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Investigation of Vegetation Discontinuities Related to the Yazoo City Tornado Scar and Enhanced Convection

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Abstract

The Yazoo City tornado occurred on April 24, 2010, traveling 240 km from Tallulah, Louisiana through Yazoo City, Mississippi and ending near Starkville, Mississippi. The tornado reached a maximum wind speed of 76 m s^{-1} and obtained a maximum width of 2.8 km. Landsat imagery showed a distinct vegetation scar along the majority of the path of the tornado. Abrupt changes in vegetation and the related sensible and latent heat fluxes have been shown to enhance convective activity along and near the resulting land surface discontinuities. The enhancement of convection is likely related to mesoscale circulations generated along thermal and moisture discontinuities and is best identified during synoptically benign periods. This study analyzed heightened convective activity (analyzed by looking at cloud-to-ground lightning data) along the Yazoo City tornado track on days of weak synoptic forcing. 2010 had the greatest percentage of convectively active synoptically benign days with 66 percent. Years prior to the Yazoo City tornado had a lower percentage of convectively active synoptically benign days with 50 percent.

Keywords: Convection; Mesoscale; Lightning; Tornado; Track; Sensible; Latent

Introduction

The Yazoo City tornado occurred on April 24, 2010, traveling 240 km (149 mi) from Tallulah, Louisiana through Yazoo City, Mississippi and ending near Starkville, Mississippi. The tornado reached a maximum wind speed of 76 m s^{-1} (170 mph) (EF4 strength) and obtained a maximum width of 2.8 km (1.75 mi). Landsat imagery showed a distinct vegetation scar along the majority of the path of the tornado. This study used lightning data to determine if the disruption of the landscape by the tornado could enhance future convection. In order to ensure that the vegetation scar and related thermal discontinuity were driving any enhancement in convection, only synoptically benign days were chosen for this study. Synoptically benign days during the months of June, July, and August 2006 – 2010 between 12 P.M. and 8 P.M. LDT were analyzed.

Abrupt changes in vegetation and related sensible and latent heat fluxes have been shown to enhance convective activity along, and near, the land surface discontinuity [1-17]. The enhancement of convection is likely related to mesoscale circulations generated along thermal and moisture discontinuities and are best identified during synoptically benign periods [2,7,9,11,12]. Decreasing the density or coverage of vegetation, and ultimately the latent heat of a region will increase the sensible heat thereby creating a pronounced thermal gradient with the surrounding undisturbed vegetation areas [2].

Convective clouds tend to occur along landscape and moisture discontinuities when increased boundary layer moisture is present [2,8,11,14,18,19]. A strong thermal gradient can be generated, similar to a sea breeze, between moist and dry surfaces, which can aid in convection especially in the presence of a moist boundary layer [9,19]. This convection tends to occur around 1700 LST, with an additional 4 to 5 hours needed to initiate deep convection through the generation of strong Non-Classical Mesoscale Circulations (NCMCs), which occur along thermal boundaries [2]. This study will attempt to determine if thermal discontinuities and related areas of enhanced uplift from the Yazoo City tornado scar can be seen in the cloud-to-ground lightning record.

Lightning is defined as an electrical discharge in the atmosphere that occurs through the separation of positive and negative charges within the cloud [20,21]. The electrical discharge that produces lightning is the result of an existing high voltage gradient occurring between clouds or a cloud and the ground that overcomes the electrical resistance of air. Lightning can occur in three ways: intra-cloud (IC), cloud-to-cloud (CC), and cloud-to-ground (CG). CG lightning is defined as any stroke of lightning that makes its way from the cloud to the Earth's surface [21]. Only 20 percent of all lightning strikes occur between the cloud and the ground [20,21]. CG lightning typically forms through a negative polarity stroke in which lightning travels from the ground (positive charge) to the base of the cloud (negative charge) in an upward current [21].

The National Lightning Detection Network (NLDN) shows thunderstorm activity in the contiguous United States through the presence of lightning strike data. These data are collected across the United States utilizing over 100 sensors that record the time and location of each lightning strike by detecting the electromagnetic radiation produced from the strike. Since 1989, the NLDN has been detecting approximately 95% of all lightning strikes in the contiguous United States and recording the location, polarity, signal strength, and multiplicity for each strike [22].

Thunderstorm development requires warm, moist air in the lower troposphere, which is readily available along the Gulf Coast and southern Atlantic Coast during the summer months of June, July, and August when lightning frequency is the greatest [21]. The contiguous United States experiences an average of 20 million CG lightning strikes annually, with the greatest strike density occurring in central Florida followed by the Gulf Coast and southern Atlantic Coast where

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thunderstorm duration is heightened [21,23,24]. Florida and the Gulf Coast also receive the highest amounts of lightning days annually due to the availability of warm, moist air, resulting in conditional instability from the Gulf of Mexico [25].

