

A Climatology, Synoptic Assessment, and Thermodynamic Evaluation for Cloud-to-Ground Lightning in Georgia: A Study for the 1996 Summer Olympics



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ABSTRACT

A lightning climatology within 50 km of nine outdoor venue locations for the 1996 Summer Olympics has been produced. Spatial and temporal patterns were analyzed for July and August from 1986 through 1993. Unusually active and inactive lightning days were isolated, and thermodynamic variables examined. At the inland sites, no pattern was found in the spatial distribution of cloud-to-ground lightning; that is, the lightning locations were random. At the one coastal site, Savannah, an inland maximum in ground flash density was observed. Although there was great day-to-day variability, there was a diurnal progression of lightning with a broad minimum from 0600 to 1400 UTC and a sharp maximum near 2200 UTC.

Composite synoptic charts were produced for eight selected active days and eight selected inactive days. At the 500-hPa level the composite dewpoint depression in central Georgia was approximately 8°C less on active days than on inactive days. At the 850-hPa level the vector-averaged wind fields on active days revealed weakly anticyclonic southwesterly flow throughout Georgia. On inactive days, the vector-averaged winds exhibited a large anticyclone centered in northern Georgia.

Some correlation was found between cloud-to-ground lightning activity and several of the thermodynamic variables. The most highly correlated was a form of convective available potential energy with a correlation coefficient of 0.70. The Showalter stability index and *K* index had correlation coefficients of 0.60 and 0.56, respectively.

Logistic regression equations were developed to forecast active and inactive lightning days from thermodynamic variables and persistence. Days of unusually low lightning activity were more accurately identified through logistic regression than days of unusually high lightning activity. To aid in forecasting lightning days, the historical probability of active or inactive lightning days is provided as a function of the logistic model output.

1. Introduction

Each year, nearly 100 people are killed and over 250 people are injured by cloud-to-ground lightning in the United States. Many of these deaths and injuries occur at outdoor sporting events. The 1996 Olympic Games will feature outdoor sporting events from

archery to yachting, to be held at nine different sites in and around Atlanta, Georgia (Fig. 1a and Table 1). While lightning activity is nearly an everyday occurrence in Georgia during summertime, National Weather Service forecasters are particularly concerned about identifying days that will be exceptional, with either unusually widespread and intense thunderstorm activity or unusually quiescent conditions.

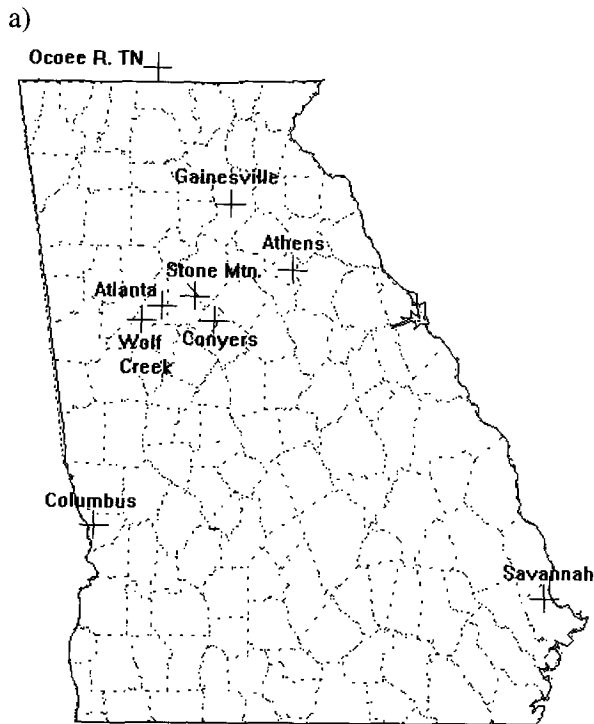
The purpose of our study is twofold. First, the lightning climatology at each of the nine outdoor venue sites was determined, including the mean spatial and temporal distributions and the daily, monthly, and yearly variability of cloud-to-ground lightning. Second, to aid those who must forecast lightning episodes, the

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b) **Flash Count vs. Local Time (EDT)**
July-August 1986-94 Cumulative Total
within 50 km of Atlanta

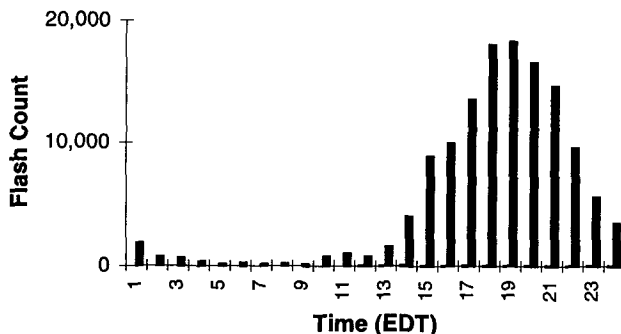


FIG. 1. (a) Outdoor venue locations for the 1996 Summer Olympic Games. (b) A cumulative 9-yr sample (July and August) of the cloud-to-ground lightning within 50 km of Atlanta [See (a)] shows the nature of the thunderstorm problem for the 1996 Olympics. The most dangerous time is from late afternoon to early evening. (Add 4 h to EDT to obtain UTC.)

factors associated with active and inactive lightning days in Georgia were studied. Synoptic charts were examined for specific patterns that could be associated with the active and inactive lightning days. In addition, soundings were analyzed for thermodynamic factors and stability indexes on the active and inactive days. Finally, a set of regression equations to pre-

dict cloud-to-ground lightning at Olympic sites from morning rawinsonde observations were developed and tested.

2. Data and methods of analysis

a. Lightning data

Lightning data used in this study were recorded from 1986 through 1995, a total of 10 years. Eight years of data, 1986–93, were used for detailed studies at the nine venue sites. The 1994 data were used as an independent set of information against which the logistic regression forecasting technique was tested. The 1995 data, received recently, were used to produce a 10-yr lightning climatology of flash density for July and August in Georgia and South Carolina (Fig. 2). During the period, 1986–95, the National Lightning Detection Network was formed from three lightning networks operating in the United States. One of these networks, begun in 1983 and operated by the State University of New York at Albany, provided uninterrupted coverage of Georgia beginning in 1986 (Orville 1991). The operation and characteristics of these networks, including the detection efficiency, have been described previously in the literature (e.g., Krider et al. 1980; Mach et al. 1986; Orville et al. 1983, 1987; Orville 1994) and will not be repeated here.

Our analysis concentrated on cloud-to-ground lightning strikes within 50 km of each of the nine outdoor Olympic venue sites, shown in Fig. 1a and

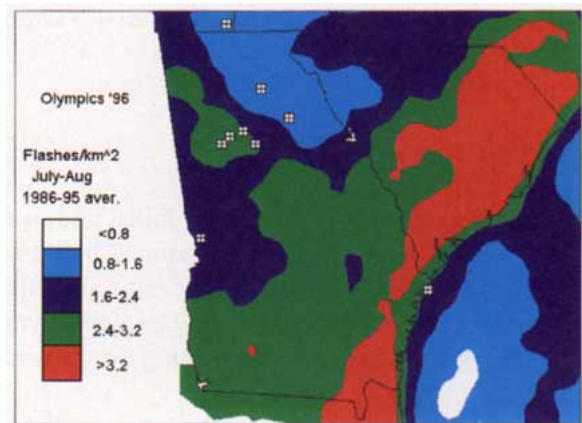


FIG. 2. Average ground flash density in Georgia and South Carolina for July and August from 1986 to 1995. This is a 10-yr climatology with the flash densities corrected for the detection efficiency of 70% (Orville 1994). Small white squares mark the nine venue sites.

