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A RADAR-BASED CLIMATOLOGY OF JULY CONVECTIVE INITIATION IN GEORGIA AND SURROUNDING AREA

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1. INTRODUCTION

General thunderstorm climatology and characteristics have been extensively documented (e.g., Byers and Braham 1949, U.S. Environmental Data Service 1968, Changery 1981, Doswell 1985). Diurnal variations of thunderstorms and precipitation in the continental U.S. have been studied (Wallace 1975). A number of more localized studies on diurnal convective development in relation to prevailing wind regimes have also been accomplished (e.g., Smith 1970, Wakimoto and Atkins 1994, Atkins and Wakimoto 1997). This current study examines specific geographical and diurnal origins of convection during July in and near Georgia. The goal of this study is to compile a detailed climatology of the time, location and movement of the initial development of convection during July for a 10-year period based on radar data.

In the month of July, Georgia and neighboring states are influenced by the subtropical anticyclone known as the Bermuda High. The common mid-summer weather regime includes warm, moist air that flows northward around the western periphery of the anticyclone into the southeastern United States. Rainfall during the summer months almost always occurs without synoptic scale influences and it is almost exclusively convective (i.e., showers and thunderstorms). Although the convection is typically scattered, notable exceptions such as large mesoscale convective systems (MCS) and infrequent tropical cyclones produce widespread rainfall.

Showers and thunderstorms typically form in the afternoon hours when convective temperatures are reached. Certain mesoscale characteristics in topography, ground cover, soil moisture, etc., result in differential heating that will cause some locations to be more prone to producing convective clouds,

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showers and thunderstorms earlier in the day and more consistently than others (Rabin et al. 1990). The current study was undertaken to locate such areas of preferred convection in and near Georgia. The focus is on convection initiated by mesoscale influences within a defined area. The area is within a 125 n mi (231 km) radius of two designated locations in Georgia: Athens and Waycross. All precipitation that originated outside that area was excluded from the study. This eliminated convection associated with progressive mesoscale and synoptic features which originated outside the 125 n mi radius.

2. DATA

The data used in this study came from National Weather Service network WSR-57 radars at Athens and Waycross (Fig. 1). Even though WSR-88D radars have been operational in Georgia since the mid-1990s, WSR-57 data were chosen to provide a uniform 10-year data set. WSR-57 hourly observations (taken at 30 minutes after the hour and more often as needed) consisted of UTC date and time, intensity, movement and location of observed precipitation. The location of precipitation was based on Manually Digitized Radar (MDR) grid boxes from the digital section of coded radar observations. The MDR boxes (Fig. 2) were based on the gridpoint spacing of the LFM model. The dimension of a box was approximately 22 n mi by 22 n mi (41 km by 41 km). The WSR-57 employed two modes of operation in deriving the intensity of a precipitating target: logarithmic and linear. The logarithmic mode was used almost exclusively after it was added to the network radars in the 1970s. In the logarithmic mode, the Digital Video Integrator Processor (DVIP) converted the power that was returned from the target into an easy-to-use unit called the VIP. Table 1 provides the VIPs, their equivalent dBZ values, and the associated rainfall rates. VIP levels ranged from the lightest precipitation (VIP1) to extremely heavy (VIP6). If a grid box contained only light rain, that box must be covered by at least 20% of the precipitation before it could be assigned a VIP1. For all higher VIP levels, the highest VIP level in the box was the value assigned to that MDR box regardless of the percentage covered by precipitation. The data were collected from both the Athens and Waycross radars for the month of July in the 10-year period from 1985 through 1994. The following criteria were used to determine whether or not the data qualified as valid convective initiation;

1. The convective initiation must occur after at least three hours of rain-free radar coverage within 125 n mi (231 km) of the radar site. (i.e., after three consecutive PPINEs : Plan Position Indicator No Echoes)

2. The convective precipitation must have persisted for at least two hours after initiation. (i.e., two consecutive hourly observations)

3. Convection that initiated outside 125 n mi and moved into that range was not included. This eliminated the inclusion of convection by a frontal system or remnants of a mesoscale convective system (MCS).

4. Radar observations that were taken immediately after PPIOMs (radar out for maintenance) were not included.

5. The MDR digital data recorded in the first observation after PPINEs was used in the study.

During the process of manually taking a radar observation, convection that originated close to the radar site may have been occasionally missed. The standard method of taking the observation required the operator to leave the radar beam rotating at 0.5 degree of elevation as the outer boundaries of the precipitation were traced. During relatively normal atmospheric conditions in which the radar beam did not experience extremes of subrefraction or superrefraction, long range effectiveness was maximized at 0.5 degree. The radar beam began at the antenna level (105 ft, 32 m). The height of the outgoing beam increased with increasing distance from the radar site. This occurred with the assumption that the beam refracted in accordance with a near standard atmosphere. At the standard 0.5 degree of elevation, water towers, mountains, radio and TV antennas, tall trees, etc., would contribute to echo returns close to the radar site. This "ground clutter" pattern that was created on the radar scope made it difficult for the radar operator to find true convection within the first 15 to 20 n mi (28 to 37 km) from the radar antenna location. Therefore, convection close to the radar site would likely be missed by the radar operator unless he or she manually raised the radar beam elevation above the "ground clutter" pattern.

The maximum elevation angle that a WSR-57 radar could achieve in scanning the atmosphere was 45 degrees above horizontal. However, the quality of the data decreased as the elevation angle approached the maximum. This meant that any precipitating target above that level of elevation would not be detected. It was possible for a shower to develop directly over the radar site and the radar operator would not know about it until he or she noticed that it was raining or was told of that developing convection by a co-worker. (The area above and immediately around a radar site is known as "the cone of silence".) A RADID monitor was available (outside of the radar room at both WSR-57 sites) so that the radar operator could dial into a neighboring radar. Once the dial-up connection was made, three scans (taking one minute) were necessary before the radar image would slowly, sector by sector, be displayed on the monitor. There were times when only one employee was on duty taking radar observations, surface aviation observations, making recordings for the radio, answering the phone, etc. The location of the radar console was in a windowless room and the console generated a constant high humming sound which made it nearly impossible to hear rain falling outside. Rain had to be manually started on the surface aviation computer (MAPSO), and a special observation may have been needed according to changes in visibility or ceiling. When widespread convection was observed on radar, the process of taking the radar observation, logging it on the form and typing it for transmission would take up to 25 minutes. At times, all of the above contributed to "the cone of silence" being worthy of consideration in this study because it was not always practical or possible to dial up a neighboring radar site. As a result of "the cone of silence" and the process that depended on a radar operator to raise the elevation of the antenna in an attempt to locate nearby convection, the MDR boxes containing and immediately adjacent to the radar site could be biased toward lower precipitation detection values. The disproportionately low convective initiation values found close to the network radar offices in this study lend credence to the bias toward lower values.

During the construction of the convective initiation contour maps (Figs. 5 and 6), MDR values 20 to 40 n mi (37 to 74 km) from the radar site were used to interpolate expected values in the low biased "ground clutter" area. The "ground clutter" pattern from the Athens radar also included mountains that were located from near 50 n mi (93 km) northwest (just east of Jasper, Georgia) to 70 n mi (130 km) north (just west of Cashiers, North Carolina) of the radar site. Contouring was also interpolated through the mountain "ground clutter" area. A small isolated feature, Tanasee Bald (5622 ft, 1714 m), in the mountain clutter pattern was located at the junction of Haywood, Jackson and Transylvania counties in North Carolina.

Although this feature may have affected initial precipitation detection to some small degree, it was not considered to be significant enough to adjust the contour map. Also, range effects were not considered during the construction of the contour maps. The contour maps were drawn with as much precision as possible assuming the convective initiation number was centrally located in the MDR box, but also considering surrounding trends. The lines indicating the number of convective initiations are in increments of four (four through 24) for both the Athens and Waycross contour maps. Significant values within closed contours were included for better illustration.