Materials and Methods

Landsat

Landsat images were used to determine the thermal difference between the tornado scar and surrounding vegetation through the extraction of skin surface temperatures. Landsat images were acquired from the United States Geological Survey (USGS). Landsat data uses digital numbers, which range from 0 – 255; 0 representing black and 255 representing white, to examine surface skin temperatures. Surface skin temperatures were used to better assess any thermal difference between the tornado scar and surrounding vegetation. Landsat data from the USGS have a pixel resolution of up to 40 meters (m), but are typically available at 250 m, 500 m, 1 km, and 2 km. Thematic Mapper (TM), a sensor package on the Landsat 5 satellite, is often used to assess environmental features. There are seven bands contained within TM and each band scans at a different wavelength. TM6 uses a wavelength of 11.457 µm to analyze Land Surface Temperatures [26]. The values extracted were converted to radiance using the formula:

$$CVr = G\left(CVdn\right) + B$$

CVr = cell value as radiance, CVdn = cell value of digital number, G = gain, and B = bias

Once radiance was calculated, the inverse of the Planck function was used to derive the corresponding temperature values [27]. The formula to calculate the Planck function is [28]:

$$\beta = \frac{hc}{k\lambda T}$$

h = Planck's constant, c = speed of light, k = Boltzmann's constant, and T = temperature in Kelvin

Therefore, the formula to convert radiance to temperature is:

$$T = \frac{K2}{\ln\left(\frac{K*E}{CVr}+1\right)}$$

T = degrees in Kelvin, CVr = cell value as radiance, and E = emissivity

For the Landsat TM, K1 and K2 is equal to 607.76 and 1260.56, respectively. For the Landsat Enhanced Thematic Mapper (ETM), K1 and K2 is equal to 666.09 and 1282.71, respectively. Emissivity is estimated through the Normalized Difference Vegetation Index (NDVI). Emissivity is typically estimated at 0.95 for satellite images taken by the USGS [27]. Temperatures were calculated in Kelvin, but then were converted into Celsius [27]. Landsat thermal imagery from June 2010, less than two months after the tornado occurred indicated a surface skin temperature gradient of 8 – 10°C between the scar and surrounding vegetation (Figure 1). Landsat imagery also revealed shallow cumulus clouds forming along the Yazoo City tornado scar (Figure 2).

Tornado tracks

Tornado track data were obtained from the SVRGIS page for the Storm Prediction Center (SPC). The Yazoo City tornado was extracted through Geographic Information Systems (GIS) as an individual shapefile from a severe report database (SVR) dating back to 1950. The shapefile comprised information about the tornado including date, time, location, strength, injuries, fatalities, starting and ending latitude, starting and ending longitude, length in miles, and width in yards. Tornado tracks are generated by connecting the beginning and ending latitude and longitude with a line (SVRGIS SPC).

The Yazoo City tornado track data were imported into GIS and a 7.5 km radius was created from the center of the tornado track. This distance was chosen because the objective of the proposed research was to investigate how vegetation discontinuities created from a tornado scar can enhance convection. A small radius of only 7.5 km should isolate processes associated with the scar and the surrounding vegetation, similar to research by Brown and Arnold [2]. The area was calculated for the tornado track by multiplying the length of tornado track by the diameter of the buffer, 15 km. The Yazoo City tornado encompassed an area of 3,600 km^2.

Four additional test tracks (100 miles north, south, east, and west of the true tornado track) were created in GIS to compare against the percentage of convectively active synoptically benign days along the Yazoo City tornado track. This was done to ensure that any differences found were associated with the thermal discontinuity related to the scar of the Yazoo City tornado.

Lightning

The lightning dataset was acquired from Vaisala's U.S. National Lightning Detection Network (NLDN). The NLDN data includes time, location, polarity, amplitude, and multiplicity of every CG flash across the country. 114 ground based lightning sensors distributed across the U.S. provide thunderstorm detection efficiency in excess of 99% and flash detection efficiency in excess of 95% through the detection of the electromagnetic signals generated as lightning comes in contact with the Earth's surface. The NLDN detects CG lightning flashes, not CC lightning flashes, with location accuracy in excess of 250 meters [29]. Lightning flashes with a current discharge less than 10 kilo amps (kA) [30] or less than 15 kA are typically associated with cloud discharges and are recommended to be removed. For this study, a more aggressive approach was used, similar to Biagi et al. [31], lightning flashes with a current discharge of 0.1 to 15 kA were removed from the dataset.

Lightning data were overlaid into GIS and used as a proxy for

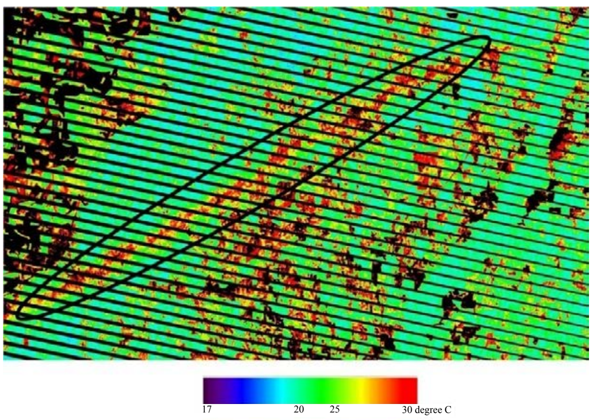

Figure 1: Lands at thermal imagery of the Yazoo City tornado scar surface skin temperature gradient.

