8.12 INCORPORATING MESOSCALE LIGHTNING CLIMATOLOGIES INTO THE NWS IFPS/GFE FORECAST ROUTINE ALONG THE GULF COAST

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1. INTRODUCTION

Cloud-to-ground (CG) lightning causes injury and death, disrupts human activity and aviation, starts fires, and damages property. This damage includes communications and electrical systems, as well as forests and structures. An accurate forecast of lightning can help reduce the number of injuries and deaths attributed to lightning, as well as the time and money spent repairing or replacing damaged property. Understanding the mesoscale processes that lead to convective development and its resulting lightning is necessary to produce better forecasts.

The first objective of this study is to create a lightning climatology for the northern Gulf Coast. Data from warm seasons in the 14-year period 1989-2002 are analyzed and categorized according to the low-level synoptic flow. Lightning flash densities are calculated every hour to study diurnal variations. Possible causes for the formation and movement of lightning patterns are examined.

The second objective is to describe the incorporation of these climatologies into the Interactive Forecast Preparation System (IFPS). The central part of IFPS is the Graphical Forecast Editor (GFE). This system allows National Weather Service (NWS) forecasters to prepare graphical depictions of present and predicted weather. The lightning climatologies described here can aid the forecaster as he/she populates these grids, thus providing the operational meteorologist with a "first guess" to summertime convection along the Gulf Coast.

2. DATA AND METHODOLOGY

In complete operation since 1989, the National Lightning Detection Network (NLDN) detects and records CG lightning flashes over the continental United States and immediate coastal waters. This network, owned and operated by Vaisala Inc., provides detection data to a variety of commercial, government, educational, and public entities. Specifics concerning network methodology and operations are described by Cummins et al. (1998).

Lightning data from the months of May to September 1989-2002 were used in this study. These warm season months were chosen because of their enhanced convection and minimal synoptic activity. Instead, mesoscale phenomena, such as sea breezes and lake breezes, interact with their environments, geographic features, and each other to produce complex patterns of convergence and resulting convection.

The study domain spanned 28˚-32˚ N and 87˚-96˚ W, encompassing the northern Gulf of Mexico coastline and adjacent waters (Fig. 1). As shown by Cummins et al. (1998), five NLDN sensors are located in this area. The flashes were counted on a 2.5 km × 2.5 km grid, corresponding to a 353 × 178 array of 6.25 km^2 grid cells.

Radiosonde data were used to categorize each day of the period according to the prevailing low-level flow in the area. The mean

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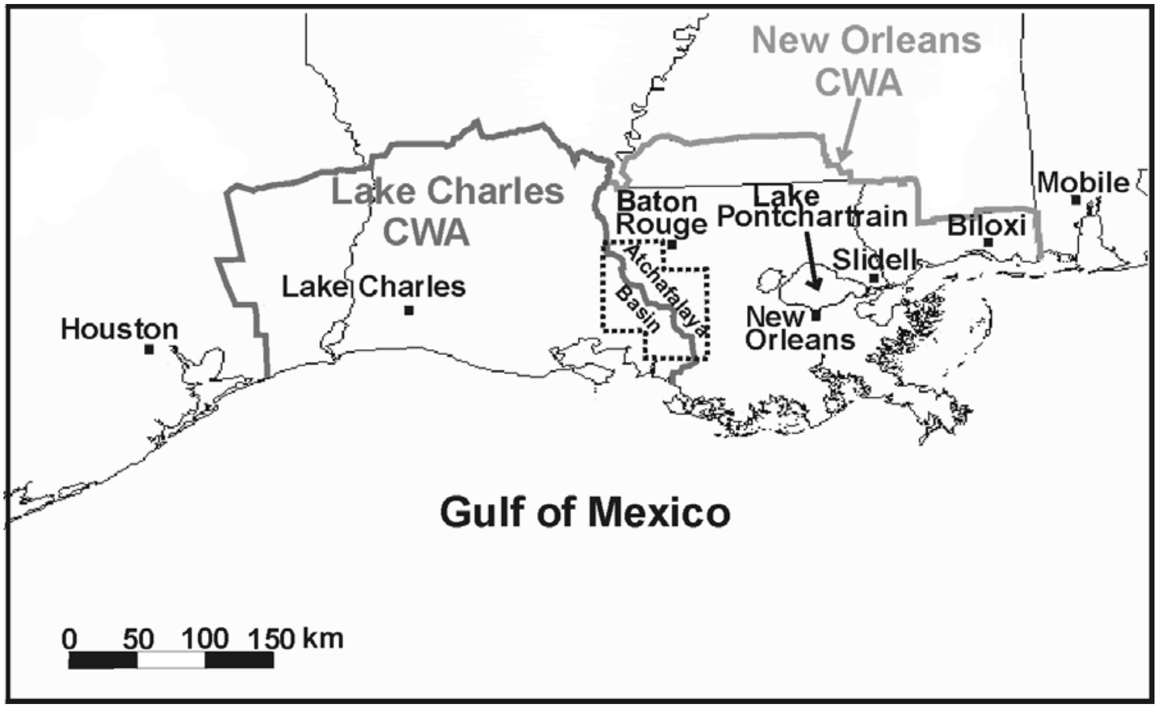

FIG. 1. Map of domain extending from 28°-32° N and 87°-96° W. Major cities and geographical features are labeled. Outlines of NWS County Warning Areas (CWA) are shaded.

vector wind in the 1000 to 700 hPa layer was computed each day using the 1200 UTC sounding. As shown in previous studies (López and Holle 1987; Camp et al. 1998; Lericos et al. 2002), the flow within this layer provides a good indication of sea breeze and thunderstorm movement during the warm season.