3. TEMPORAL AND AREAL CHARACTERISTICS

a. Time of Convective Initiation

Using the criteria mentioned above, there were 187 unique convective precipitation events from the Athens radar and 177 from the Waycross radar for July during the 10-year period from 1985 to 1994. Figs. 3 and 4 show the frequency of convective precipitation start times for the Athens and Waycross radars, respectively. Convective precipitation detected by the Athens radar began most often at 16 UTC with 46 of the 187 (25%) precipitation events beginning at that time. The southern half of Georgia (Waycross radar coverage area), had its maximum with 29 of the 177 (16%) precipitation events at 18 UTC (Fig. 4). Interestingly, 61% of the events in the north began within the 3-hour period of 15 to 17 UTC, while only 35% of the events in the south began in that time interval. However, by including one hour at each end of that interval, i.e., from 14 to 18 UTC, the percentage rose to 60% in the south. Both radars showed a significant drop in the frequency of convective initiation immediately after the maximum. Of the 177 events in the south, the maximum of 29 occurred at 18 UTC and precipitation only began 10 times at 19 UTC. In the north, the maximum of 46 convective precipitation initiations occurred at 16 UTC. Forty-one convection initiations occurred at 17 UTC in the north followed by 14 occurrences at 18 UTC. Thus, both radars displayed a sharp decline in convective initiation frequency immediately following the time of maximum occurrence. These findings indicate that convective initiation in and near Georgia during July most often begins in the early afternoon and decreases significantly by late afternoon.

Convection over the Atlantic Ocean within 50 n mi (93 km) of the northeast Florida coast had a tendency to develop in the early morning. Eleven of the 15 (73%) convective initiations that were detected off the Florida coast occurred from 07 to 13 UTC. The remaining four of 15 (27%) occurred at 14 and 15 UTC. Showers and thunderstorms over the Atlantic Ocean within 50 n mi of the Georgia coast had a tendency to develop in the mid-day hours. Seven of the 27 (26%) events located over Georgia's coastal waters occurred from 05 to 10 UTC. Twenty of 27 (74%) occurred from 14 to 19 UTC. There were 10 convective initiations in the only MDR box that was completely offshore over the Gulf of Mexico. Six occurred from 04 to 10 UTC and four occurred from 14 to 16 UTC.

Following are some key features of the frequency distributions (Figs. 3 and 4) of convective initiations detected by the two radars:

Athens

- Only two convective initiations occurred from 01 through 07 UTC
- 158 (84%) initiations occurred from 12 through 20 UTC
- 115 (61%) initiations occurred from 15 through 17 UTC
- 6 (3%) initiations occurred from 21

through 00 UTC

Waycross

- No convective initiations occurred from 23 through 03 UTC
- 56 (32%) initiations occurred from 04 through 13 UTC
- 116 (66%) initiations occurred from 14 through 19 UTC
- 76 (43%) initiations occurred from 16 through 18 UTC

b. Location of Convective Initiations

This study also evaluated the climatology of the location of the first detectable convective precipitation return. The location of convective initiation is marked in terms of the MDR grid box spacing of the digital section of the radar observation (Fig. 2). By counting the number of times a MDR grid box contained an echo within the first hour of a convective precipitation event, it is possible to identify locations that are maxima or minima for convective precipitation development.

The area containing the highest frequency of occurrence in or near north Georgia was in the southern Appalachians from near Rome, Georgia to the vicinity of Asheville, North Carolina (Fig. 5). The maximum of 25 occurrences was located 20 to 25 n mi (approximately 40 km) southwest of Asheville. Convective initiation decreased rapidly eastward into the French Broad River Valley near Asheville. Two MDR grid boxes, each with seven initiations, were noted east and northeast of Asheville where the Craggy and Black Mountains are located. The number of convective initiations gradually decreased from the maximum near Asheville going west-southwest down the southern Appalachians toward Rome. Secondary maxima were located to the southwest and south of Atlanta where rainfall initiation occurred 15 times between Lagrange and Carrollton and 14 times between Columbus and Thomaston. A less significant maximum of 10 was located at Augusta and was surrounded by single digit occurrences. This elongated area of six to 10 occurrences was situated along the geographical transition zone from the Piedmont to coastal plain. The minimum of convective initiations extended across the Piedmont of South Carolina. During the period of this study there were no initiations from near Charlotte, North Carolina to Greenwood, South Carolina. This absolute minimum was separated from the absolute maximum by only 50 n mi (93 km).

Fig. 6 is a contour map of the number of times each Waycross MDR grid box contained precipitation in the first observation of a valid data set. This shows that precipitation in July most often began along the Atlantic and Gulf coasts and to the west of the Okefenokee Swamp. The absolute maximum was along the Florida Gulf Coast. Twenty-five of the 177 precipitation initiation events occurred just northwest of Cross City, Florida. The Atlantic Coast maximum consisted of eight to 14 convective initiation occurrences from near Savannah, Georgia to the Daytona Beach, Florida vicinity. Within this maximum, there were two areas of greater initiation occurrences. The broadest maximum covered the central Georgia coast where 14 occurrences were found approximately 10 to 15 n mi (19 to 28 km) north-northwest of Brunswick. A smaller maximum area with 13 occurrences was located west of St. Augustine, Florida in central St. Johns County. A maximum with 13 occurrences was between the Atlantic and Gulf Coast maxima. This included the city of Valdosta, Georgia and locations just to the east. An area of fewer convective initiations extended from the southern tip of the Okefenokee Swamp extending south along the central Florida peninsula. There was a distinct minimum located northeast of Tallahassee, Florida, mainly in Thomas County, Georgia. Over the remainder of the Waycross radar coverage area, there were a few minor features of convective initiation to note. There were a couple of minor maxima located over the offshore waters near the Gulf Stream. There was a broad inland area featuring relatively few convective initiations which coincided with the lower terrain under the umbrella of the Athens radar.

c. Movement of New Convection

Each radar observation also contained the direction and speed of movement of the precipitation. It should be noted that in the first radar observation containing echoes, the radar operator was not *required* to record a movement since there was no previous position from which a movement could be derived. The cell movement from the second hour observation was often used in this study. Cell motion on a typical summer day is usually consistent for several hours.

Looking at both the Athens and Waycross radar data and using an eight-point compass, the predominant movement either had a component from the west or was stationary. From the Athens radar (Fig. 7), movement was from the west (to the east) 33% of the time (62 of the 188 convective precipitation events) and was stationary 22% of the time. From the Waycross data (Fig. 8), cells were nearly stationary 27% of the time. In south Georgia, precipitation movement was most often from the southwest, with nearly 52% of motion being from either the south, southwest, or west. The movement of the Athens precipitation was slightly different with nearly 56% of the motions from either southwest, west, or northwest. The movement in the remainder of the directions contained single digit percentages. The general movement of initial convection from the Waycross and Athens radars was indicative of the circulation around the western periphery of the Bermuda High. Looking at the Waycross and Athens data together, there is a strong westerly component dominating the movement of the initial precipitation in Georgia.

4. DISCUSSION

Showers and thunderstorms in the absence of any frontal lifting generally begin forming around noon or during the early afternoon hours as convective temperatures are reached. In north Georgia during July, this occurs most often at 16 UTC. Across southern Georgia, the time of most frequent occurrence is 18 UTC. Convergence of outflow boundaries will contribute to convective initiation at all times of the day. This would account for much of the variability, particularly outside of the times convective temperatures are first reached. Capping inversions would favor late day convective development or none at all. Differential heating between land and ocean surfaces would favor convection over the land during the day and over the water at night. The tendency for convection to develop offshore from Georgia during the mid-day hours is left to the reader to speculate.

The effectiveness of radar to detect low topped convection decreases significantly beyond 100 n mi from the radar site. Using a 0.5 degree elevation scan under near standard atmospheric conditions, the center of the radar beam is near 12,000 ft (3659 m) at 100 n mi (185 km) and near 17,000 ft (5183 m) at 125 n mi (231 km). Convection that is initially below those heights at those ranges would be overshot by the radar beam and would not be detected. This would result in a low bias in and near the 100 to 125 n mi range around each radar site.

a. Athens Radar Data

A study of cloud-to-ground lightning in Georgia (Livingston et al. 1996) was conducted prior to the 1996 Summer Olympics. A flash count vs. local time graph of a cumulative nine year sample (1986-1994) during July and August within 50 km of Atlanta, indicated cloud-to-ground lightning beginning to increase during the mid-day hours. According to their data, flash counts were very low from 09 to 13 UTC and were slightly higher from 14 to 16 UTC. Flash counts began to increase at 17 UTC and continued to increase until late afternoon. The time of the beginning of the flash count rise correlated very well with the maximum period of convective initiation from the Athens radar data (Fig. 3).

