figure 4. Spatial Distribution of First Convective Events (1990-1994) with Physiographic boundaries.

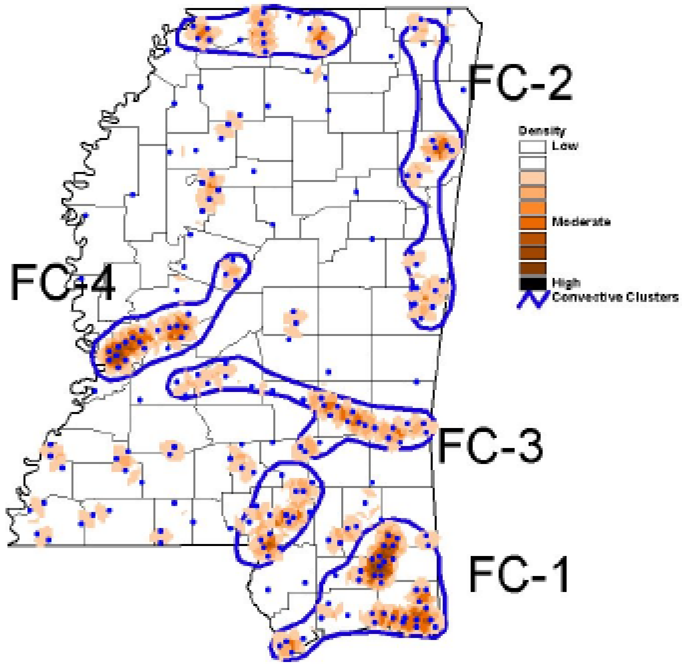

Figure 5. First Convection Clusters and High Density Centers (1990-1994).

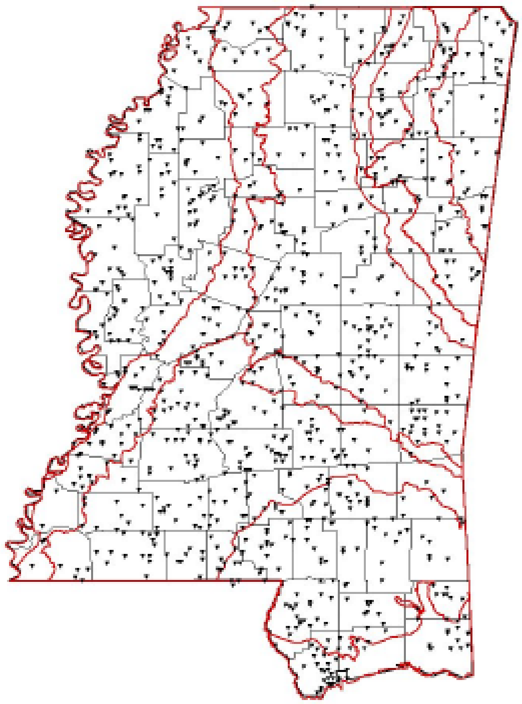

Figure 6. Spatial Distribution of Historical Tornado Events (1950-2000).

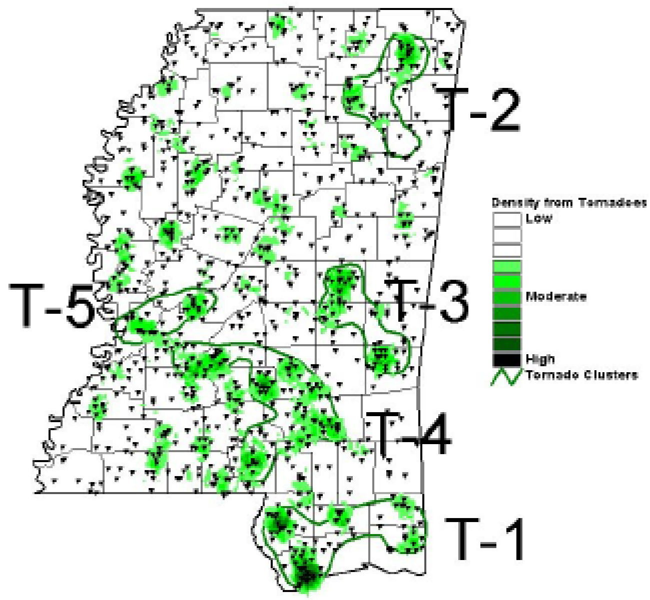

Figure 7. Historical Tornado Clusters and High Density Centers (1950-2000).