Two radiosonde sites were chosen to describe the low-level flow in the region—Lake Charles (LCH) in the western portion of the domain and Slidell (LIX) in the domain's eastern portion (Fig. 1). Based on these mean vector winds, each half of the domain each day was placed into a particular flow regime. The low-level flow in a coastal region can be described by two directional components: parallel and perpendicular to the coastline. The flow also can be light and variable; thus a "calm flow" category was created to account for days when the mean vector wind speeds were less than 2.5 m s^{-1}. All directions are included in this regime. An average coastline orientation of 86° was assumed across the region, and days with mean vector wind speeds greater than 2.5 m s^{-1} were categorized into four quadrants or flow regimes based on this orientation. These flow regimes have equal directional ranges (90°) and are denoted northeast (356°-86°), southeast (86°-176°), southwest (176°-266°), and northwest (266°-356°).

3. LIGHTNING CLIMATOLOGIES

To investigate general lightning patterns in the northern Gulf Coast region, all flashes were grouped together and examined as a composite case, without consideration of wind direction or time of day. Fig. 2a shows a very active region of lightning over the northern Gulf Coast land mass. An east-to-west decrease in flash densities is evident from Alabama to Texas. Enhanced flash densities generally are seen along the entire Gulf of Mexico coastline, suggesting a link to the sea breeze. However, the strongest maximum is in coastal Mississippi, near Biloxi. Its flash density values are greater than 8.0 flashes km^{-2} yr^{-1}, with "year" defined as the warm season from May to September. Most of the other maxima along the northern Gulf Coast are located near major metropolitan areas. The areas near Houston, Lake Charles, New Orleans, and Mobile all exhibit flash density maxima of 5-8 flashes km^{-2} yr^{-1}. City locations and geographic features are shown in Fig. 1. Each of these maxima may be caused or enhanced by several factors, including convergence due to sea, lake, swamp, and river breezes, convex coastlines, urban heat island effects, and air pollution.