Convective initiation in and near north Georgia appears to be strongly influenced by elevation. Days with little synoptic scale forcing, typical around Georgia in July, were found to be dominated by mountain convection (Weisman 1990). Convection is most likely to begin along the Appalachian Mountains and over the higher terrain south and southwest of Atlanta. Mountain ridges warm more rapidly than heavily forested or ridge shaded valleys during a sunny day. As warm air rises from the higher peaks, cooler valley air moves in to replace it. The resulting updraft can produce convection depending on the amount of instability available on a given day. The highest mountains contribute to the formation of unstable lapse rates due to rapid warming of the summits extending into the cooler air aloft. The differential heating results in the highest peaks having convection sooner and more consistently than mountains with lower elevation. This explains why the mountains southwest of Asheville, where elevations are around 6000 ft (1829 m), have a relatively high number of convective initiations in July. The values decrease rapidly going east into the lower terrain of the French Broad River Valley but increase to seven east and northeast of Asheville in the high terrain. Mount Mitchell, the highest peak (6684 ft or 2038 m) east of the Mississippi River, is located about 20 n mi (37 km) northeast of Asheville just inside the 125 n mi (231 km) radius around Athens. The Great Smoky Mountain National Park contains mountains with elevations in excess of 6000 ft (1829 km), but the center of the park is about 100 n mi (185 km) from the radar. Range resolution is decreased significantly at that distance and the mountains of the ground clutter pattern would tend to block initial convection from being detected because echo tops could be low. A valley-to-mountain breeze develops during the formative stage of mountain convection. This creates divergence with sinking motion over the lower terrain and temporarily suppresses convective initiation over the non-mountainous areas (Gibson and Vonder Haar 1990). Initial convection occurs to a smaller degree over higher terrain to the south and southwest of Atlanta resulting in a secondary maximum. Fig. 9 illustrates the general variation in elevation across the southeastern United States.

The less evident maximum of mainly six to ten occurrences located from east-central Georgia through central South Carolina is in the region where the Piedmont trough most commonly develops. Koch and Ray (1997) conducted a study of central and eastern North Carolina summertime convergence boundaries. Different types of boundary layer convergence zones were identified and defined. Sixteen out of 95 identified boundaries were originally classified as “unknown (origin) stationary”. Thirteen of the 16 boundaries corresponded well with the location of the Fall Line which is the transition between the hard, crystalline rocks of the Piedmont to the soft, sedimentary rocks of the coastal plain. The soil in the coastal plain is primarily sand and sandy loam and the soil of the Piedmont is primarily clay. Several studies (e.g., Ookouchi et al. 1984 and Mahfouf et al. 1987) have demonstrated that circulations caused by soil and soil moisture discontinuity can influence convective initiation. Intense solar heating occurs along the Fall Line resulting in the formation of the

Piedmont trough and thus it is a favored region for convection. All of the Piedmont troughs in the Koch and Ray (1997) study were found to be autoconvective (produced convection without the need for interaction with other features). Nearly all of these troughs extended into South Carolina in the vicinity of the Fall Line. This cluster of trough positions corresponded well with the elongated maximum of convective initiations in Fig. 5. Weisman (1990) found the Piedmont trough to be present about 40 percent of the time between May and September in 1984 and 1985. On days with a Piedmont trough, convergence and ascent were found to be especially strong in the lowest kilometer of the troposphere during the afternoon. Weisman (1990) also showed cloud-to-ground lightning increased significantly from 16 UTC and continued to increase through the early afternoon. This corresponded well with the Athens radar's convective initiation times (Fig. 3). His study demonstrated that convective development near the Fall Line during the summer may be most favored on days with a moderate level of cyclonic forcing.

The location of the absolute minimum of convective initiation was found to be over the northeast portion of the Piedmont of South Carolina. This minimum extended from Greenwood County northeast toward Charlotte, North Carolina. There are no geographical features that would promote convective initiation because this region has gentle, rolling hills with a consistent soil type (mostly clay). It is not surprising that a minimum of convective initiation would be located in that area. What is surprising is that there were no initiations in that area during July throughout the 10-year period.

b. Waycross Radar Data

Convective initiation as indicated from the Waycross radar generally had maxima aligned along the Atlantic and Gulf coasts. This results mainly from the influence of the sea breeze. The terrain in this region is relatively flat and soil type throughout the coastal plains is mainly composed of sand or sandy loam.

Changery (1991) shows July thunderstorms are more frequent along Florida's west coast than at the same latitude on the east coast. An analysis of the mean number of thunderstorms in July indicates 24 to 30 occur from Cross City to Tallahassee compared with 20 to 22 from Jacksonville to near Daytona Beach. Another analysis shows the primary hour of thunderstorm initiation in July to be around 18 UTC for those same coastal locations. Also, inland areas of north Florida generally have thunderstorm initiation from 19 to 20 UTC. The findings in Changery (1981) were consistent with the locations and generally consistent with the timing of convective initiation in the current study.

Henry et al. (1994) state that the water temperature of the Gulf of Mexico is generally warmer than the Atlantic Ocean in July. Sea water temperatures in the Gulf at that time of year are well into the 80s °F, while Atlantic temperatures are in the lower 80s °F and are more commonly subjected to upwelling causing localized cooler temperatures. Wind trajectories over the Gulf will impart more moisture to the air than trajectories over the Atlantic. A southwest wind tends to create more showers and thunderstorms over Florida and adjacent areas in Georgia than other wind patterns. The development of showers and thunderstorms is dependent on the lack of a sufficiently strong high pressure system which would produce enough subsidence to suppress convection.

Much of the July convective initiation over north Florida and adjacent areas in south Georgia is dependent on convergence of mesoscale boundaries, especially sea breeze fronts. The development of sea breeze fronts is strongly dependent on diurnal temperature differences between land and sea caused by the different response of the two surfaces to insolation. If there is sufficient solar radiation to warm the ground, the land will heat rapidly during the day. Widespread cloudy skies will prevent sea breeze front formation. A sea breeze typically begins when the land is 5 to 6°F warmer than the adjacent ocean. Sea breezes most often begin at 10 to 11 a.m. Speeds of inland movement are typically 5 to 15 mi/h (4 to 13 km/h) (Henry et al. 1994). Normal high temperatures in July across north Florida and south Georgia are generally in the lower 90s°F and early morning lows are in the lower 70s°F. The diurnal air temperature variation above the sea surface is on the order of one degree (Wallace and Hobbs 1977). On a typical mostly sunny morning, the land gradually warms creating rising air which is replaced by cooler air from the sea. The air that has risen over the land is then redirected aloft toward the sea to replace the air that has moved inland from the sea. Cumulus clouds form over the land while the sky over the ocean surface becomes relatively cloud-free around noon and generally remains that way throughout the remainder of the daylight hours. Enhanced vertical motion in the vicinity of the sea breeze front occurs because of the convergent wind flow and solenoidal circulation. Sea breeze fronts usually form around 16 UTC. Visible satellite imagery aids in following the formation and evolution of a sea breeze front. On Doppler radar, 1.1 km, 0.5 degree reflectivity and radial velocity images are usually very helpful in tracking the progress of a sea breeze front (Gould et al. 1996).

The land cools rapidly near sunset. Around 0100 UTC on a typical July evening, the temperature of the land and ocean are about the same. The land gradually becomes cooler than the sea after this time. During the early morning hours, when this difference is most significant, a land breeze occurs as air rises over the sea and is replaced by air from over the cooler land. This circulation is weaker than a typical sea breeze because the difference between land and sea temperature is usually less than 5°F . Turbulent mixing with a land breeze may be just as vigorous near the coast as a typical sea breeze, although land breezes generally produce less convection over the sea surface (Henry et al. 1994). Southwest to westerly winds tend to create convection over the eastern part of Apalachee Bay as the land breeze converges with the prevailing wind. A southerly wind helps to focus convection south of St. Marks, FL due to convergence of the land breezes from the southwest and southeast facing shores.

