The Preconvective Environment of Summer Thunderstorms over the Florida Panhandle

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ABSTRACT

The preconvective environment of summer thunderstorms over the Florida Panhandle is investigated. Geostationary satellite imagery as well as surface and radiosonde data were examined during the summers of 1990 and 1991. Days were classified either as synoptically disturbed or undisturbed based on the imagery. The undisturbed days then were subjectively subdivided into those having strong, weak, or no convection. Composite sounding profiles of various meteorological parameters were constructed for each category of the undisturbed days. Composites of various stability indexes also were calculated.

Midtropospheric moisture (particularly from 700 to 500 mb) and low-level instability were the best thermodynamic parameters for forecasting convection over the Florida Panhandle. The surface-based lifted index was the most useful stability index for predicting convective development. Wind direction also was related to the degree of convective activity in the Florida Panhandle. The strong convection days tended to have low-level winds from the south or southwest. Low-level winds on the driest days generally had northerly and easterly components.

1. Introduction

Florida has the highest concentration of thunderstorms of any state in the nation (Court and Griffiths 1986). Locations in the Florida Panhandle experience thunderstorms about 70 days per year, with most occurring during the warm season in the afternoon and early evening. Three basic ingredients are required for thunderstorm development: sufficient water vapor, instability, and a source of upward motion.

Although there has been considerable research into thunderstorm development over Florida, most studies have examined the central and southern portions of the state. Byers and Rodebush (1948) proposed that convergence from coastal sea breezes was the dominant dynamic mechanism leading to almost daily thunderstorms over the peninsula during summer. Locations of this convection and its diurnal variability were found to be related to the prevailing wind direction and speed (Gentry and Moore 1954; Frank et al. 1967). This was confirmed by later studies using data from the Florida Area Cumulus Experiment (FACE) (e.g., Ulanski and Garstang 1978; Cooper et al. 1982; Watson and Blanchard 1984). Watson et al. (1991) found that lightning was most frequent during low-level southwesterly flow and least frequent with northeasterly winds. Interactions between sea-breeze circulations and the prevailing flow also have been investigated using numerical models (e.g., Pielke 1974; Nicholls et al. 1991; Arritt 1993).

The thermodynamic structure of the atmosphere in the vertical also is important in forecasting thunderstorm development over the Florida peninsula (e.g., Gentry 1950; Frank and Smith 1968). Burpee (1979) found little difference between the magnitude of average surface convergence on dry and wet sea-breeze days. However, there were large differences between their midtropospheric moisture profiles and smaller differences between temperature profiles. Similar findings were reported by Watson et al. (1991).

Lopez et al. (1984) examined both the winds and thermodynamics associated with convection over south Florida. They noted that interactions between synoptic-scale flow patterns and mesoscale sea-breeze circulations determined convective activity. Gentry and Moore (1954) also had observed these relationships. Similarly, multivariate regression has shown that winds, stability, and humidity are all important in forecasting Florida thunderstorms (Neumann and Nicholson 1972).

There has been little research into the factors leading to summertime thunderstorms over the Florida Panhandle. However, there may be differences with south Florida since the panhandle is oriented primarily west to east instead of north to south, it is at a higher latitude, and it is closer to the main continental landmass. The panhandle also has a single sea breeze, while the peninsula has a sea breeze on both coasts. Smith (1970)

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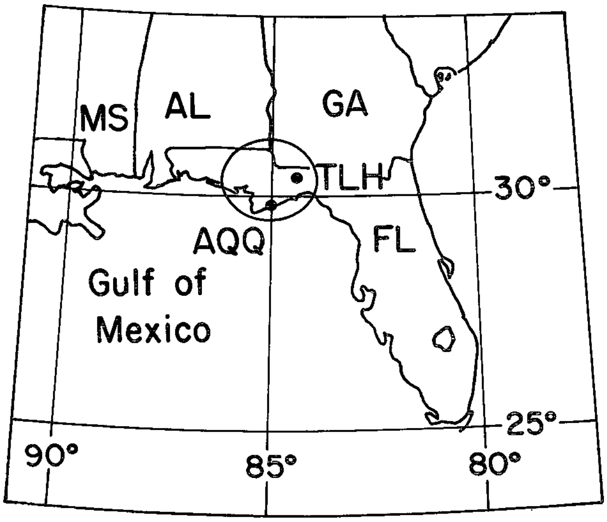