Flash densities over coastal Louisiana generally

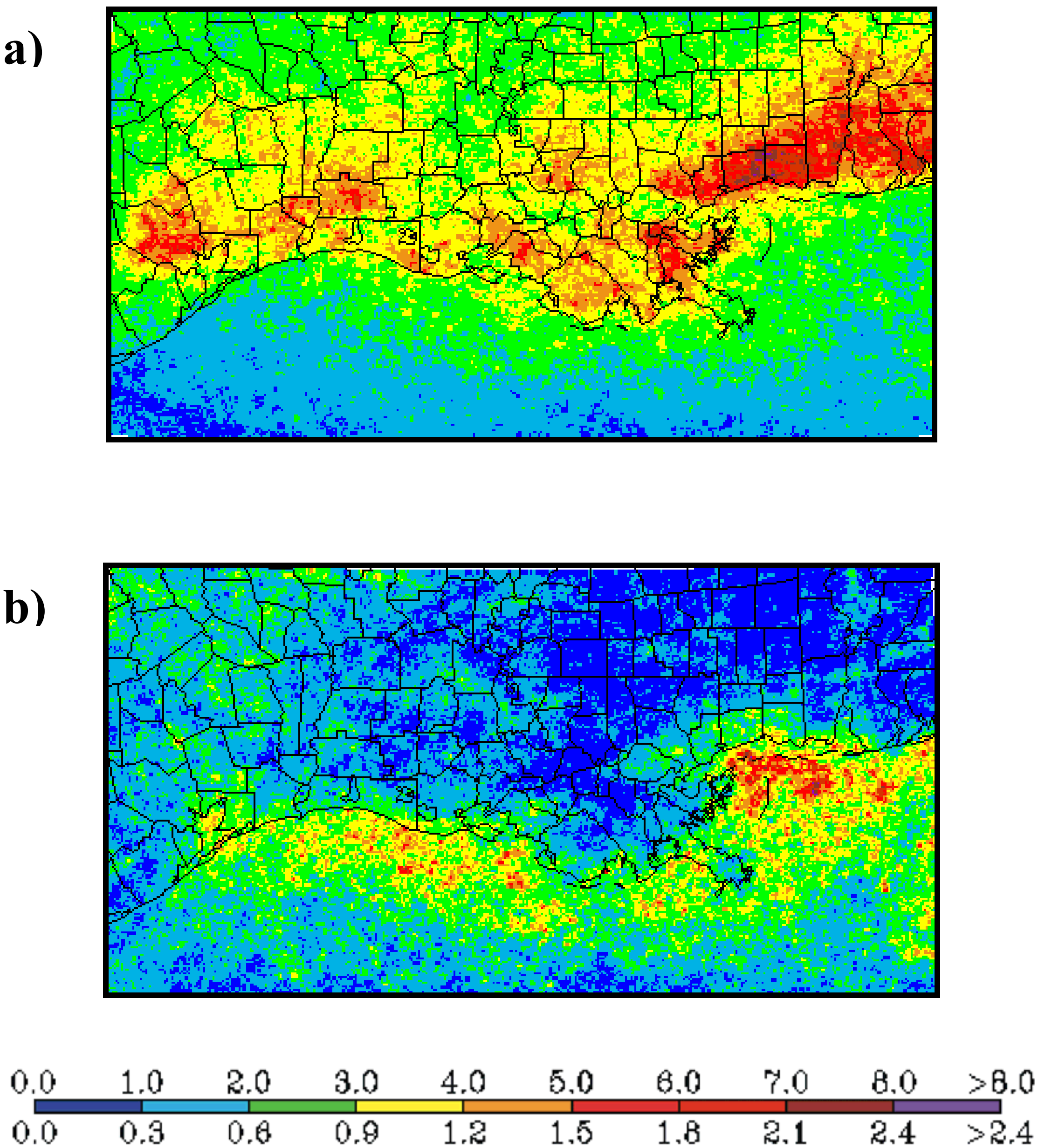

FIG. 2. Composite lightning flash density maps (flashes km^{-2} yr^{-1}) for all warm season days from 1989-2002, where "year" corresponds to the warm season from May to September. The upper scale corresponds to (a) the 24-hour composite, while the lower scale is for (b) the nighttime lightning composite from 0300-1200 UTC (2200-0700 CST).

are weaker than those over coastal Mississippi and Alabama. Furthermore, relative flash density minima are located over Lake Pontchartrain and the Atchafalaya Basin (Fig. 2a). The cooler and more stable air associated with Lake Pontchartrain caused flash densities to be between 2-4 flashes km^{-2} yr^{-1}. The Atchafalaya Basin, as well as much of coastal Louisiana, is a region of swamps, marshes, lakes, and small rivers, which exhibits relatively small flash densities. The northern portion of the study region (Fig. 2a) has smaller flash densities because the sea breeze typically does not propagate that far inland, and moisture supplies are more limited. The open waters of the Gulf of Mexico have fewer flashes because of three factors. First, the dominant forcing mechanism, the sea breeze, is a daytime inland phenomenon. Second, convection is usually weaker over water than over land, resulting in a smaller number of flashes (Orville and Henderson 1986). Third, the NLDN sensors are located only over land. Detection efficiency and location accuracy decrease as distance from the coastline increases (Cummins et al. 1998).

To further understand the synoptic environment of the region, reanalysis data were obtained from the National Center for Environmental Prediction (Kalnay et al. 1996). Specifically, 1000 hPa geopotential height data from each warm season day in the 14-year period were averaged to create one composite chart (Fig. 3). The subtropical ridge axis extends westward from central Florida into Louisiana. A trough is located over southern Alabama, with a relatively strong height gradient evident over southeast Texas and southwest Louisiana.

The diurnal distribution of lightning flashes for the composite (all days, all flows) case is shown in Fig. 4. Hourly values range from approximately 172 000 during the nighttime to near 1.4 million at the afternoon peak of 2000 UTC (1500 CST). A smaller, secondary peak occurs during the early morning at 1200 UTC (0700 CST). It is thought to be attributed to the land breeze, which is associated with early morning offshore convection. The smallest number of flashes occurs at 0500 UTC (0000 CST) when convection is minimal.

To investigate the small number of flashes during the nighttime, flash densities were calculated and plotted for the period 0300-1200 UTC (2200-0700 CST) (Fig. 2b). Flash densities for this nighttime period are much smaller than those of the 24-hour composite case (Fig. 2a), indicating that the majority of flashes during the 24-hour period is due to daytime convection. However, the decrease in lightning from east to west still is evident during the night.

Enhanced nighttime flash densities stretch from just offshore of Galveston Bay (southeast of Houston) to the eastern edge of the domain (Fig. 2b). The area of maximum flash densities is offshore of coastal Mississippi. The reason for this maximum is uncertain. However, it may be due to a merger of land breezes from the Mississippi and Louisiana coasts. As suggested by Lericos et al. (2002), enhanced offshore nighttime flash densities also can be due to the warm, shallow waters in that region. Conversely, weaker offshore flash densities occur just off the coastline southwest of New Orleans. This relative minimum may be due to the convex coastline in the area, which promotes localized divergence.

3.1 *Calm Flow*

The calm (light wind) flow regime contains all days when the 1000-700 hPa mean vector wind speed is less than 2.5 m s^{-1}, regardless of wind direction. There are several regions of enhanced and diminished flash densities across the region during calm flow (Fig. 5a). Flash density minima are found over large bodies of water and in regions of marshes and swamps. Thus, Galveston Bay (southeast of Houston), the Atchafalaya Basin, Lake Pontchartrain, and Mobile Bay (adjacent to Mobile) all exhibit flash densities between 0.0-0.04 flashes km^{-2} regime-day^{-1}. Enhanced flash densities in the coastal areas are organized in a line that parallels the coastline. Hourly flash density maps (not shown) indicate that this line is caused by the sea breeze penetrating inland only slightly. Large-scale winds less than 2.5 m s^{-1} are too weak to keep the circulation offshore or move it farther inland.

The strongest density maximum within the study area (greater than 0.08 flashes km^{-2} regime-day^{-1}) is located in coastal Mississippi (Fig. 5a). This area is favored for convection because of enhanced convergence due to flow interaction with the convex-shaped coastline and bay. Additional, weaker maxima (Fig. 5a) are noted in the vicinity of other metropolitan areas, such as Houston, Lake Charles, New Orleans, and Mobile.