The locations where convective development is most favored are determined by the low-level (below 700 mb) wind regime present on any particular day (Smith 1970; Gould et al. 1996). Light and variable low-level winds tend to favor convective initiation along the southwest and southeast facing coasts of the Big Bend area of Florida. Sea breeze fronts generally do not extend very far inland during the light and variable wind regime. During a southerly regime, sea breeze fronts are pushed further inland from Apalachee Bay with the combined effects of the sea breeze and the wind pattern of the day. During a westerly wind regime, the sea breeze front along the west coast of the peninsula is pushed well inland. Also with this type of regime, convergence is most significant along the Atlantic coast as that sea breeze front moves inland against the westerly wind flow. Northerly and easterly wind regimes are generally drier although a flow from the north would tend to converge with a northward moving sea breeze front from the Apalachee Bay area. The latter regimes are also considered to be somewhat rare in July.

The configuration of the coastline also contributes to convective initiation. Places located near the landward tip of bays and inlets tend to favor the development of convection before other land areas. This is due to the combined effects of the sea breeze and bay/inlet breeze which results in a stronger flow within the boundary (Gould et al. 1996). The increased flow near the tip of the bays/inlets also creates divergence between bays/inlets which results in less convection. The varying configuration of the Georgia coastline provides many locations of converging and diverging sea breezes which also combines its effect with bay, marsh or sound breezes. The portion of the Georgia coastal area from Brunswick to Savannah is largely composed of numerous small rivers and streams flowing into marshland and also includes part of the Altamaha River just before it flows into the Atlantic. The marshes are a large expanse of somewhat shallow water that provides a good moisture source for convection. This would help to create a higher frequency of convective initiation along the Georgia coast.

The amount of thermodynamic instability has been found to play a significant role in whether convection occurs along a sea breeze front. A study by Fuelberg and Biggar (1994) focused on 'The preconvective environment of summer thunderstorms over the Florida panhandle.' A study by Gould et al. (1996) further emphasized the importance of examining the local upper air soundings to determine the likelihood of sea breeze precipitation. As the latter study states, "The thermodynamic variability within each flow regime holds the key to successful sea breeze forecasting."

The Convection and Precipitation Electrification Experiment (CAPE) was conducted during July and August 1991 near Cape Canaveral, Florida by a multi-agency group (Wilson and Megenhardt 1997). The CAPE project demonstrated the importance of mesoscale boundaries, such as sea breeze fronts, moving in a similar direction and speed with pre-existing cumulus clouds (a pre-existing updraft). It was determined from previous studies (e.g., Moncrieff and Miller 1976 and Weisman and Klemp 1982) that storm merger, organization, and lifetime were greatly enhanced when the clouds were moving at a similar velocity as the convergence line. This project also exhibited a case where the portion of a boundary in an unstable environment produced thunderstorms when the boundary intercepted pre-existing cumulus clouds. The other portion of this boundary was moving through a more stable atmosphere with no pre-existing cumulus and no convective initiation occurred. Winds during July over north Florida at the 2 to 4 km level generally have a westerly component. The average prevailing wind direction in July at both Tallahassee and Jacksonville is from the southwest (Henry et al. 1994). This would tend to contribute to greater convective initiation along Florida's west coast because the sea breeze front and the clouds would likely be moving along a similar vector.

A location with a significant maximum along the East Coast was located between the Saint Johns River and Saint Augustine, Florida. As the St. Johns River flows north from Lake Monroe (at Sanford, Florida) the closest approach to the Atlantic Ocean before reaching Jacksonville is near St. Augustine. A 20 n mi (37 km) portion of the river near St. Augustine is approximately parallel to the Atlantic Coast. Also at this point, the St. Johns River is located only about 15 n mi (28 km) from the beach. The nearly parallel orientation of the river and coastline creates a favorable situation for mesoscale boundary convergence. A river breeze that converges directly with a sea breeze produces the maximum forcing for upward motion as opposed to these boundaries meeting at an angle.

The convective initiation minimum located over Thomas County, Georgia could be explained by divergence of the sea breeze around Apalachee Bay. The shape of the Gulf coast of northwest Florida, specifically the area between Apalachicola and Cross City, is concave. A study conducted by Smith (1970) examined low-level prevailing winds in this region. In the light and variable low-level wind regime [average of 5 knots (10 km/h) or less in the lowest 5000 ft (1524 m)], which contained from nearly a third to as much as a half of the data in that study, a sea breeze develops at mid-day around Apalachee Bay and moves a few miles inland to the northwest and northeast. Local divergence results in the area from the northern point of Apalachee Bay to northeast of Tallahassee extending to near the Georgia/Florida border (Fig. 9). Convection from the sea breezes on light and variable wind days was generally confined to within 20 n mi (37 km) inland from the coast. In the light and variable prevailing low-level wind conditions, convective development is minimized in the area of sea breeze divergence throughout the afternoon. When the prevailing flow is from the south, the diverging effects may be projected further inland. On occasions with a prevailing low-level wind other than from the south, local divergence would not be favored and may explain why the maximum along the Gulf coast separates the minimum over Thomas County from Apalachee Bay. Although the effects of this local divergence resulting from the sea breezes have been previously considered to not extend into Georgia, there is clearly some mesoscale process at work to limit convective initiation. Velocity of the prevailing wind was not considered in this study and was not a factor during the construction of the contour map (Fig. 6).

The very light wind at the various levels of the troposphere was evident on many occasions while watching the ascent of radiosonde balloons at Waycross. There were some days during the warm season with relatively clear skies when the balloon would be observed to go straight up over the launch site for much of the duration of the flight. This observance was best in the evenings as the setting sun would brighten the brownish, red balloon against an increasingly dim sky. The balloons would usually reach a height of over 100,000 ft (30,488 m) in about two hours.

Comparing the Smith (1970) study to the Gould and Fuelberg (1996) study, areas of convective initiation are similar for the given wind regimes. Early morning convection tends to cease over the water and then begin over land with the ‘light and variable’ wind regime. This contrasts with the ‘southerly’ and ‘westerly’ regime where morning convection over the water propagates onto the land by late morning (Smith 1970).

A relative maximum between Jacksonville and Tallahassee connected the east coast sea breeze maximum to the west coast sea breeze maximum. This maximum bridge encompassed part of the Suwannee River Basin. The highest number of convective initiation occurrences in this area was 13 which occurred from Valdosta, Georgia to a few miles west of the Okefenokee Swamp. The location of this maximum was between the Wahlacoochee and Suwannee Rivers. The Alapaha River flows through the center of this maximum. The Suwannee River flows from the west side of the Okefenokee Swamp. The swamp’s northern point is around 10 n mi (19 km) south of Waycross and is approximately 50 n mi (93 km) long from north to south and 20 to 30 n mi (37 to 56 km) wide from east to west. It has been the experience of the authors of this study to observe (by way of the WSR-57 radar) a shower or storm to move over the Okefenokee Swamp from the west and build vertically several thousands of feet in height as it came under the influence of the swamp waters. On many occasions, the weather observer at the Waycross office could look to the south and witness a vivid lightning display over the swamp. As this convection moved east of the swamp it would then decrease in vertical extent to around its previous level. It is possible that towering cumulus could experience increased development and begin to precipitate as they move into this area of increased moisture availability. The influence of the warm, shallow swamp waters of the Okefenokee combined with the moisture supply from the rest of the Suwannee River Basin may account for the convective initiation maximum in this area.

Range resolution should also be considered when evaluating the Waycross radar data. A developing shower with a top of 10,000 ft (3049 m) would be detected over Brunswick, GA but not detected over Ocala, FL. Brunswick is 45 n mi (83 km) from the Waycross radar site and Ocala is 122 n mi (226 km) from that point. Using a radar beam elevation of 0.5 degrees, the mid-beam height above ground would be 3623 ft (1105 m) over Brunswick and 16,227 ft (4947 m) over Ocala. Flagler Beach, on Florida's east coast, is at a range of 124 n mi (230 km) from Waycross.