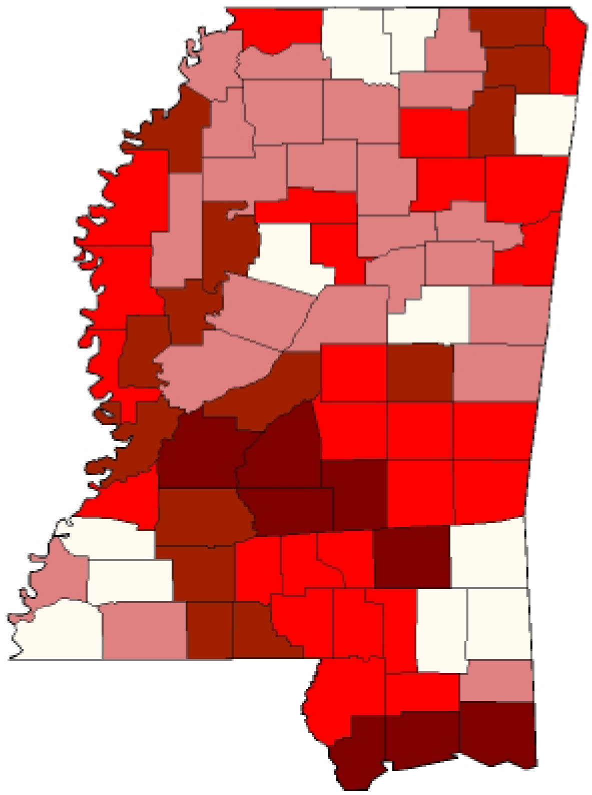

Figure 8. County Level - Population Per Square Mile Normalized Tornado Data (darker shading indicates a higher number of normalized tornado events)

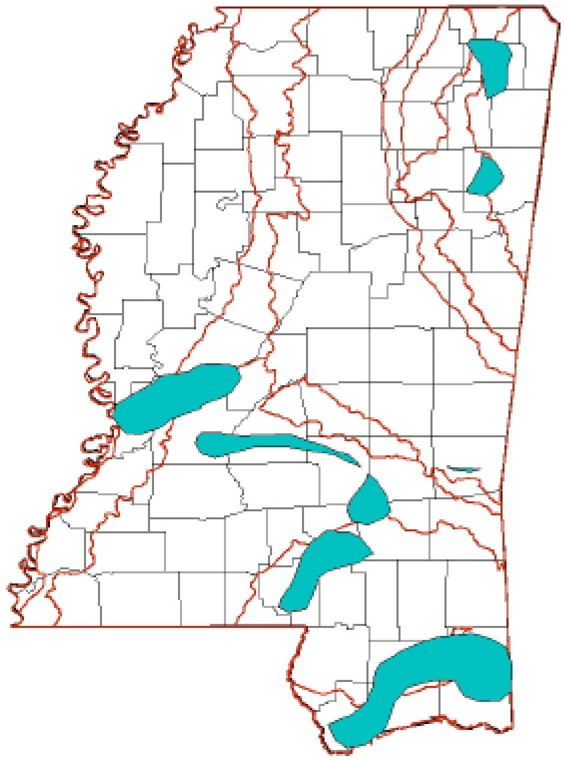

Figure 9. Regions of First Convection and Historical Tornado Cluster Overlap.