TABLE 1. Outdoor venue locations and events for the 1996 Summer Olympic Games. Latitude is in degrees north; longitude is in degrees west.

Venue	Latitude	Longitude	Event
Olympic ring	33.74	84.40	Various
Columbus, GA	32.52	84.95	Softball
Conyers, GA	33.67	83.97	Equestrian, cycling
Athens, GA	33.95	83.32	Football (soccer)
Ocoee River, TN	35.07	84.45	Canoeing
Stone Mountain, GA	33.80	84.13	Tennis, cycling, archery
Wolf Creek, GA	33.67	84.57	Shooting
Savannah, GA (Wassau Sound)	32.13 (31.95)	81.20 (80.93)	Yachting, beach volleyball
Gainesville, GA	34.32	83.83	Rowing

listed in Table 1. The period of study for the venue sites is for the months of July and August in each of the years 1986–93, thus producing 16 study months. The Olympic Games will begin on 20 July 1996 and end on 4 August 1996, and lightning activity during July and August is assumed to be representative of the 2-week Olympic period.

Ground flash densities for each of the 16 study months were computed separately on grids with a resolution of 2.6 km × 2.6 km. The gridded data were then multiplied by 1.4 to account for the 70% detection efficiency of the lightning network (Orville 1991, 1994). The results were contoured to create maps of ground flash density for each venue site. The maps help determine the spatial distribution of lightning as well as the year-to-year variation of the flash density spatial distribution. Only representative maps are reproduced in this paper; a complete set of maps is found in Livingston (1995).

Active and inactive cloud-to-ground lightning days were identified during July and August. A cumulative histogram plot of the hourly cloud-to-ground lightning within 50 km of Atlanta for the years 1986–94 is shown in Fig. 1b. The dangerous period for thunderstorms is in the afternoon and evening, with peak activity shortly before sunset. Based on this diurnal cycle of lightning activity, a lightning day is defined as beginning and ending at 1200 UTC (0800 EDT). This

time was selected because the morning is a minimum time for lightning activity. Active lightning days were defined as those in which at least 1000 flashes occurred within 50 km of at least three of the nine outdoor Olympic sites. Inactive lightning days were defined as those in which no flashes were recorded within 50 km of at least seven of the nine outdoor venue sites. These definitions yielded 29 active and 106 inactive lightning days, which together compose approximately 26% of the total number of days. The active and inactive days represent the two ends of the spectrum; the other days can be considered as moderately active days.

b. Rawinsonde data

The U.S. rawinsonde network data used in our study have neither the spatial nor the temporal resolution of the lightning data. This presents a problem

when inferring conditions at one location from a sounding that may be hundreds of kilometers away. This is especially true when the two locations are on opposite sides of a discontinuity, such as a front or thunderstorm outflow boundary. Frontal passages in Georgia are extremely rare in July and August, but convection and the resulting outflows are common.

Since the thunderstorm activity is highly diurnal with a maximum at about 2200 UTC and a broad minimum from 0600 to 1200 UTC, the 1200 UTC sounding should not be influenced significantly by convective contamination caused by thunderstorms. The sounding prior to the convective activity (1200 UTC) may therefore be better correlated to thunderstorms than the sounding during the convective activity (0000 UTC). This is fortunate. It is the 1200 UTC soundings (prior to the convective activity) that the Olympic forecasters will use to determine the convective potential for the day.

The rawinsonde data used in our study are from the 1200 UTC soundings during July and August for the years 1986–94. Data from the entire United States were used to produce synoptic charts. Data from Athens, Georgia, and Waycross, Georgia, were used to determine thermodynamic variables and stability indexes.

The individual soundings at Athens, Georgia, on active and inactive lightning days were analyzed for

convective available potential energy, using mean parcels from the lowest 500 m (convective available potential energy, CAPE) and the lowest 2000 m (CAPE 2000), convective inhibition, Showalter stability index (SSI), lifted index, K index, mean 925–500-hPa relative humidity, and surface equivalent potential temperature (θ_e). Correlation coefficients were computed for each of the variables against the active and inactive lightning days. These coefficients indicate which variables are relevant when trying to predict active versus inactive lightning days. The statistical analysis also used persistence, defined as 0 if the previous day was inactive, 2 if active, and 1 if moderately active.

To investigate the possibility that a suitable combination of stability indexes may be useful in forecasting active or inactive lightning days, logistic regression analyses were constructed. Predictors were retained if the probability of no real relationship between the predictor and predictand (the p value) was less than 0.1. Both stepwise regression and backward elimination were used to construct models (Freund and Littell 1991; Wilks 1995, 188–189), and in all cases, both methods yielded the same set of predictors. The models were constructed using data for 1986–93 and tested on the independent 1994 dataset. The accuracy of the forecasts was determined using the probability of detection (POD), the false alarm ratio (FAR), and the critical success index (CSI) (Wilks 1995, 240–241).

3. Results

a. Lightning climatology

1) SPATIAL DISTRIBUTION AND VARIABILITY

The average ground flash density is contoured for the 10-yr period (1986–95) for Georgia, nearby portions of South Carolina, and the Atlantic Ocean during the months of July and August (Fig. 2). The grid spacing for Fig. 2 is 11.2 km. During these months a broad maximum exists along the coast and extends 100–150 km inland. A local minimum is evident in northeast Georgia, just east of the Appalachians, and a local maximum is centered near Atlanta.

The spatial distribution of ground flash density varied greatly from site to site and from year to year. Of the eight *inland* sites, the highest monthly average ground flash density (1.6 flashes km^{-2} month $^{-1}$ with a local maximum exceeding 2.9 flashes km^{-2} month $^{-1}$) for the 8-yr period was found near Wolf Creek for the month of July (Fig. 3). The coastal site, Savannah, on

the other hand, had a higher 8-yr monthly average ground flash density (1.7 flashes km^{-2} in July averaged over the area defined by a 50-km radius around Savannah) than any of the inland venue sites, with local maxima exceeding 2.8 flashes km^{-2} (Fig. 4). Fortunately, the Olympic yachting events near Savannah are to be held at Wassau Sound, on the coast, where the lightning activity is significantly less. Some of the lowest ground flash density values among the nine venue sites were found near the Ocoee River, Tennessee (< 0.7 flashes km^{-2} in July), near the venue site (Fig. 5).

The 8-yr averages, 1986–93, conceal extreme year-to-year variations in the monthly ground flash densities. Figure 6a shows the cumulative number of flashes in July within 50 km of each venue site for the month of July. The sequence of venue sites along the abscissa, Savannah to the Ocoee River, is roughly from the south to the north. The height of each color shows the relative amount of lightning for a particular year. Low amounts of lightning were recorded in 1988 and 1990; high numbers of flashes were recorded in 1993. Figure 6b shows the same information for August. All nine venue sites had their maximum July flash count in 1993, and six out of the nine outdoor venue sites had their minimum July flash count in 1988.