The sea breeze fronts from Florida's east and west coasts often converge after 19 UTC. This usually produces showers and thunderstorms. However, for the purpose of this study, showers and thunderstorms normally would have already occurred prior to that time period within the range of the Waycross radar. Therefore, according to this study's definition of valid convective initiation, late afternoon convection would usually be excluded.

c. Overlapping Radar Coverage

In comparing the overlap region between the Athens and Waycross radars, there were a couple of common features of interest. According to the Waycross radar, there was a slight increase of convective initiation located near Augusta, Georgia. This minor maximum was coincident with the Piedmont trough maximum that was clearly evident from the Athens radar data. Augusta is approximately 75 n mi (86 km) from the Athens radar site and approximately 125 n mi (144 km) from Waycross. Comparing this location between the two radars illustrates the limitation on radar due to range effects beyond 100 n mi (185 km). Also, the minimum observed in the Waycross data over central Georgia was coincident with the minimum observed from the Athens radar. These locations do not have any known geographical features that would promote convective initiation.

Since this study only dealt with MDR digital data in which each box has an area roughly 484 sq n mi (896 sq km), some precision was lacking in determining exact locations of initiation. Therefore, the exact mountains where convective initiation occurred could not be determined within the Athens radar service area. Likewise, the exact location within the Waycross radar service area where convergence from sea breeze or river breeze interaction took place could not be determined.

The movement of precipitation was generally stationary or slow. The speed rarely exceeded 20 kt (37 km/h). The average speed derived from both radars was around 9 kt (16 km/h). The high percentage of stationary convection and the low average speed is indicative of the light wind field through the lower atmosphere during the month of July.

5. SUMMARY

This study produced a detailed climatology of the time, location and movement of the initial development of convection during July for a 10-year period based on conventional radar data. The data were obtained from WSR-57 radar observations taken at Athens and Waycross, Georgia from 1985 to 1994. An effort was made to eliminate the inclusion of convection that originated outside the 125 n mi radius of each radar. Only convective initiations during the first hour after at least three consecutive hours of rainfree radar coverage were considered. Contour maps were drawn indicating the number of convective initiations for locations within a 125 n mi radius around each radar site.

The times of the initial convection in July show a maximum occurrence at 16 UTC in the Athens coverage area and at 18 UTC in the Waycross coverage area. The number of initiations decreases rapidly after those hours. Convective initiation in the absence of synoptic scale influences typically occurs as a result of convective temperatures being reached or convergence of mesoscale boundaries such as a sea breeze, river breeze, or outflow from previous thunderstorms.

According to the Athens radar data, the greatest number of convective initiations occurred over the higher terrain of the southern Appalachian Mountains. The highest mountains are more efficient at producing convection because they induce upslope flow and their summits extend into the cooler air aloft creating lapse rates that are steeper than those found over adjacent lower terrain. Less significant maxima were found over a very hilly area south and southwest of Atlanta. An elongated maximum was in the vicinity of the Fall Line. Koch and Ray (1997) found the Fall Line to be a favorable location for autoconvective development. No convective initiations occurred during the 10-year period in the Piedmont from Greenwood, South Carolina to near Charlotte, North Carolina.

According to the Waycross radar data, the greatest number of convective initiations occurred along the Gulf Coast of Florida near Cross City. A long, less significant maximum extended along the Atlantic Coast from southern South Carolina to near Daytona Beach, Florida. The maxima along the coasts were the result of convective initiation along sea breeze fronts.

Data from both radars showed the movement of the initial convection was nearly stationary about one fourth of the time. When there was movement, it was most often from the southwest in southern Georgia and from the west in northern Georgia. The predominant movement of initial convection was indicative of flow around the western periphery of the Bermuda High.

This study utilized conventional radar data from the last decade of the era when observations were taken manually. Data available from the WSR-57 radars consists of the hand written observations and poor resolution reflectivity photographs. The photographs were taken every 5 minutes in non-severe situations and every other 20-second scan during severe weather. The ability of the WSR-88D to archive large amounts of high resolution reflectivity and velocity data makes the newer radar much more useful for scientific research. Perhaps this project will encourage future studies of convective initiation using WSR-88D technology.

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Table 1. VIPs, their equivalent dBZ values and the associated convective rainfall rates.

VIP 1 = 18-30 dBZ (convective rainfall rates of less than 0.2 in/h (0.5 cm/h))

VIP 2 = 30-41 dBZ (convective rainfall rates of 0.2 to less than 1.1 in/h (2.8 cm/h))

VIP 3 = 41-46 dBZ (convective rainfall rates of 1.1 to less than 2.2 in/h (5.6 cm/h))

VIP 4 = 46-50 dBZ (convective rainfall rates of 2.2 to less than 4.5 in/h (11.4 cm/h))

VIP 5 = 50-57 dBZ (convective rainfall rates of 4.5 to less than 7.1 in/h (18.0 cm/h))

VIP 6 = any dBZ greater than or equal to 57 (convective rainfall rates of 7.1 in/h or greater)