FIG. 1. Map of the southeastern United States with the region of study circled. TLH and AQQ represent Tallahassee and Apalachicola, respectively.

used digitized radar data from Apalachicola and pilot balloon observations (PIBALs) from Tallahassee to examine the timing and location of summertime radar echoes under various wind regimes. He found that the prevailing low-level wind direction, as well as the shape of the coastline, were important in determining locations for storm development. Smith (1970) did not examine the role of thermodynamics on convective development.

The current paper examines the preconvective environment of summer thunderstorms over the Florida Panhandle that are caused primarily by sea-breeze-induced convergence. High-resolution visible satellite imagery is used to describe the area coverage and location of thunderstorm development. The extent of the convection then is related to thermodynamic and wind parameters from radiosonde soundings in the area. Our major objective is to improve the understanding of summertime thunderstorms over the panhandle so that better forecasts will result.

2. Methodology

Our study area (circled in Fig. 1) stretched approximately 150 km east and west of Apalachicola (AQQ) and northward to near the borders of Georgia and Alabama. Tallahassee (TLH) is located in the eastern portion of the study area. We examined the summers of 1990 and 1991 using 1-km visible Geostationary Operational Environmental Satellite (GOES) imagery at half-hourly intervals to locate the thunderstorms. The imagery had been ingested, using The Florida State University's direct-readout GOES ground station (Smith and Fuelberg 1989), and archived on videotape. The sample image in Fig. 2 shows clouds oriented along