One remarkable result, we believe, is the observation that although there is a large year-to-year variability of cloud-to-ground lightning flashes, in both location and number, the long-term average of flash densities showed little geographical variation at eight

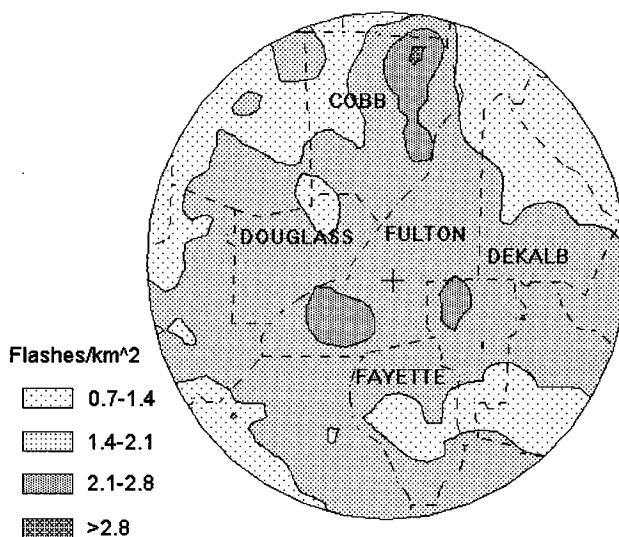


FIG. 3. Average ground flash density within 50 km of Wolf Creek, Georgia, for July from 1986 to 1993. These contours were obtained by summing the lightning to ground flashes for eight Julys and eight Augusts, dividing by eight, and contouring the results.

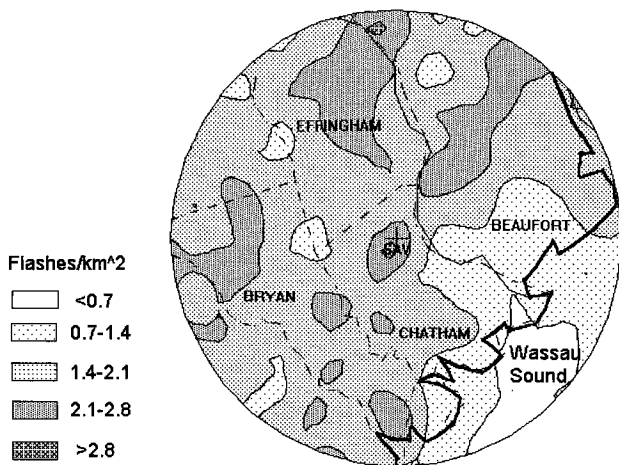


FIG. 4. Average ground flash density within 50 km of Savannah, Georgia, for July from 1986 to 1993. Note that the Olympic events will be at Wassau Sound, where the flash density is relatively low.

of the nine venue sites. This is apparent in the cloud-to-ground lightning for the Atlanta, Georgia, area. Figure 7 tells the story. Ground flash density is plotted for the period 20 July–4 August, covering the duration of the Olympics. This period is shown for 1990 (Fig. 7a), 1993 (Fig. 7b), and 1986–93 (Fig. 7c). Figures 7a and 7b demonstrate the variability of the flash density between years, while Fig. 7c shows the average flash density for the 8 years in the Atlanta area.

A smooth distribution of the ground flash density was not found at Savannah, Georgia. The 8-yr average within 50 km of Savannah shows a maximum over the land and a minimum over the water. There is a fa-

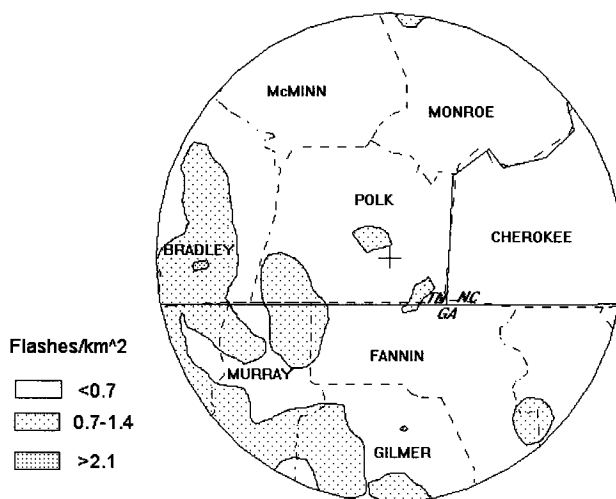


FIG. 5. Average ground flash density within 50 km of the Ocoee River in Tennessee for July from 1986 to 1993.

vored location for cloud-to-ground lightning. This is evident in Fig. 4 and is clearly shown, for example, in Fig. 8a, where the July 1986 cloud-to-ground lightning is contoured within 50 km of Savannah. Evidence of the sea-breeze convergence effect on thunderstorms is apparent in the maximum band that extends across Fig. 8a from the southwest to the northeast. In other years, this effect was not so pronounced, for example, July 1990 (Fig. 8b). The yachting events will take place in Wassau Sound where there are relatively fewer cloud-to-ground lightning flashes in all years studied to date.

2) TEMPORAL DISTRIBUTION AND VARIABILITY

We examined the daily lightning activity for July and August for the Olympic venue sites. Most days

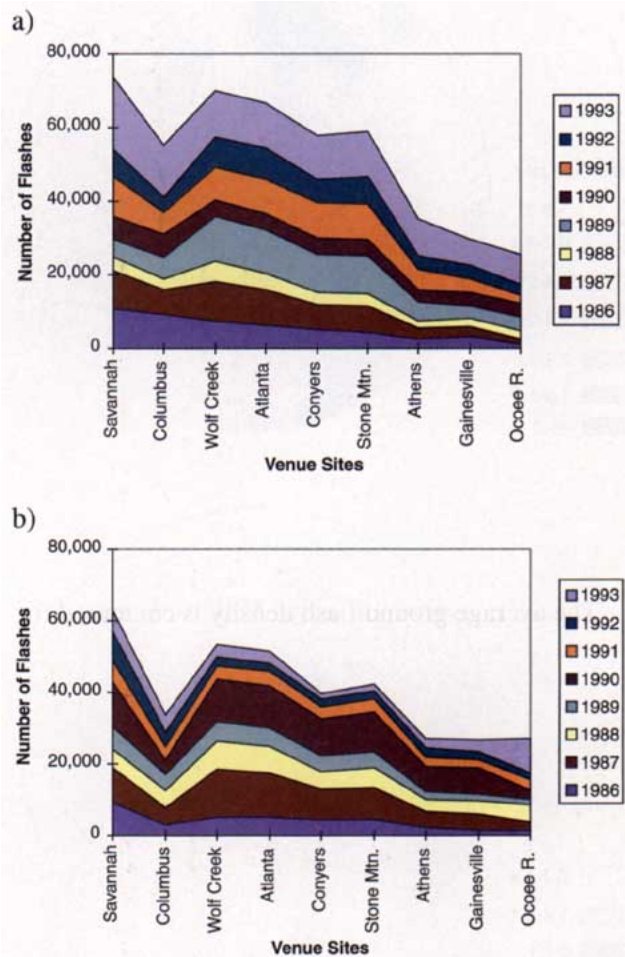


FIG. 6. (a) Variability of flash counts within 50 km of the nine venue sites for July from 1986 to 1993. The number of flashes on the ordinate is the cumulative total for successive years. (b) Variability of flash counts within 50 km of the nine venue sites for August from 1986 to 1993. The number of flashes on the ordinate is the cumulative total for successive years.