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Figure 2: Lands at imagery of shallow cumulus clouds forming along the Yazoo City tornado scar.

	2006	2007	2008	2010
North Track	53	51	50	52
South Track	51	52	55	52
East Track	52	53	50	52
West Track	55	50	55	55
Yazoo City Track	52	50	51	66

Table 1: Percentage of convectively active synoptically benign days.

deep convection. Lightning data analyzed in this study existed within a region extending from southeast Kansas eastward through central Kentucky, and southward into the northern Gulf of Mexico. If five or more cloud-to-ground lightning strikes occurred within a 7.5 km radius of the tornado track between 12 P.M. and 8 P.M. LDT the day was considered convectively active. If less than 5 lightning strikes were recorded on a given day, that day was considered non-convectively active. This time period was used since convection tends to occur in the afternoon in the Southeast during the summer. If both of these parameters were met, the synoptically benign days were considered convectively active.

After a "Yes" was given to all the synoptically benign days considered convectively active pre- and post- tornado years were compared. This comparison should determine whether or not convection has increased due to the tornado scar, and related thermal gradient.

Synoptically benign days

Synoptically benign days were categorized as any day with no synoptic forcing present within 500 km of the study region. These criteria include: Winds of 25 knots or less at 250 millibars (mb); 15 knots or less at 500 mb; and 10 knots or less at the surface [2]. Surface and upper air analysis charts were analyzed at 12Z and 0Z to confirm these conditions were met at Jackson, Mississippi. Jackson, Mississippi was used since the Yazoo City tornado occurred across central Mississippi. Synoptically benign days during the months of June, July, and August 2006 – 2010 were analyzed. These months were used since this is typically when the Southeast experiences the greatest number of synoptically benign days. Vegetation foliage and evapotranspiration are heightened during this time period, which should enhance any vegetation discontinuity and therefore related thermal gradient generated between the tornado scar and surrounding vegetation. Data prior to 2006 were not analyzed due to the landscape-altering effects of Hurricane Katrina in August 2005. Additionally, if any time step, 12Z or 0Z at Jackson, did not meet the criteria of a synoptically benign day, that day was removed from the dataset.

Results and Discussion

GIS was used to visually and quantitatively depict the number of strikes within the 7.5 km radius of each tornado track so that the number of convectively active synoptically benign days could be determined. June, July, and August 2006 - 2010 had a total of 127 synoptically benign days. For the Yazoo City tornado track, 2010 had the greatest percentage of convectively active synoptically benign days with 66 percent. Years prior to the tornado, 2006 - 2008, had a lower percentage of convectively active synoptically benign days with 50 percent. All four test tracks from 2006 - 2010 had an average around 50 percent (Table 1).

A binomial test was used to compare the number of convectively active synoptically benign days to those which were not convectively active. This test utilized categorical data (yes/no convectively active day). It is important to note that this study analyzed the total number of days with 5 or more lightning strikes, not the total number of strikes per day. Any synoptically benign day that had 5 or more lightning strikes was given a yes, while any day with fewer than 5 lightning strikes was given a no. This test provided a likelihood of occurrence at 52 percent. The likelihood of occurrence was determined by the average percentage of convectively active synoptically benign days along each track from 2006 – 2010, excluding 2009. The binomial test returned a p-value of 0.024 for 2010 and was statistically significant at 0.05 indicating that there were more convectively active days post-tornado along the actual tornado track.

Abrupt changes in vegetation can cause enhanced convective activity due to sensible and latent heat fluxes [1-17]. Mesoscale circulations, which often form along thermal and moisture discontinuities, can aid in enhanced convection [2,7,9,11,12] and convective clouds when adequate boundary layer moisture is present [2,8,11,14,18,19]. It was hypothesized that similar results would be found in this study due to the thermal and moisture discontinuities between the tornado scar and surrounding vegetation and the strong presence of boundary layer moisture in the Southeast during the summer. It was determined that a strong thermal gradient between the tornado scar and surrounding vegetation, due to latent and sensible heat fluxes, enhanced convective activity (analyzed by looking at cloud-to-ground lightning data) along the Yazoo City tornado track on days of weak synoptic forcing. Landsat thermal imagery indicated a surface skin temperature gradient of 8-10°C between the scar and surrounding vegetation on June 2010 (Figure 1). An increase in surface temperatures within the tornado scar in conjunction with increased moisture across the surrounding vegetation led to increased instability and more storms. Landsat imagery revealed shallow cumulus clouds forming over the Yazoo City tornado scar (Figure 2). 2010 was the only year that showed an increased percentage of convectively active synoptically benign days along the Yazoo City tornado track. Post- tornado years showed no signs of enhanced convective activity along any of the test tracks.

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