3.2 *Northeast Flow*

Days when the 1000-700 hPa mean vector wind direction is between 356°-86° are classified in the northeast flow category. Magnitudes and patterns of flash densities differ considerably over the western

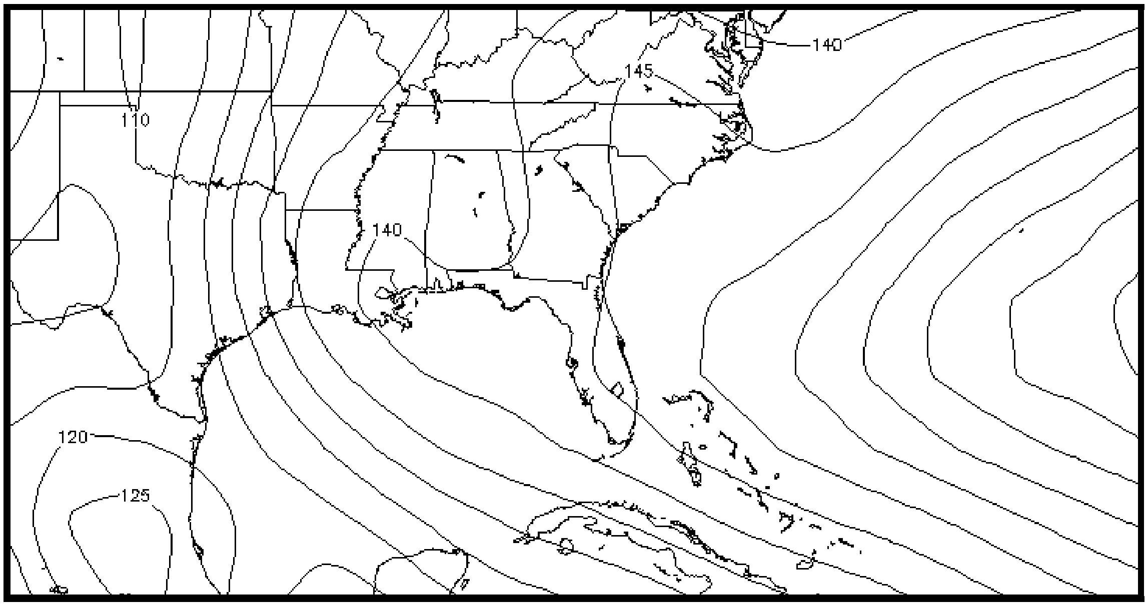

FIG. 3. Average 1000 hPa heights for the composite case. Contours are in 5 m increments.

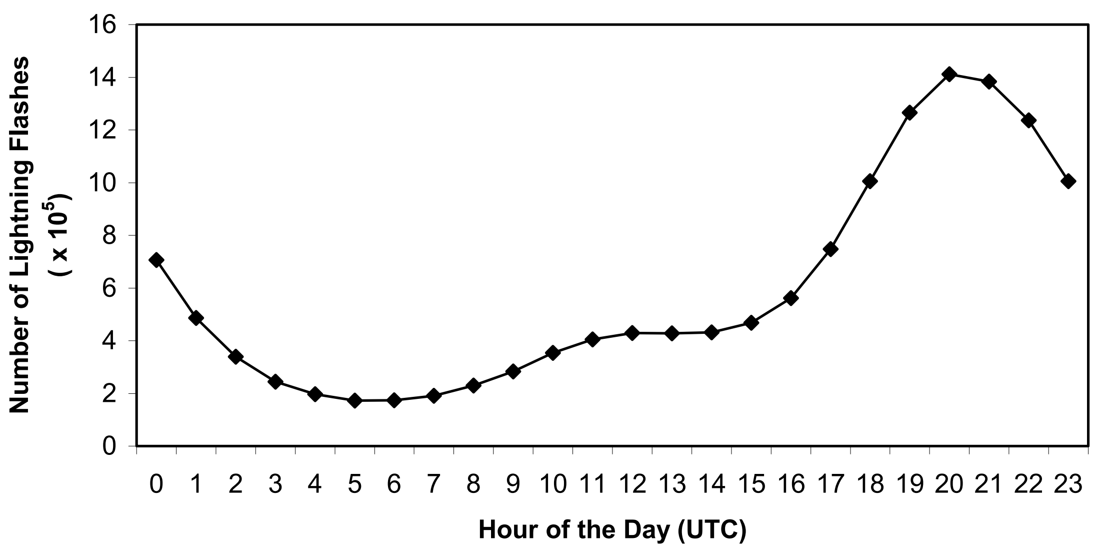

FIG. 4. Diurnal distribution of all flashes ($\times 10^5$) in the region shown in Fig. 1. Hour 1 UTC denotes flashes between 1:00-1:59 UTC.