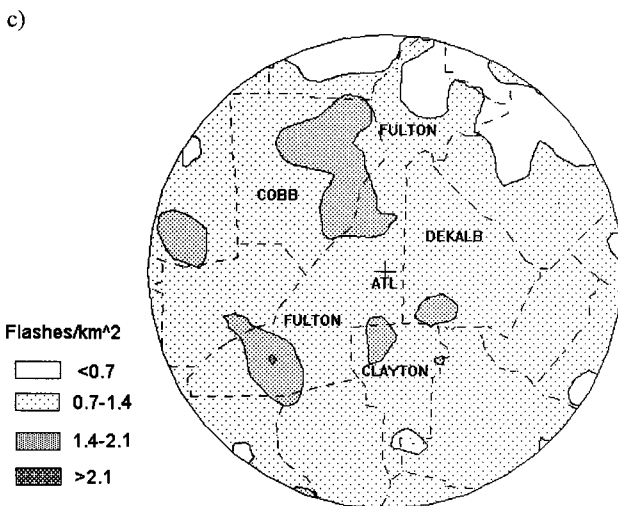
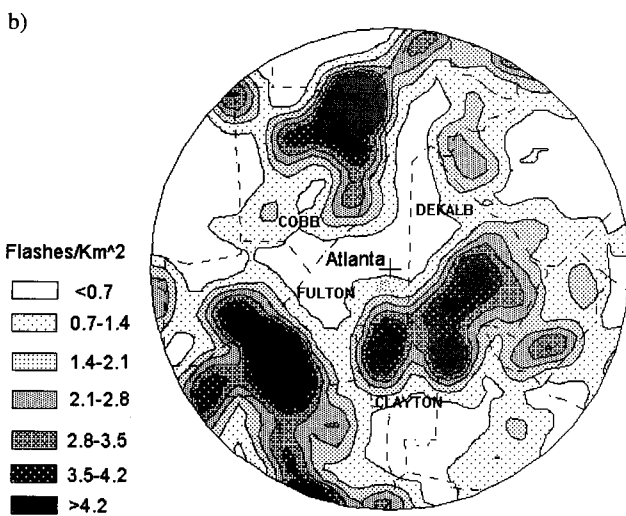
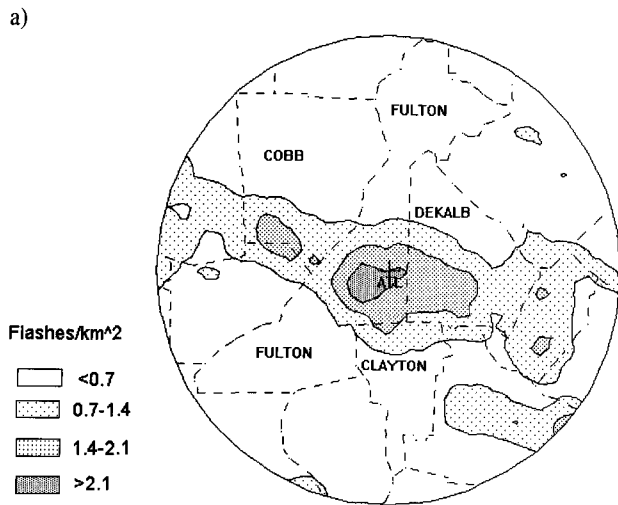


FIG. 7. (a) Ground flash density within 50 km of Atlanta, Georgia, from 20 July to 4 August 1990. (b) Ground flash density within 50 km of Atlanta, Georgia, from 20 July to 4 August 1993. (c) Average ground flash density within 50 km of Atlanta, Georgia, from 20 July to 4 August, for the 8 years 1986-93.

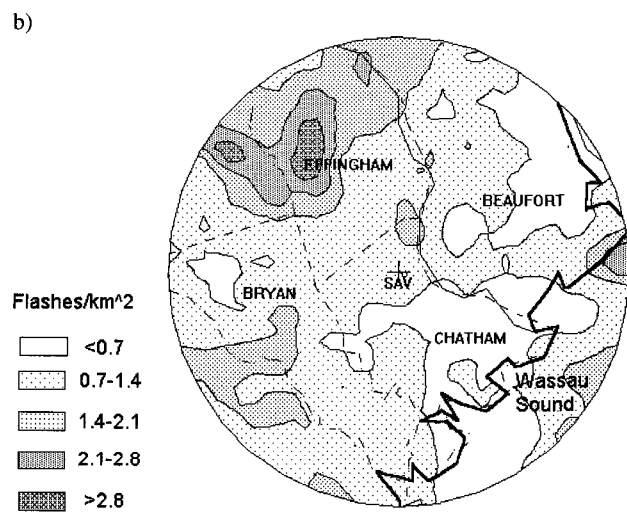
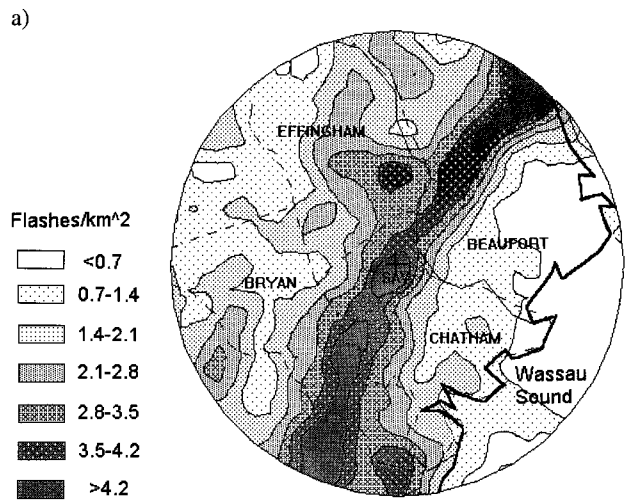


FIG. 8. (a) Ground flash density within 50 km of Savannah, Georgia, for July 1986. The Olympic yachting events will take place at Wassau Sound, where there are, fortunately, relatively fewer cloud-to-ground lightning flashes. (b) Ground flash density within 50 km of Savannah, Georgia, for July 1990.

had little or no lightning, while a few days were quite electrically active. Figure 9 shows the distribution of cloud-to-ground lightning within 50 km of Gainesville, Georgia, during July (Fig. 9a) and August (Fig. 9b), both in 1986. Note that 40% of the July flash count and 27% of the August flash count occurred on one day and that the days with lightning tended to cluster. It appears, also, that if thunderstorms occurred on one day, they would occur on the next. The same can be said of the days without thunderstorms. On the average in the regions of the eight inland venue sites, during the month of July, 19% of the cloud-to-ground lightning flashes occurred on one day, while in August, 21% of the flashes occurred on