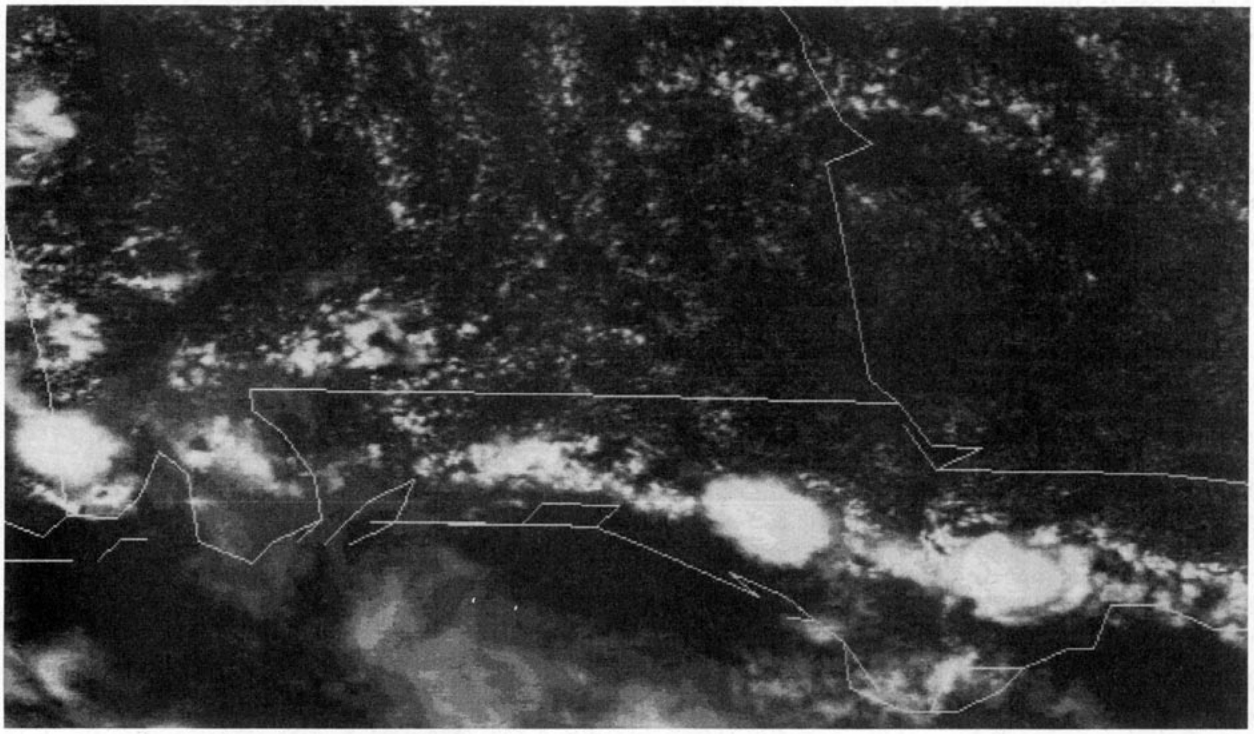

FIG. 2. GOES 1-km visible image for 1530 EDT (1930 UTC) 5 August 1991. Note the sea-breeze front and thunderstorms. This is an example of a strong convection day.

a line inland from the coast. These clouds indicate the location of the sea-breeze front, defined as the region of convergence at the landward limit of the sea-breeze penetration. Several well-developed thunderstorms are located along the sea-breeze front.

Radiosonde data were used to describe the prevailing winds and vertical thermodynamic structure of the atmosphere within the region. Soundings at 0800 EDT (1200 UTC) were employed since they are the latest that can be used in preparing the afternoon forecast. These sondes typically are released near 0715 EDT. The AQQ radiosonde site was used until 12 June 1991 when it was moved about 100 km northeastward to TLH. We believe that this move did not have an appreciable affect on our results. Various equipment and data problems occurred occasionally during the two years. The data collection period for 1990 was 26 June–16 September during which 66 days had both usable satellite imagery and upper-air data. During 1991 there were 93 usable days between 16 May and 31 August.

Days were classified subjectively according to the areal coverage of cloudiness and convection. The synoptically "disturbed" category contained days having appreciable low- and/or higher-level cloudiness (greater than 50% coverage) at any time during the morning. Our objective was to investigate synoptically quiet days on which the sea breeze was the dominant forcing mechanism leading to thunderstorm development. Since morning cloudiness usually indicated important synoptic-scale forcing, the 35 disturbed days during the two summers were omitted from the data pool. This is consistent with the methodology used for south Florida by Burpee (1979) and Burpee and Lahiff (1984).

The remaining 115 days, classified as synoptically "undisturbed," were divided into three subcategories based on the imagery: strong convection (SC), weak convection (WC), and no convection (NC). The SC group contained days when the largest thunderstorm cell within the region of interest (Fig. 1) covered an area greater than 500 km^2. Storm areas were estimated from the satellite imagery. The example in Fig. 2 was classified SC. Of the 115 undisturbed days, 66 were categorized as having strong convection. The other extreme category, NC, was noted on 26 days. Although cumuloform cloudiness frequently occurred in the region on these days, the imagery indicated no precipitation. Finally, weak convection days had one to five small precipitation cells in the study area, with the area of the largest cell less than 500 km^2. There were 23 WC days during the two summers. The undisturbed category did not contain cases when sea-breeze-induced convection formed just north of the study area (Fig. 1) without also occurring within the domain.

3. Results

a. Temperature and humidity

We calculated differences between each day's 0800 EDT sounding and the average sounding for all undisturbed days. Average temperature differences for each undisturbed category are shown in Fig. 3. The profiles show that temperatures on the strong convection days differ little from those of the NC or WC days. This finding contrasts with results for south Florida (Burpee 1979; Lopez et al. 1984). Burpee (1979) found that temperatures between 850 and 450 mb on the driest days were consistently warmer than the mean of all days; however, that is not observed over the panhandle.