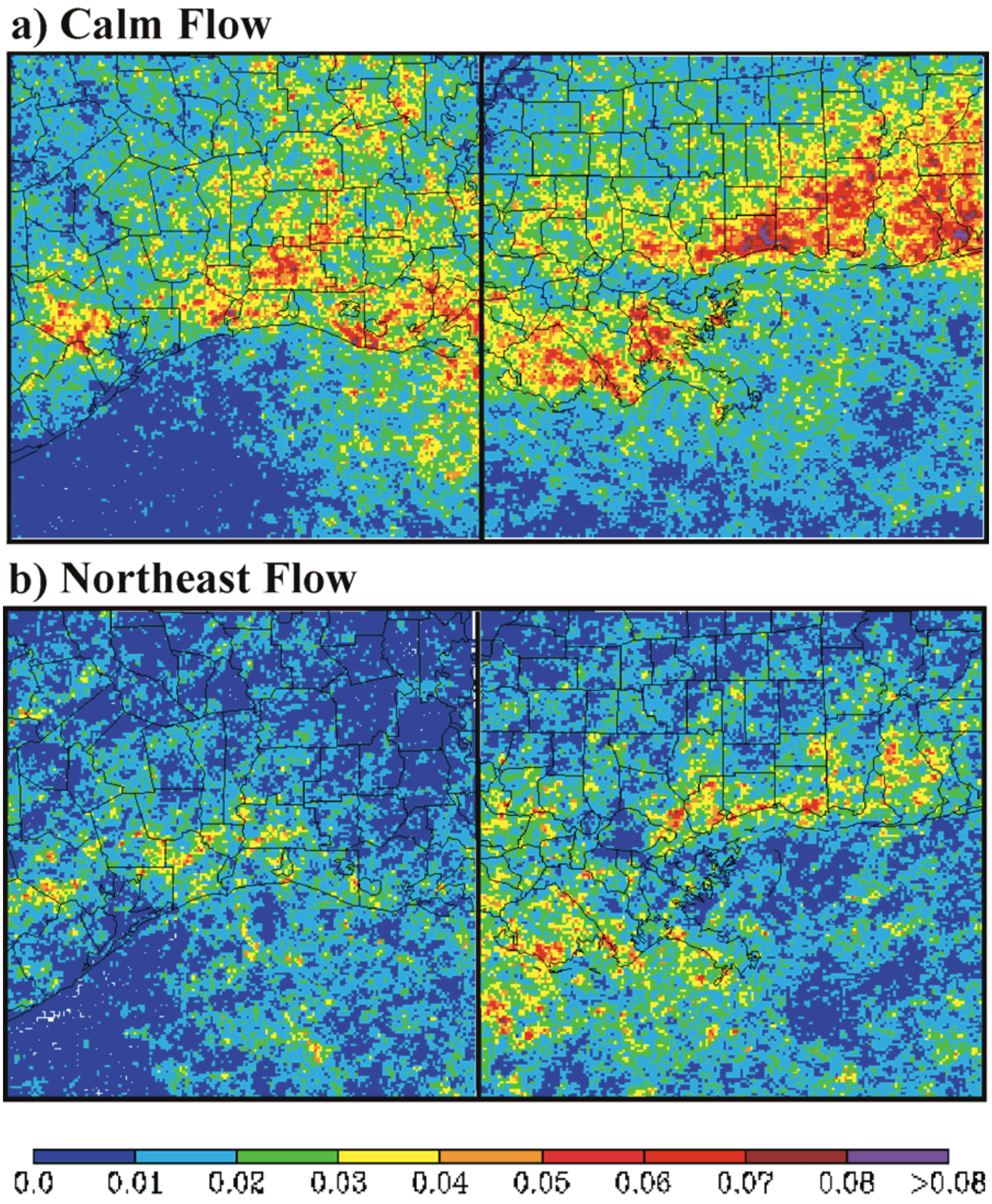

FIG. 5. Lightning flash density maps (flashes km^{-2} regime-day^{-1}) for the five flow regimes: (a) calm flow, (b) northeast flow, (c) southeast flow, (d) southwest flow, and (e) northwest flow. The solid black line indicates the division between the western and eastern components of the domain. The flow regimes of the western (eastern) half were based on the 1000-700 hPa vector mean winds at Lake Charles (Slidell).