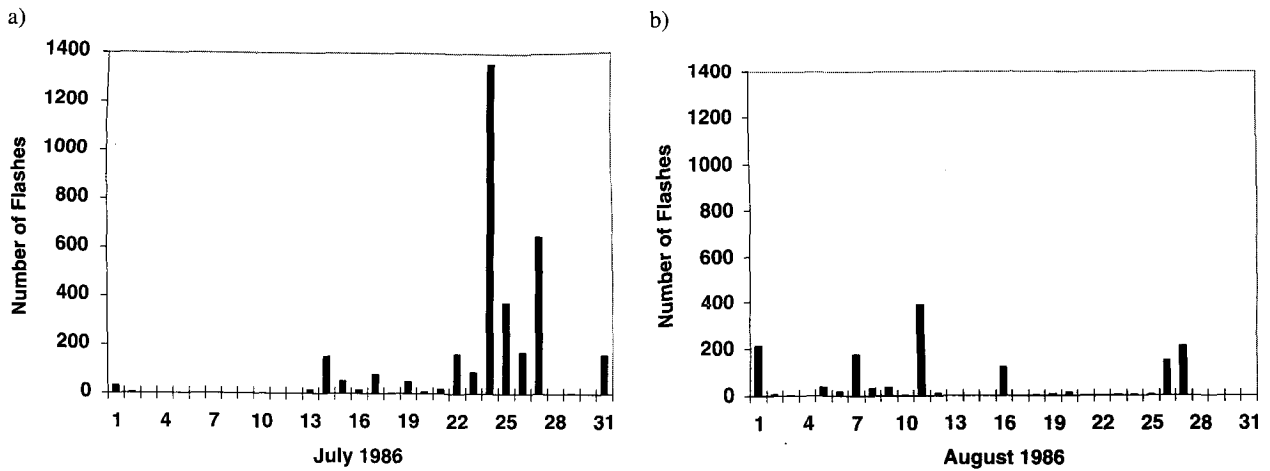


FIG. 9. (a) Daily distribution of cloud-to-ground lightning within 50 km of Gainesville, Georgia, for July 1986. Days are from 1200 to 1200 UTC. Percentage of the total monthly flashes is shown above the most active day. Note that a large fraction of the monthly lightning total occurs on one day. (b) As in (a) except for August 1986.

one day. These results lead us to define active and inactive lightning days, to be examined in a later section of this paper for their synoptic and thermodynamic characteristics.

The daily distributions of cloud-to-ground lightning flash counts are qualitatively different for Savannah, Georgia, than all other sites. Examples are shown for July 1992 (Fig. 10a) and for August 1992 (Fig. 10b). Lightning occurred on nearly every day and was not clustered among only a few days. The maximum daily flash count for Savannah was 16% of the July count (Fig. 10a) and 12% of the August count (Fig. 10b). This pattern is representative and can be expected in 1996.

b. Synoptic assessment

Upper-air analyses were composited for eight inactive lightning days. Widely spaced dates were chosen so as to avoid unduly weighting one or more persistent episodes.

Watson et al. (1994) found that lightning in the American southwest was strongly modulated by the upper-level flow pattern: an upstream trough was associated with periods of active lightning, while an upstream ridge was associated with periods of inactive lightning. Such a relationship was not prominent in our composites. The 500-hPa winds (Fig. 11a) were very light and generally westerly, although the airflow was from the southwest for the active composite and

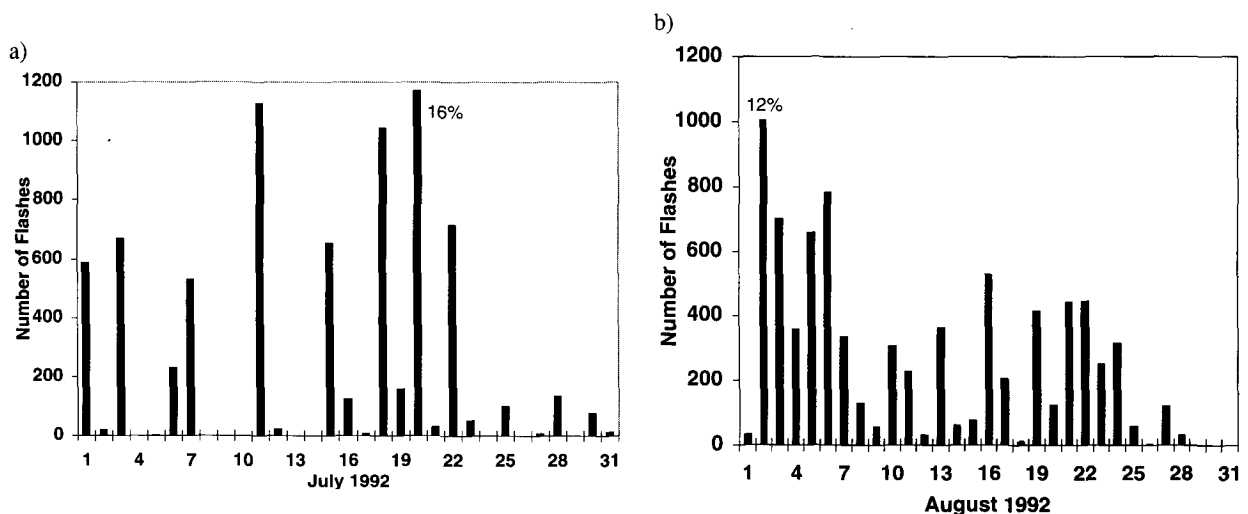
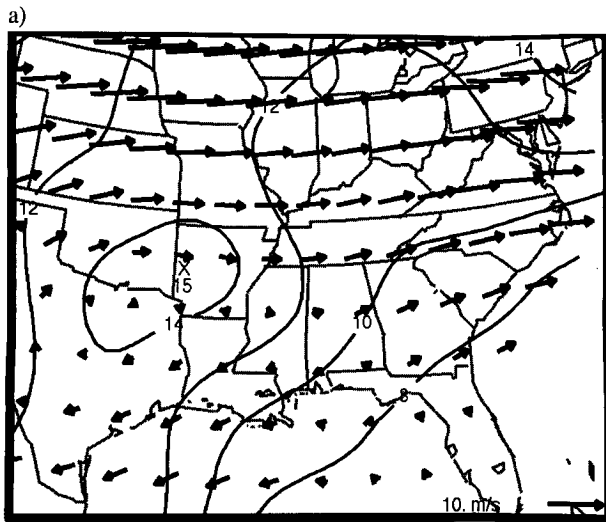
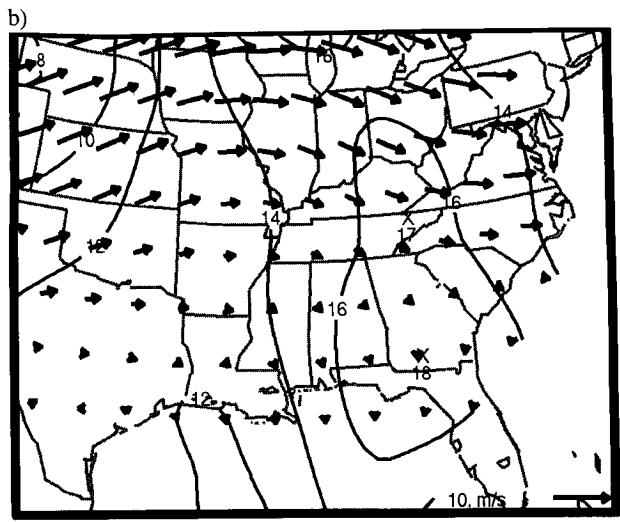


FIG. 10. (a) Daily distribution of cloud-to-ground lightning within 50 km of Savannah, Georgia, for July 1992. Days are from 1200 to 1200 UTC. Percentage of the monthly flashes is shown beside the most active day, July 20 in this case. (b) As in (a) but for August.