We investigated whether low-level inversions or stable layers suppressed storm development on NC days. Specifically, the minimum lapse rate between 950 and 650 mb (over at least a 10-mb-thick layer) was calculated for each 0800 EDT sounding. Results (not shown) indicate that the mean minimum lapse rate for the NC category is not appreciably different from those of the other groups. In summary, temperature soundings at 0800 EDT give little indication about the likelihood for afternoon convection over the Florida Panhandle.

Sounding differences for dewpoint temperature show interesting contrasts (Fig. 4a). The NC category is drier at all levels than the other two categories; greatest differences are 4°–6°C between 700 and 500 mb. The WC category actually is more humid at most levels than the SC category, especially above 600 mb.

The moisture contrasts between categories also are reflected in profiles of mean relative humidity (Fig. 4b). Greatest differences again occur between 700 and

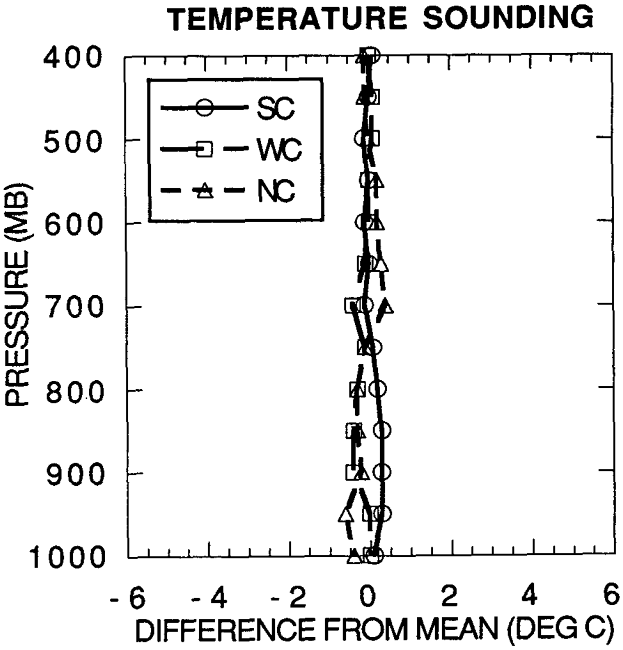

FIG. 3. Vertical profiles of mean temperature differences between each day's 0800 EDT sounding and the average for all undisturbed days. Averages are given for three categories: strong convection (SC), weak convection (WC), and no convection (NC).