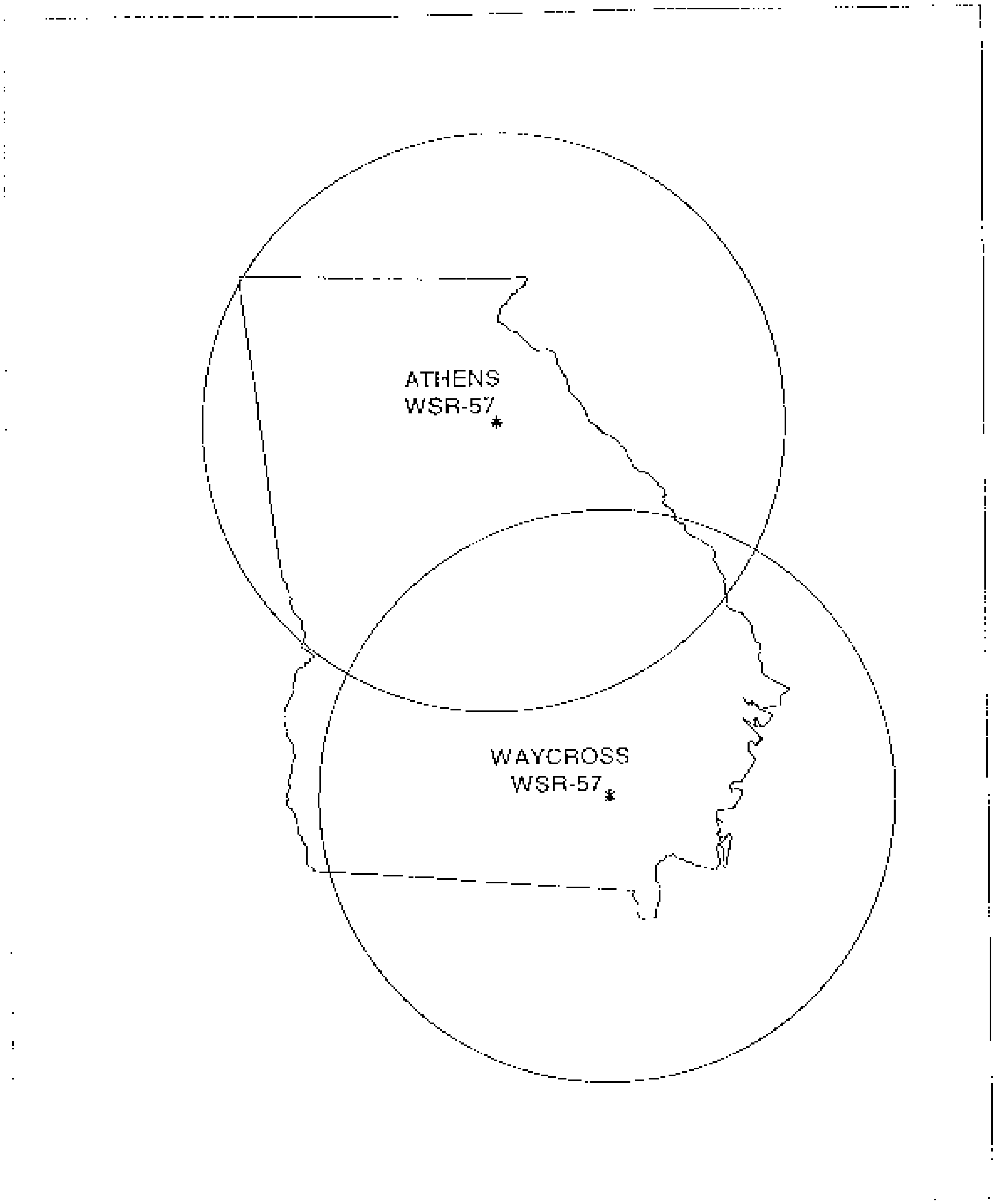

Fig. 1. Athens and Waycross, GA radar locations

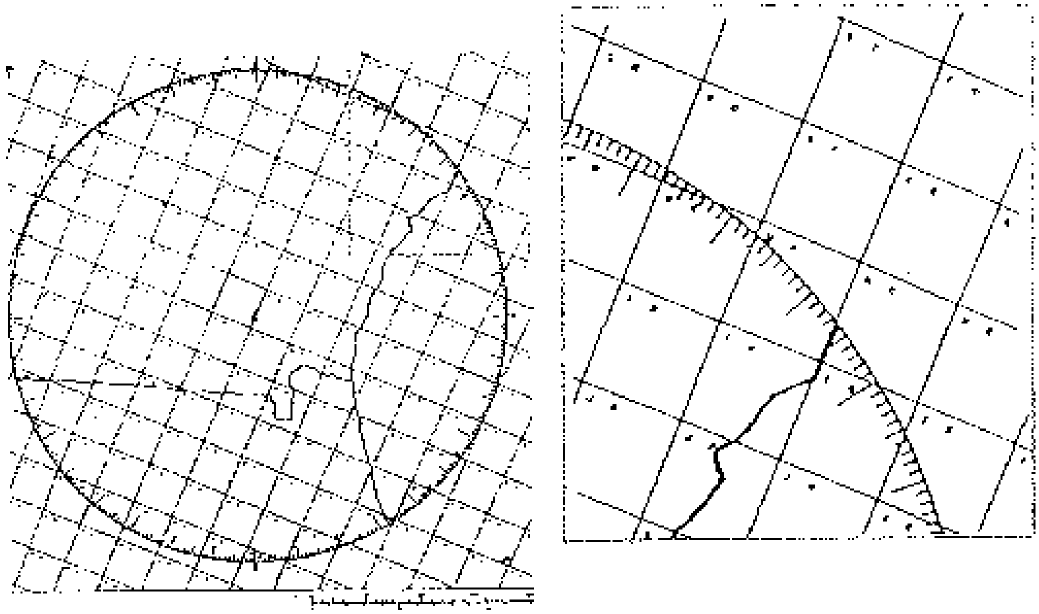

Fig. 2. MDR grid box overlay centered on Waycross, GA (left) and close-up of upper corner of the grid box (right)

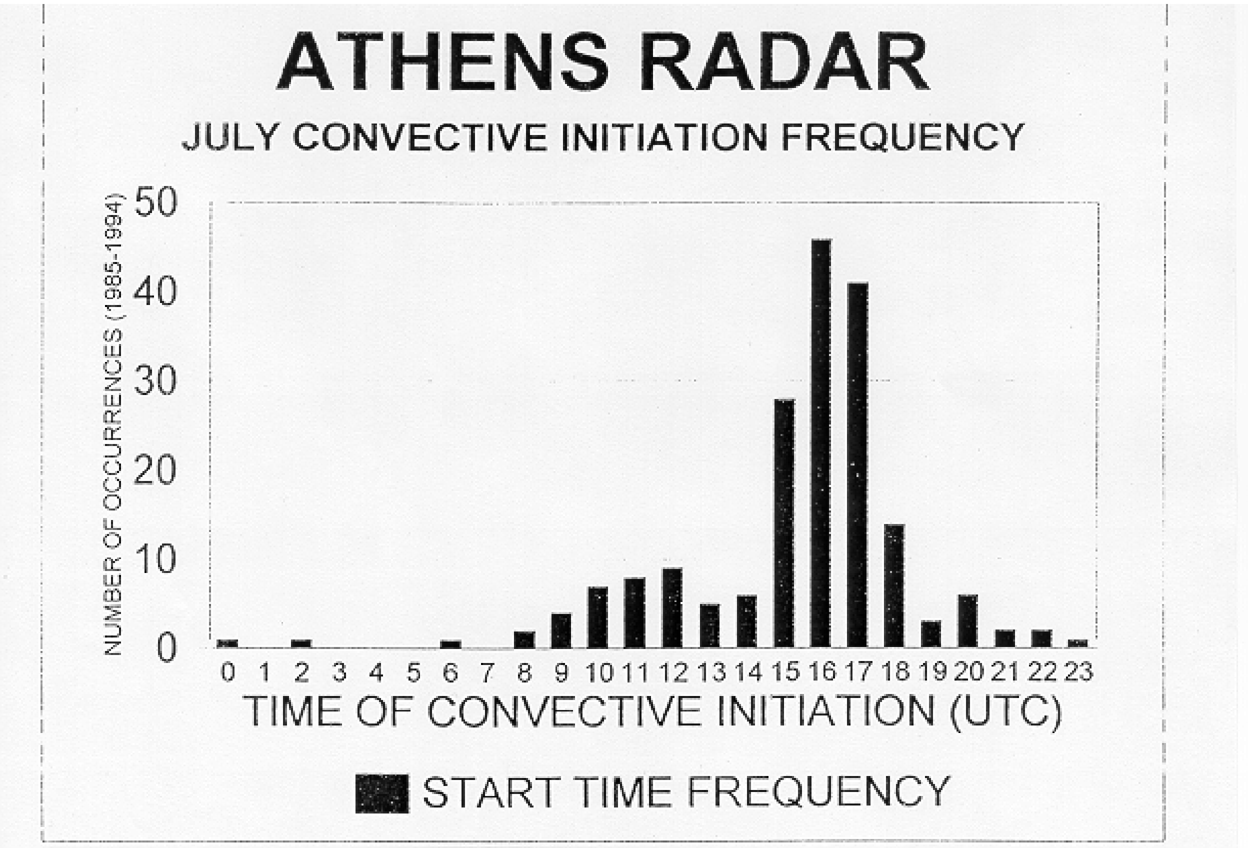

Fig. 3. Athens convective initiation times for July during the 10-year period from 1985 to 1994