500 MB ACTIVE COMPOSITE WIND & DEWPOINT DEPRESSION



500 MB INACTIVE COMPOSITE WINDS & DEWPOINT DEPRESSION

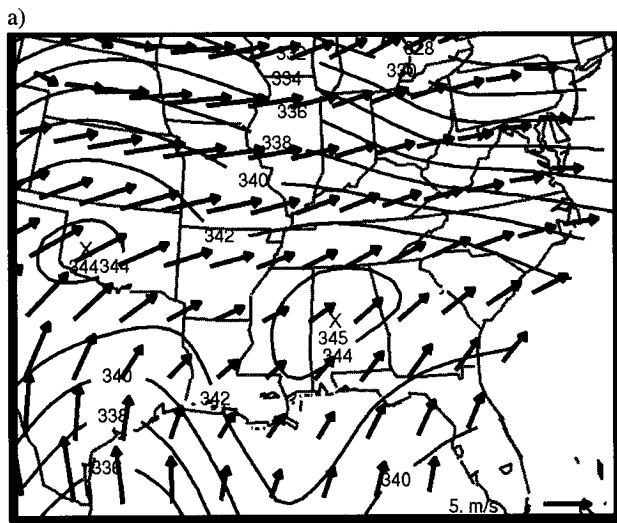
FIG. 11. (a) Contours of average constant dewpoint depression for the eight selected active lightning days at 500 hPa. Vector-averaged winds are plotted as arrows in m s^{-1} . (b) As in (a) except for inactive lightning days.

from the northwest for the inactive composite. Large case-to-case variability was present, however, and exceptions to this tendency are common. Somewhat more prominent was the difference in 500-hPa dewpoint depression (Fig. 11b). Composite dewpoint depressions were twice as large for inactive days as for active days.

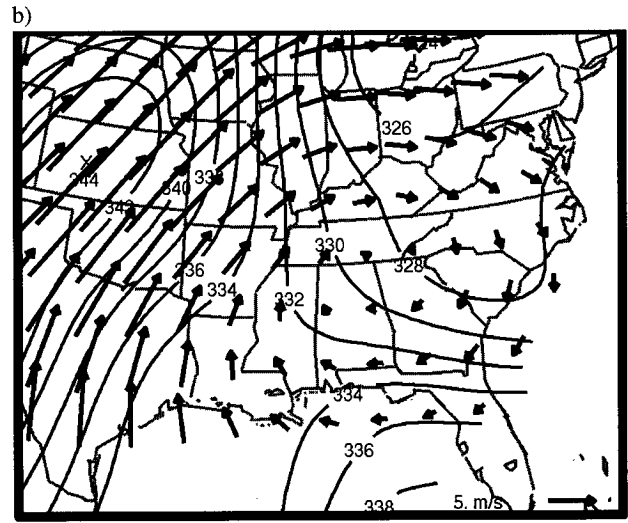
More dramatic differences were found between the composites at 850 hPa (Fig. 12). The active day composite shows an absolute maximum of Θ_e over Alabama with 850-hPa flow from the southwest. In

contrast, the inactive day composite shows northeasterly, downslope flow with negative Θ_e advection. Over Georgia, Θ_e ranges from 342 to 344 K in the active day composite and from 320 to 332 K in the inactive day composite.

Low-altitude fields such as horizontal divergence and moisture flux convergence were also examined. Although closely related to the daily spatial distribution of cloud-to-ground lightning, the compositing process removed the important local variation and left broad, undifferentiated fields.



850 MB ACTIVE COMPOSITE WIND & EQUIV. POT. TEMP.



850 MB INACTIVE COMPOSITE WIND & EQUIV. POT. TEMP.

FIG. 12. (a) Average equivalent potential temperature at 850 hPa for eight selected active lightning days. Vector-averaged winds are plotted as arrows in m s^{-1} . (b) As in (a) except for inactive lightning days.

c. Thermodynamic diagnosis

The 16 inactive and 6 active days from the 1993 data were used to examine the relationship between stability parameters and lightning activity. Of all the parameters evaluated, seven thermodynamic variables and persistence appeared to be significant predictors of cloud-to-ground lightning activity. The seven thermodynamic variables are CAPE, CAPE 2000 (lifted parcel determined by the average temperature and average dewpoint from the lowest 2000 m), *K* index, lifted index, Showalter stability index, θ_p , and the mean relative humidity from nine levels between 925 and 500 hPa.

Figure 13 shows the linear correlation coefficients of the thermodynamic variables and stability indexes for all of the 29 active and 106 inactive days in July and August from 1986 through 1993. The most highly correlated indicators of lightning activity are CAPE 2000 (0.70) and SSI (-0.60), followed closely by the *K* index (0.56).

Values of CAPE 2000 on active days ranged from 14 J kg⁻¹ to 1284 J kg⁻¹, while CAPE 2000 on inactive days spanned 0–997 J kg⁻¹ (Fig. 14). The inactive days had a highly skewed distribution due to the existence of outliers. The skewness on active days was 0.51, while the skewness on inactive days was 4.91. The mean on active days was 538 J kg⁻¹ and the mean on inactive days was 46 J kg⁻¹. Figure 14 shows there

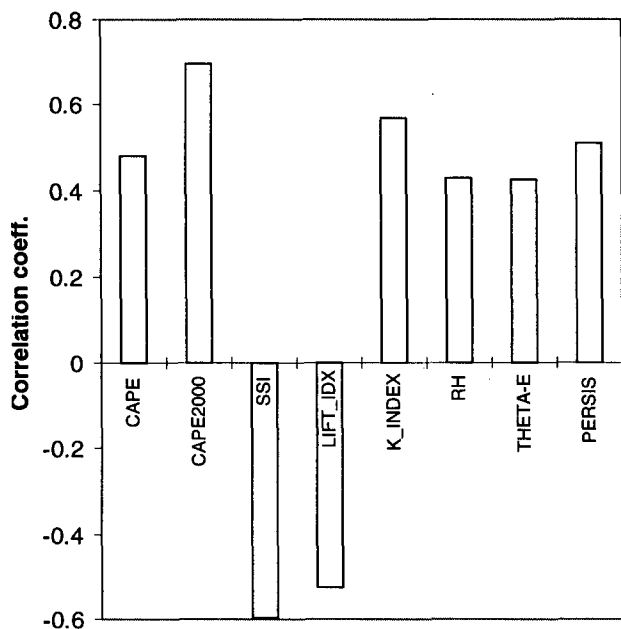


FIG. 13. Correlation between lightning activity and seven thermodynamic and stability variables for all the active and inactive lightning days from 1986 to 1993.

was a good delineation between active days and inactive days near 200 J kg⁻¹.