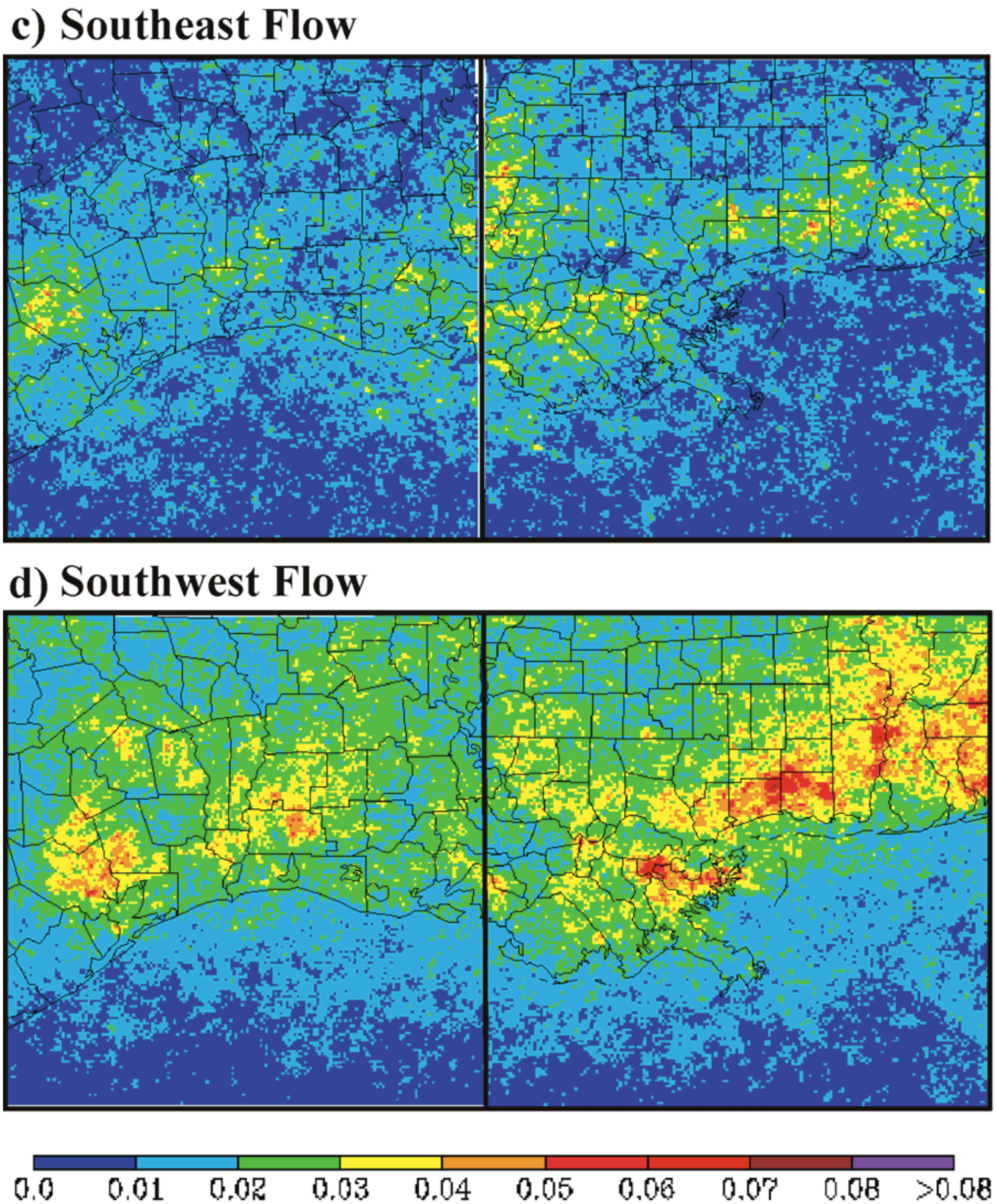

FIG. 5—continued.

e) Northwest Flow

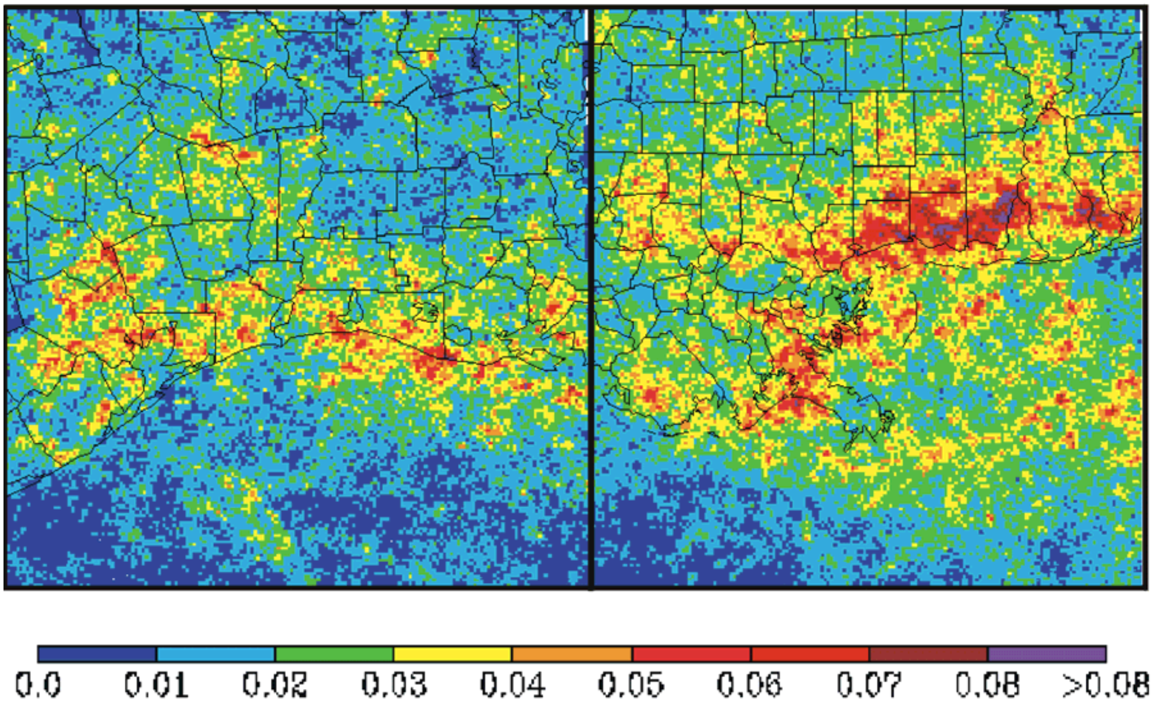

FIG. 5—continued.

and eastern domains during northeast flow (Fig. 5b), with values in the western half being much smaller. The reason for this diminished activity is unclear. The largest densities (0.03-0.06 flashes km^{-2} regime-day^{-1}) are in a broken line stretching from Houston to Lake Charles. They are associated with the sea breeze but are farther inland and weaker than expected. The western portion of coastal Louisiana consists of marshes, swamps, and lakes. Because of these geographic features, the thermal circulation of the sea breeze may be farther inland where there are stronger temperature gradients between land and water. Flash densities are weaker because of the weaker thermal circulation.

Flash densities across the eastern half of the domain are greater in magnitude and areal coverage (Fig. 5b). Two areas of large values are evident: along the Mississippi coastline and along the Louisiana coast south of New Orleans. Thunderstorms remain along the coasts because the advance of the northward moving sea breeze is limited by the large-scale northeasterly winds. Enhanced flash densities also are found over the coastal waters south and southwest of New Orleans. Hourly flash density maps (not shown) indicate that this lightning is caused by early morning offshore convection. Northeast flow produces flash density minima over Lake Pontchartrain and the Atchafalaya Basin.