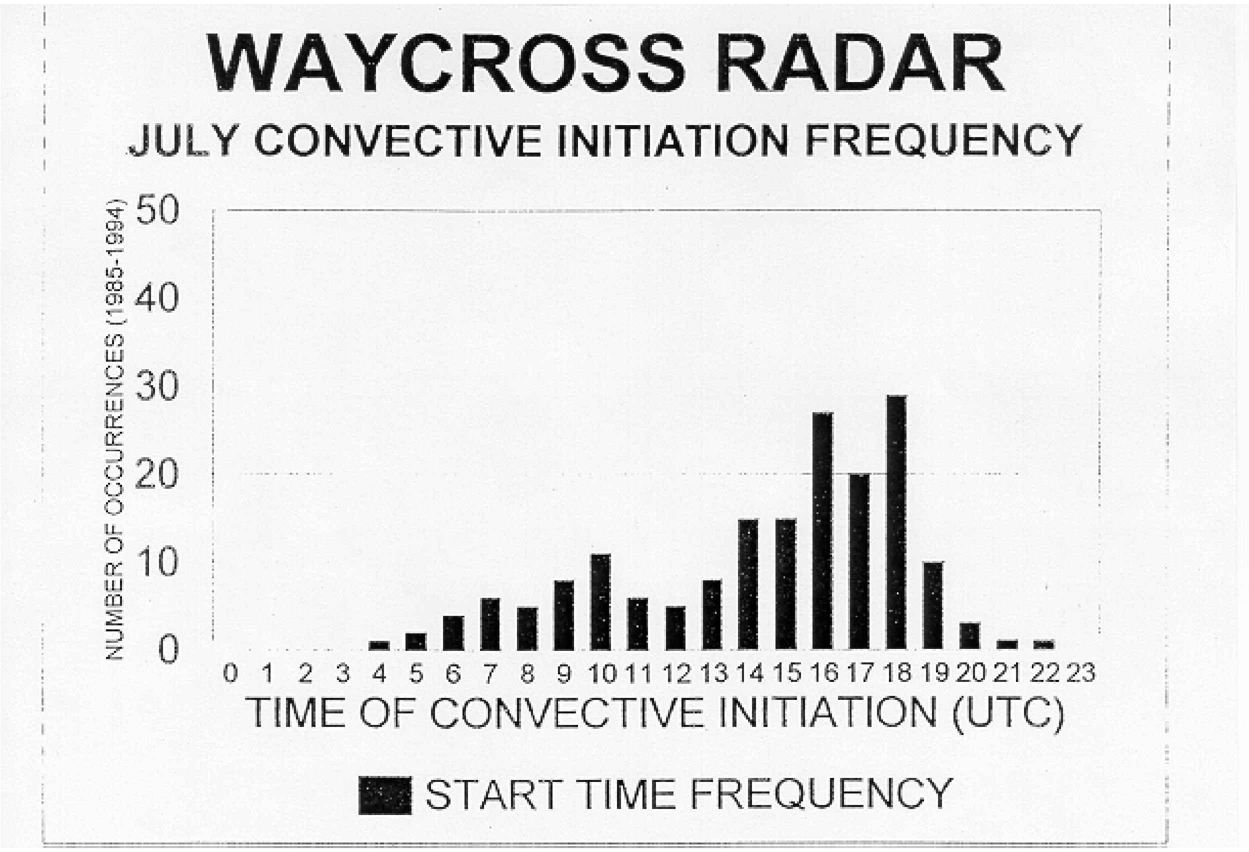

Fig. 4. Waycross convective initiation times for July during the 10-year period from 1985 to 1994

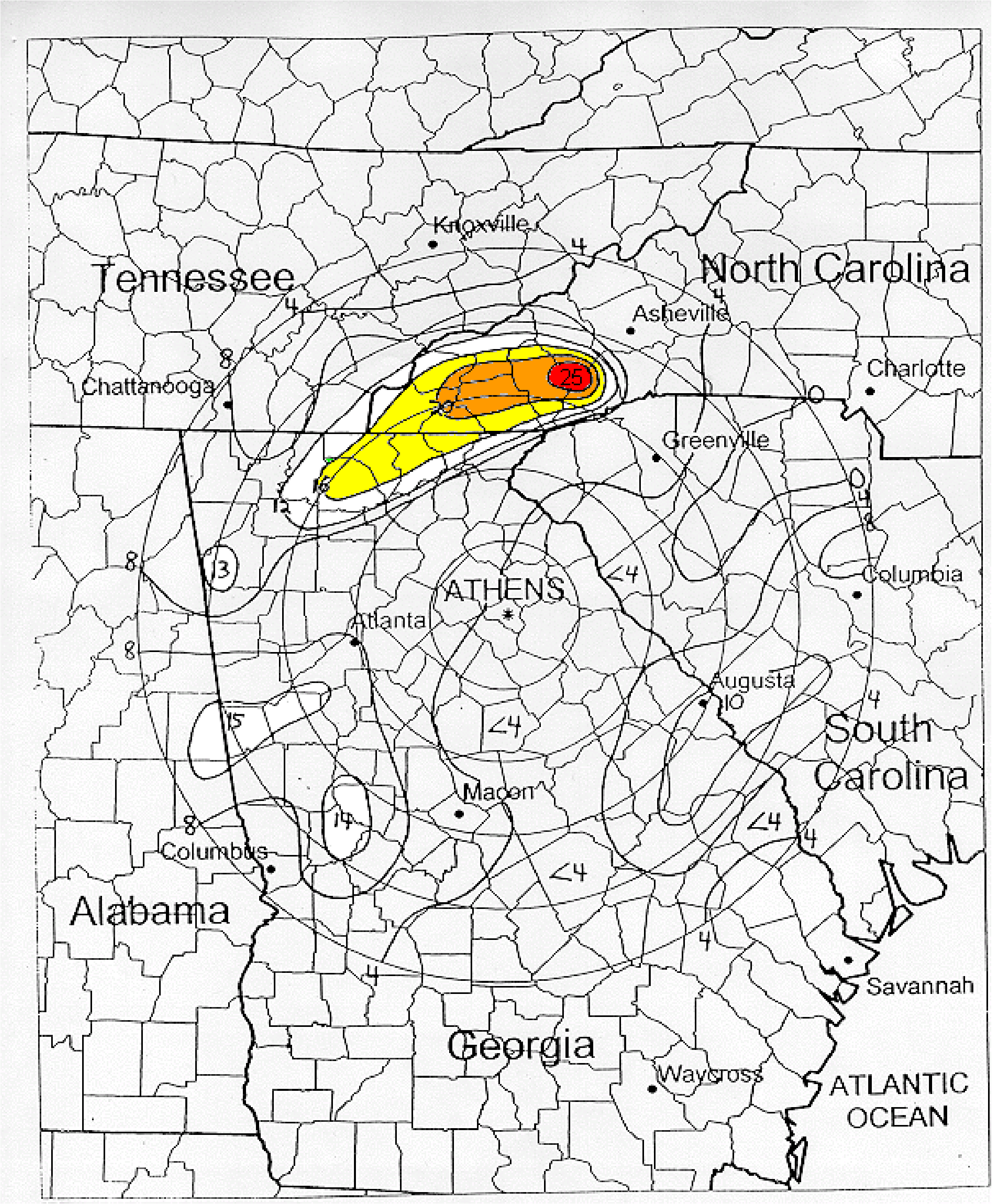

Fig. 5. Athens convection initiation contour map with the number of convective initiations during the 10-year period from 1985 - 1994