Figure 15 shows the comparison of SSI on active and inactive days. The SSI on active days ranged from -5 to 2, while the SSI on inactive days spanned from -3 to 12. The mean on active days was -2.1 and the mean on inactive days was 3.1. From Fig. 15 we see that the delineation between active and inactive days was zero. Ninety percent of the active days had SSI values of less than 0. Approximately 81% of the inactive days had values of SSI greater than 0. Using the predictor of greater than (less than) 0, SSI correctly predicted activity versus no activity from this dependent dataset 96% of the time.

Figure 16 shows the comparison of the *K* index on active and inactive days. The range of *K* values on active days was 28–42, while the range of *K* index on inactive days was 3–37. A good discriminator for active versus inactive thunderstorm days is a *K* index of 32. Eighty-six percent of active lightning days had a *K* index of more than 32, while 83% of the inactive days had a *K* index of less than 32.

A suitable combination of stability indexes should be superior in forecasting thunderstorms than a single index. Toward that end, logistic regression equations were developed to differentiate active days from all

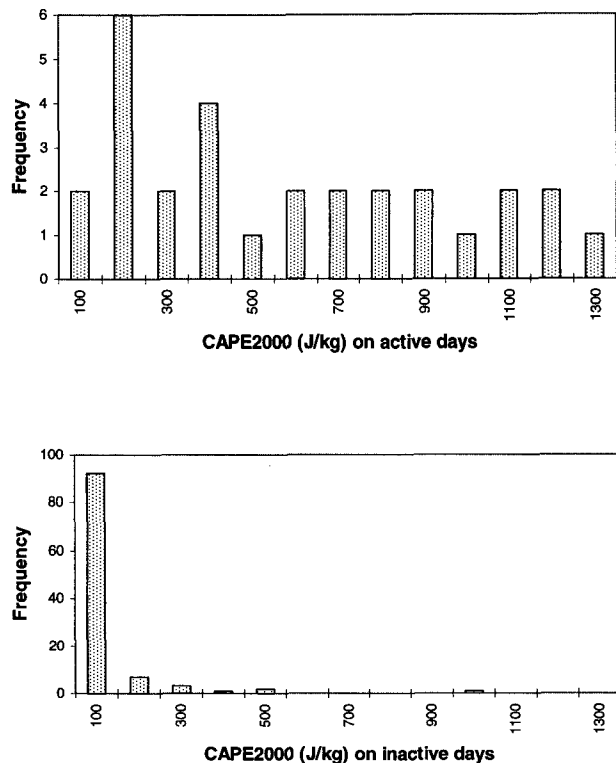


FIG. 14. Comparison of CAPE 2000 on active lightning days (top) and on inactive lightning days (bottom).

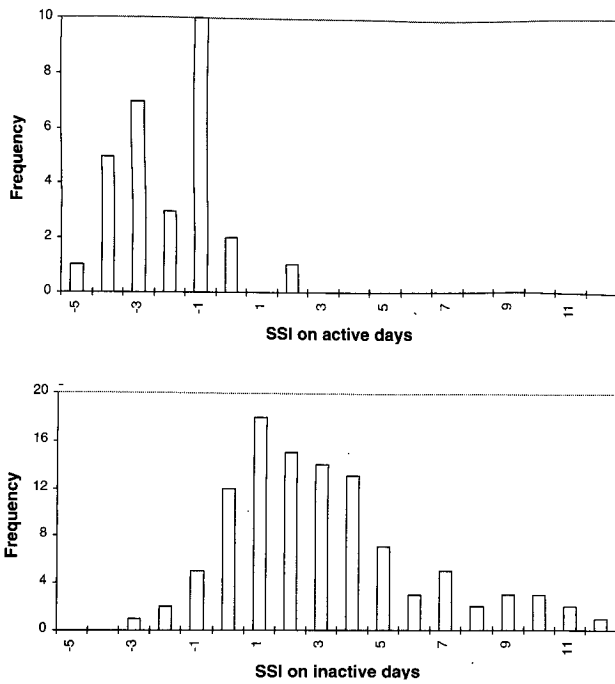


FIG. 15. Comparison of Showalter stability index on active lightning days (top) and on inactive lightning days (bottom).

other days and inactive days from all other days. Note that this is a more difficult forecast problem than simply distinguishing active from inactive days, since most days are neither active nor inactive.

The logistic regression equation assigns an output, y , between zero and one from a linear combination of predictors, x_i , as follows:

$$x' = \beta_0 + \sum \beta_i x_i$$

$$y = \frac{e^{x'}}{1 + e^{x'}}$$

For the purposes of forecast verification and skill estimation, the decision points (critical values of y) were chosen to maximize the CSI.

For forecasting active lightning days, the most significant predictors are SSI, persistence, and CAPE 2000 (Table 2). Using a criterion of $y \geq 0.2$ as a forecast of an active lightning day, the model correctly predicts 15 out of 29 active days and incorrectly predicts an active day on 33 out of 462 other days from 1986 to 1993. The probability of an active day for various values of y are given in Table 3. The CSI for 1986–93 was 24.2%, the POD was 51.7%, and the FAR was 68.1%. When tested on 1994 data, for which

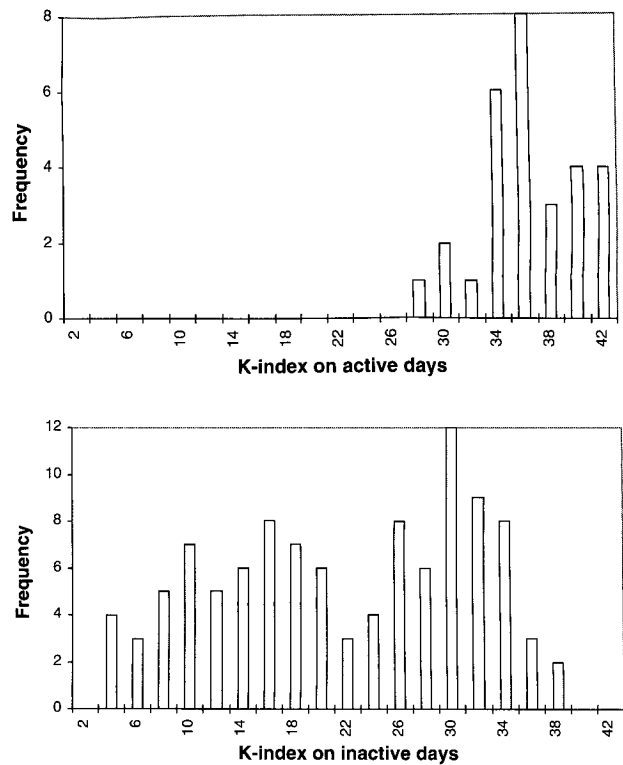


FIG. 16. Comparison of K index on active lightning days (top) and on inactive lightning days (bottom).

4 out of 62 days were active, the model successfully predicted 2 out of 4 active days and only two false alarms, for a CSI of 33%.