3.3 Southeast Flow

The southeast flow regime consists of days whose mean vector wind directions are between 86°-176°. The flash density map for southeast flow (Fig. 5c) indicates little lightning across the region. The sea breeze is weak and advances onshore quickly, often without producing significant convection. However, a weak, broken line of enhanced densities stretches from Houston to Mobile, slightly inland from the coast. This line appears to result from the weak sea breeze. An area of enhanced flash densities (only 0.03 and 0.06 flashes km^{-2} regime-day^{-1}) also stretches from Baton Rouge northward into Mississippi. This area may result from propagating outflow boundaries, interactions between geographic features and the low-level flow, or urban influences (i.e., heat island effects, industrial pollution, etc.). As with northeast flow, relative flash density minima are noted over Lake Pontchartrain and the Atchafalaya Basin.

3.4 Southwest Flow

Days with southwest flow are characterized by mean 1000-700 hPa wind directions between 176°-266°. In the western half of the region, areas of enhanced flash densities (0.04-0.06 flashes km^{-2} regime-day^{-1}) are over Houston and Lake Charles, with smaller values (0.02-0.04 flashes km^{-2} regime-day^{-1}) in between (Fig. 5d). As previously discussed, the swampy geographic features in the nearcoast areas cause weaker sea breeze circulations that take longer to form and evolve, producing less convection and lightning. Also, compared to some of the other flow regimes, the southwest category has relatively little offshore activity.

Flash densities across the eastern portion of the region are greater than farther west (Fig. 5d). Maxima of 0.05-0.08 flashes km^{-2} regime-day^{-1} are over New Orleans, in coastal Mississippi, and in a north-south line extending northward from Mobile. The convection in this region is enhanced by interactions between the sea breeze, local circulations (i.e., bay and lake breezes), and topography.

3.5 Northwest Flow

Days with vector mean 1000-700 hPa wind directions between 266°-356° are classified in the northwest flow category. The flash density map for northwest flow (Fig. 5e) shows active regions of lightning. Sea breeze induced maxima are confined to the coastline by the large-scale flow. Values are largest in the eastern portion of the region. Densities greater than 0.08 flashes km^{-2} regime-day^{-1} extend along the coast from Biloxi to Mobile. In addition, there is considerable lightning farther offshore. Hourly maps (not shown) reveal that these offshore areas of enhanced flashes are associated with nighttime and morning convection. Relative minima of flash density are noted over Lake Pontchartrain and its shadow region, as well as over the Atchafalaya Basin.

4. IFPS/GFE

With IFPS, the forecaster uses grids of weather elements to make a forecast, rather than typing a text product. IFPS "tools" allow the forecaster to interpolate, fill in other associated weather elements, check consistency among weather elements, publish grids to a national data base, generate graphical products for the web, and produce routinely scheduled text products for public, marine, and fire weather services. Instead of using only model data to fill the forecast grids, the forecaster also can incorporate local climatologies into the grid (Fig. 6), thereby improving the final product. These serve as "value-added" input to the forecast.

Flash density values are contained in hourly grids which are converted to netcdf format for recognition by GFE. Once in GFE, the climatologies can be used on any day with suitable low-level winds. For example, if the next forecast day will have calm (light) winds, the forecaster can populate the next day's grid with this additional information. To further expand the utility of the flash density grids, the values can be converted into POPs, weather, and QPF by using procedures and smart tools.

Lightning climatologies for Florida have already been developed and are being implemented in NWS offices across the state (Watson et al. 2003). The incorporation and implementation of lightning climatologies have paved the way for other climatologies, such as radar, precipitation, and temperature, to be used in IFPS.

5. SUMMARY AND CONCLUSIONS

It is clear that complex and sometimes subtle forcing mechanisms are important in producing the flash patterns that are observed in the northern Gulf Coast region (Figs. 2, 5). One important mesocale forcing mechanism is the large-scale sea breeze, and a second is enhanced convergence/divergence patterns due to the shape of the coastline and to lakes. The maxima near major urban areas also may be influenced by urban factors, including air pollution and heat island effects (e.g., Orville et al. 2001; Steiger et al. 2002; Westcott 1995).

These lightning climatologies provide improved resolution, enabling more detailed forecasting of the times and locations of convective storm development. Incorporating these climatological data into the NWS IFPS/GFE provides much needed assistance to the meteorologist faced with the challenge of making detailed forecasts of summertime convection along the Gulf Coast.

6. REFERENCES

Camp, J. P., A. I. Watson, and H. E. Fuelberg, 1998: The diurnal distribution of lightning over north Florida and its relation to the prevailing low-level flow. *Wea. Forecasting*, **13,** 729-739.

Cummins, K. L. , M. J. Murphy, E. A. Bardo, W.