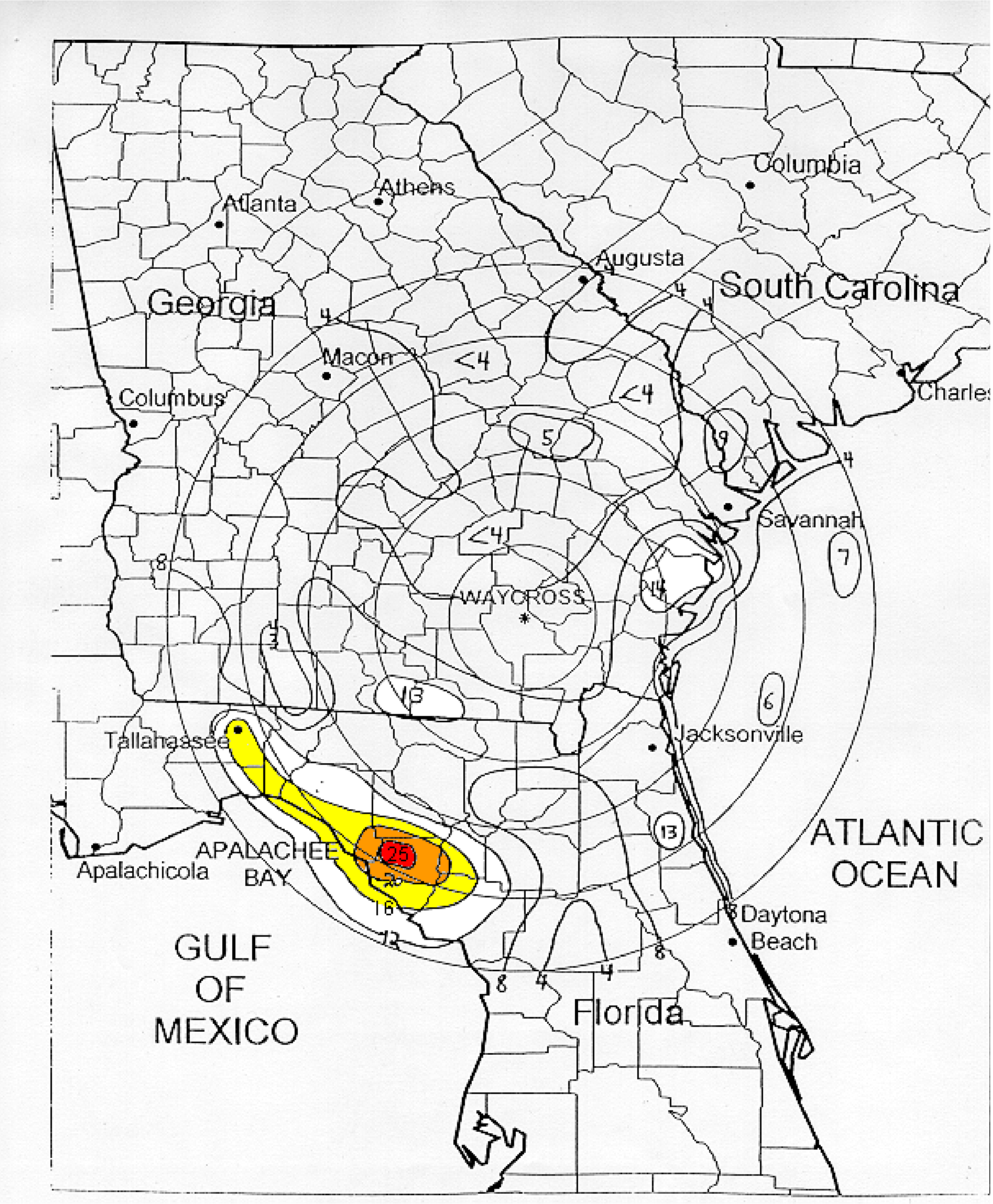

Fig. 6. Waycross convection initiation contour map with the number of convective initiations during the 10-year period from 1985 - 1994

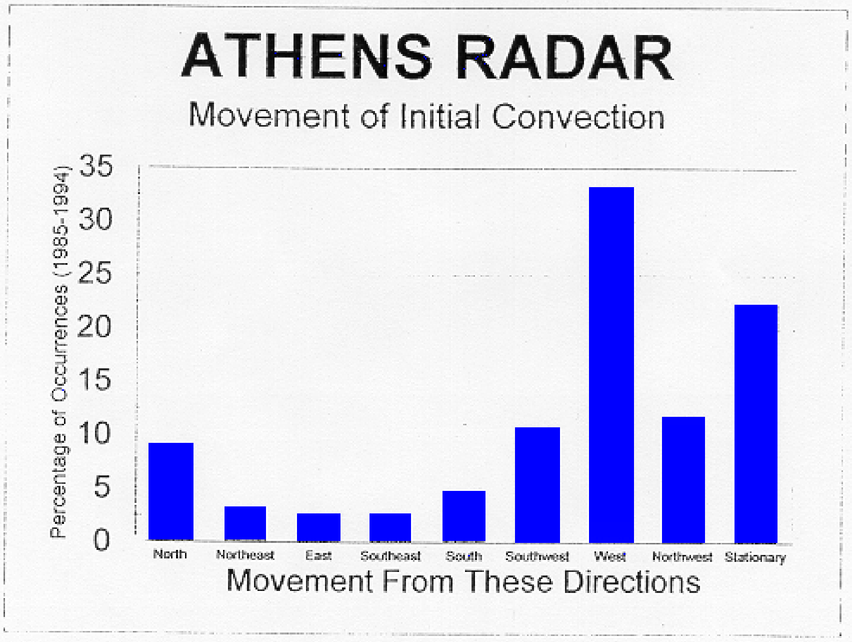

Fig. 7. Movement of initial convection detected by the Athens radar.

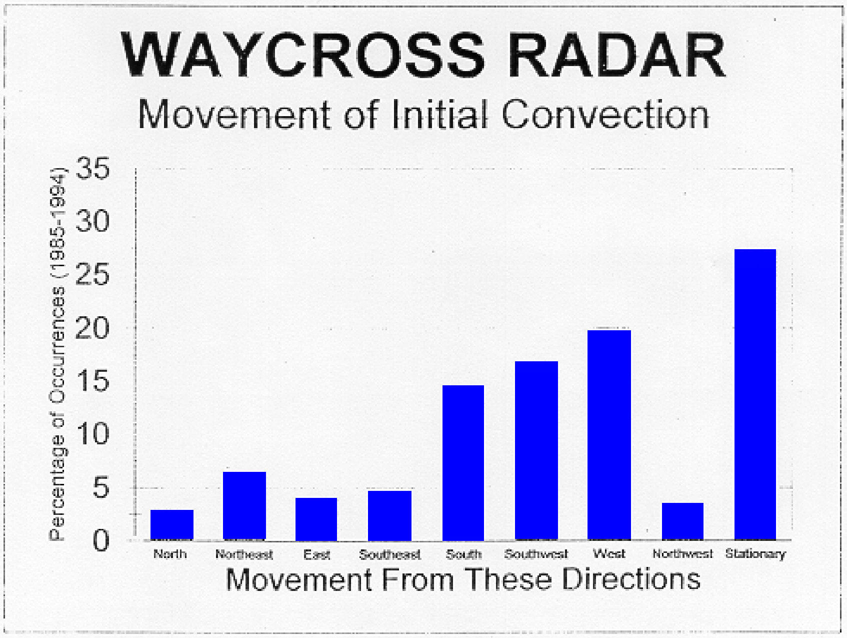

Fig. 8. Movement of initial convection detected by the Waycross radar.

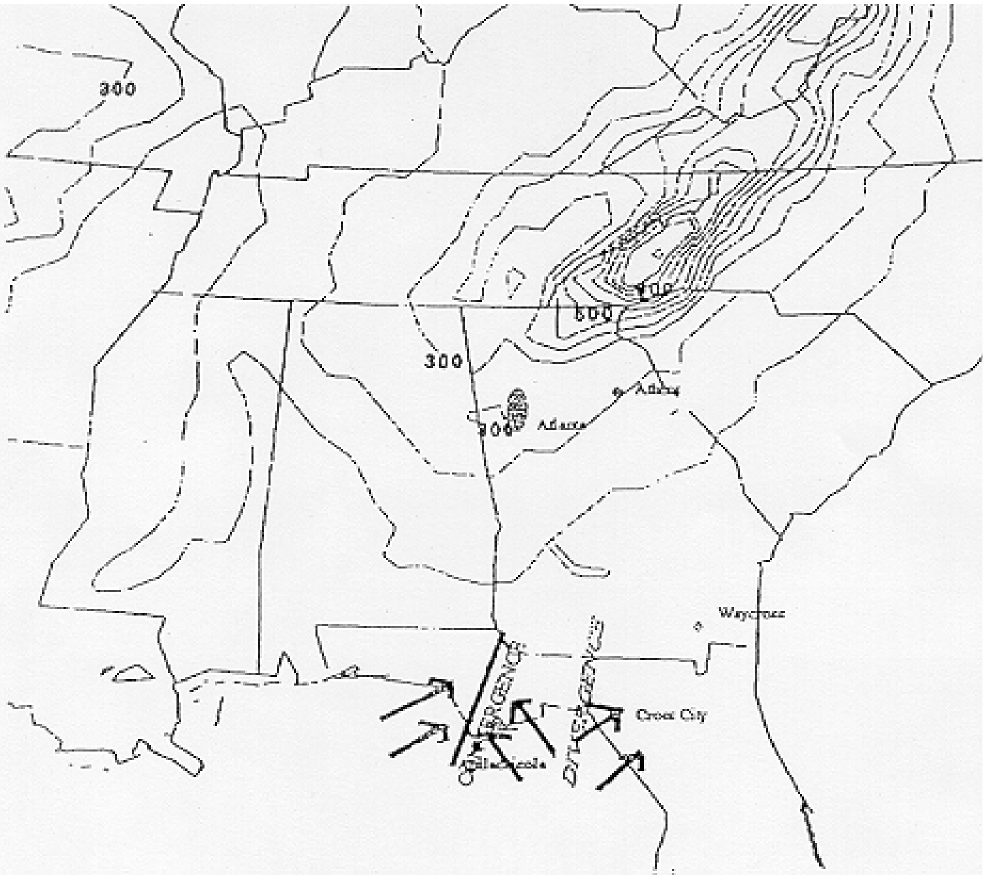

Fig. 9. Topography of the southeast United States in meters and sea breeze flow on the Florida coast with convergence and divergence lines.