For forecasting inactive lightning days, the most significant predictors were lifted index, persistence, K index, and mean 925–500-hPa relative humidity (Table 4). Using a criterion of $y \leq 0.85$ as a forecast of inactive lightning day, the model correctly predicts 95 of 106 inactive days and incorrectly predicts an inactive day on 83 out of 385 other days from 1986 to 1993. The probabilities of an inactive day for various values of y are given in Table 5. The CSI for 1986 to 1993 was 50.3%, the POD was 89.6%, and the FAR was 46.6%. In 1994, which had 17 inactive lightning days, the model achieved a CSI of 43%, a POD of 88%, and a FAR of 55%.

4. Discussion and conclusions

a. Lightning climatology

The two venue locations that consistently had the lowest monthly flash counts were east of the Appalachians in southern Tennessee and northeastern Georgia. The Ocoee River, Tennessee, and

TABLE 2. Logistic regression parameters for active lightning days.

Variable	Coefficient, β_i	Probability of significance, p_i
Intercept, (β_0)	-1.6325	
SSI	-0.4141	0.003
Persistence	0.6698	0.007
CAPE 2000	0.00148	0.022

Gainesville, Georgia, venues had the lowest and second lowest number of flashes, respectively, of all the nine sites for the 8-yr period, 1986–93. There seems to be an “Appalachian effect” in this area, which tends to reduce the lightning activity. Since this relatively low flash rate region has a southwest-to-northeast topographic slope, any winds with a westerly or northerly component would produce downslope conditions in northeast and north-central Georgia, thereby acting to suppress any convective activity.

There were no small inland terrain features found to affect the spatial flash distribution. Indeed, all of the sites experienced a large year-to-year variability in the number of flashes and the location of these flashes. Average ground flash density maps reveal a fairly uniform pattern. This strongly suggests that on a small scale (i.e., within 50 km of a given location) the distribution of cloud-to-ground lightning at inland sites is essentially random. This result is supported by the previous work of Lopez and Holle (1986) and Gibson and Vonder Haar (1990), who suggest that the distribution of cloud-to-ground lightning may be entirely random in areas void of significant terrain features.

The coastal site, Savannah, did not show this uniformity in the distribution of the cloud-to-ground lightning locations. The 8-yr averages for July and August revealed a maximum approximately 50 km from the coastline and parallel to it. Furthermore, Savannah had the highest flash total for the 8-yr period of any of the nine venue sites. Both of these observations we attribute to the sea breeze. The elevated flash count near Savannah was due to its proximity to a persistent low-altitude

convergence zone located at the western extent of the sea breeze.

The day-to-day variability in cloud-to-ground lightning at each of the venues leads us to suggest that the temporal variation in lightning activity was governed by the synoptic patterns. Days of elevated lightning activity tended to occur in groups of three or four and were frequently separated by 7–10 days of reduced activity. This effect also led to the identification of persistence as a statistically significant predictor in both logistic regression models. Day-to-day variability was smaller at Savannah, where lightning activity appeared to be strongly forced on the mesoscale by the sea breeze.

b. Synoptic assessment

During the 8 inactive days sampled, an east–west 500-hPa ridge axis extended from central Texas into the western Atlantic, off the coast of Georgia. There was a distinct dry pocket at 500 hPa in the composite in central and southern Georgia, possibly associated with subsidence in the vicinity of the ridge. During the active lightning days, this east–west ridge was located farther north, and southwesterly flow dominated across Georgia. The contours of constant dewpoint depression were parallel to the mean flow. On average, the dewpoint depression was approximately 8°C less on active lightning days than on inactive lightning days.

A more pronounced difference between active and inactive lightning days was found at 850 hPa. The composite flow was from the southwest on active days but from the northeast and anticyclonic on inactive days. The average θ_e value over most of Georgia was 343 K on active days while it was only 330 K on inactive days. At 500 hPa, large case-to-case variability was observed, but most individual 850-hPa maps agree with the corresponding composites.

TABLE 3. Probability of active lightning day (1986–93), given logistic regression model output.

Logistic model output, y	Probability of active lightning day	Total number of active lightning days
0.00–0.05	1.5%	5
0.05–0.10	8.0%	5
0.10–0.40	20.0%	14
0.40–1.00	60.0%	5

TABLE 4. Logistic regression parameters for inactive lightning days.

Variable	Coefficient, β_i	Probability of significance, p
Intercept, (β_0)	-1.0935	
Lifted index	-0.2413	0.0001
Persistence	0.5104	0.0004
K index	0.0715	0.007
Relative humidity	0.0349	0.02

c. Thermodynamic factors

Seven selected stability indexes and thermodynamic parameters were found to be significantly correlated to active and inactive lightning days. Both SSI and K index correlation coefficients (-0.60 and 0.57, respectively) compare favorably with those found by Jacovides and Yonetani (1990) of -0.52 for SSI and 0.59 for the K index. The findings of Stone (1985) of -0.61 and 0.54 for the SSI and the K index, respectively, in the eastern United States compare favorably with our findings in Georgia.

CAPE 2000 was found to be more correlated to lightning activity than CAPE (0.70 vs 0.48). This is due to the fact that CAPE 2000 acts as an elevated CAPE. Rather than using a surface to 500-m average of temperature and mixing ratio, as does CAPE, CAPE 2000 averages the lowest 2000 m to estimate the surface values of temperature and mixing ratio. This discriminates against days with shallow moist layers, which are not conducive to thunderstorm activity.

Logistic regression equations were derived from 1986-93 data to forecast exceptional lightning events. Since the logistic models were as accurate for the independent 1994 dataset, the models can be assumed to be robust. Both models use a stability index as their first predictor and persistence as their second, suggesting that Georgia summertime weather regimes change slowly and that the various stability indexes do not provide independent information.

The model for forecasting inactive lightning days was more successful than

the model for forecasting active lightning days. Evidently, active lightning days are not easily distinguished from ordinary lightning days on the basis of thermodynamic indexes and persistence alone. We propose that the logistic regression models be used in conjunction with Tables 3 and 5 to obtain a probability forecast of active and inactive lightning days. This objective forecast should be combined with interpretation of synoptic and seasonal features and local experience to arrive at a forecast of lightning activity for Olympic venues. Forecasters should be aware that on about 3 days out of 4 the Georgia summertime lightning activity will be light to moderate, *not meeting* the criteria for either an active day or an inactive lightning day.

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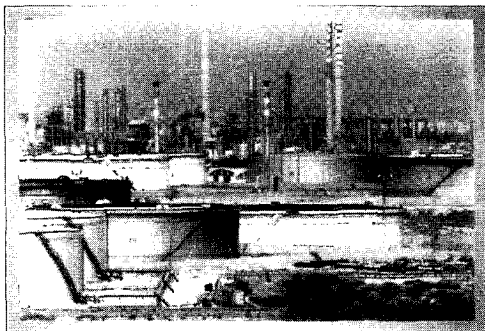
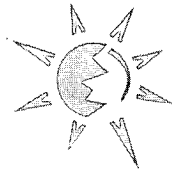
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TABLE 5. Probability of inactive lightning day (1986-93), given logistic regression model output.

Logistic model output, y	Probability of inactive lightning day	Total number of inactive lightning days
0.00-0.20	85%	27
0.20-0.60	65%	39
0.60-0.85	35%	29
0.85-0.95	5%	10
0.95-1.00	1%	1

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