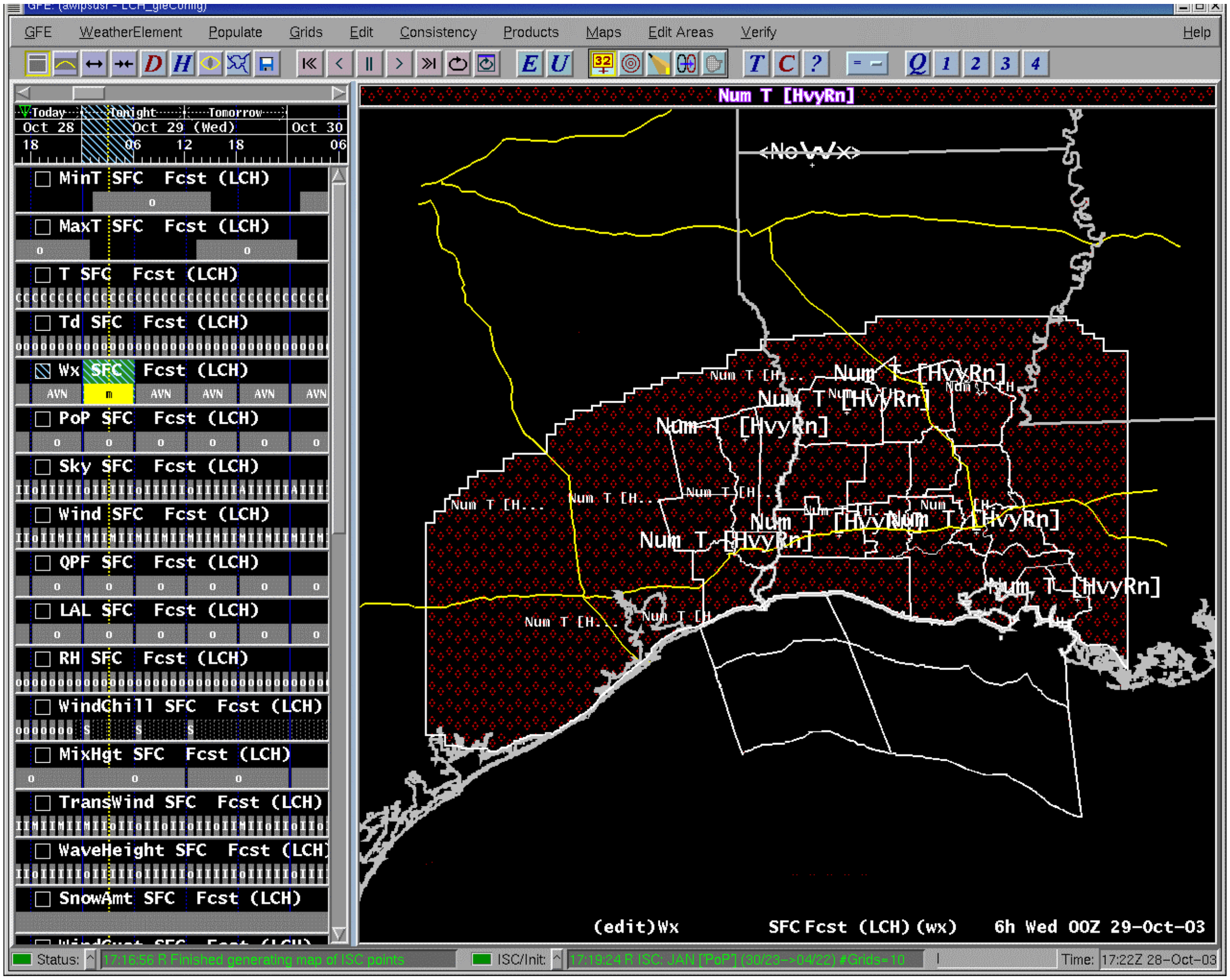

FIG. 6. GFE grid for the Lake Charles NWS County Warning Area.

L. Hiscox, R. B. Pyle, and A. E. Pifer, 1998: A combined TOA/MDF technology upgrade of the U.S. National Lightning Detection Network. *J. Geophys. Res*, **103,** 9035-9044.

Kalnay, E., and Coauthors, 1996: The NCEP/NCAR 40-Year Reanalysis Project. *Bull. Amer. Meteor. Soc.*, **77,** 437-471.

Lericos, T. P., H. E. Fuelberg, A. I. Watson, and R. L. Holle, 2002: Warm season lightning distributions over the Florida peninsula as related to synoptic patterns. *Wea. Forecasting*, **17,** 83-98.

López, R. E., and R. L. Holle, 1987: The Distribution of summertime lightning as a function of low-level wind flow in central Florida. NOAA Tech. Memo. ERL ESG-28, National Severe Storms Laboratory, Norman, OK, 43 pp.

Orville, R. E., and R. W. Henderson, 1986: Global distribution of midnight lightning: September 1977 to August 1978. *Mon. Wea. Rev.*, **114,** 2640-2653.

-----, G. Huffines, J. Nielson-Gammon, R. Zhang, B. Ely, S. Steiger, S. Phillips, S. Allen, and W. Read, 2001: Enhancement of cloud-to-ground lightning over Houston, Texas. *Geophys. Res. Lett.*, **28,** 2597-2600.

Steiger, S. M., R. E. Orville, and G. Huffines, 2002: Cloud-to-ground lightning characteristics over Houston, Texas: 1989-2000. *J. Geophys. Res.,* **107,** D11, 10.1029/2001JD001142.

Watson, A. I., T. J. Turnage, K. J. Gould, J. R. Stroupe, T. P. Lericos, H. E. Fuelberg, C. H. Paxton, and J. E. Burks, 2003: *Preprints, 19th Conference on Interactive Information Processing Systems (IIPS) for Meteorology,* *Oceanography, and Hydrology*, Long Beach, CA, Amer. Meteor. Soc.

Westcott, N. E., 1995: Summertime cloud-to-ground lightning activity around major midwestern urban areas. *J. Appl. Meteor.*, **34,** 1633-1642.

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