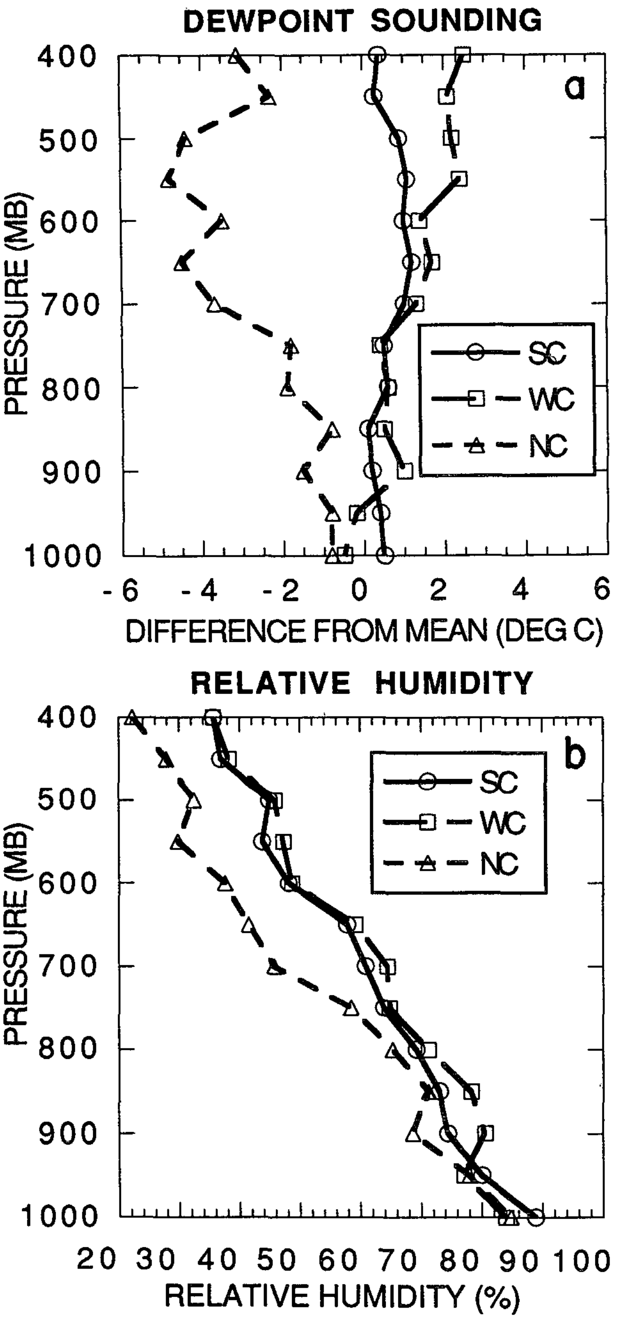

FIG. 4. (a) As in Fig. 3 but for dewpoint temperature. (b) Vertical profiles of mean relative humidity for three categories of convection.

500 mb, where values for the NC category are approximately 20% smaller (drier) than those of the two convection groups. Average relative humidities on the SC and WC days range from approximately 85% near the surface to 35% at 400 mb. Our finding that midtropospheric humidity, especially between 700 and 500 mb, is important in determining the presence or absence of convection agrees with results for south Florida (Burpee 1979; Lopez et al. 1984; Watson et al. 1991). Although a dry midtroposphere often is associated with severe convection over the Midwest and Great Plains, that dryness inhibits typical summertime convection over Florida.

b. Wind

We investigated possible relationships between convection and wind direction and/or wind speed. Average speeds for the three subcategories (Fig. 5a) differ less than 1.5 m s^{-1} at all levels. Burpee and Lahiff (1984) and Lopez et al. (1984) found that lighter wind speeds were associated with an increased degree of convective activity over south Florida; however, there is little evidence of that over the panhandle.

Vector mean wind directions (Fig. 5b) show major differences between categories. Mean wind directions on SC days are from the southwest at most levels. On the other hand, NC days are characterized by northerly or northwesterly flow. Winds veer considerably with height in the WC average, being from the east near the surface, the south at 850 mb, and the west near 500 mb. Differences between the SC and NC categories are most pronounced near 850 mb. Numerical simulations of sea breezes (Arritt 1993) have shown that the thermally induced circulations were apparent for offshore synoptic flow as strong as 11 m s^{-1}. Since none of our northerly wind cases was this strong, sea-breeze convergence zones probably occurred on each day.

To investigate further, we calculated for each category the percentage of days when 850-mb winds were from northerly, easterly, southerly, and westerly quadrants (Fig. 6). Strong convection days most often have winds from the west (37%) or south (28%). However, NC days rarely have an 850-mb wind from the southerly quadrant (15%); their flow most often is from the east (35%).

Current results are consistent with those of Smith (1970), who calculated mean winds over the Florida Panhandle at 1000, 3000, and 5000 ft (i.e., up to approximately 850 mb). He found that most convection was associated with southerly, westerly, or "light and variable" flow. Conversely, there was little convection with easterly winds, and there were too few cases of northerly winds to examine. He noted that anticyclonic flow typically is associated with easterly winds over the panhandle. For south Florida, Lopez et al. (1984) found that winds in the lower half of the atmosphere were almost due easterly on dry days but southerly on wet days. Their composite 1000–700-mb flow patterns for the eastern United States indicated that the strength and position of the subtropical high pressure region and its relationship to the peninsula, as well as to tropical or midlatitude disturbances, were major factors in explaining the degree of convection over the area. Those factors certainly are important over the Florida Panhandle as well.

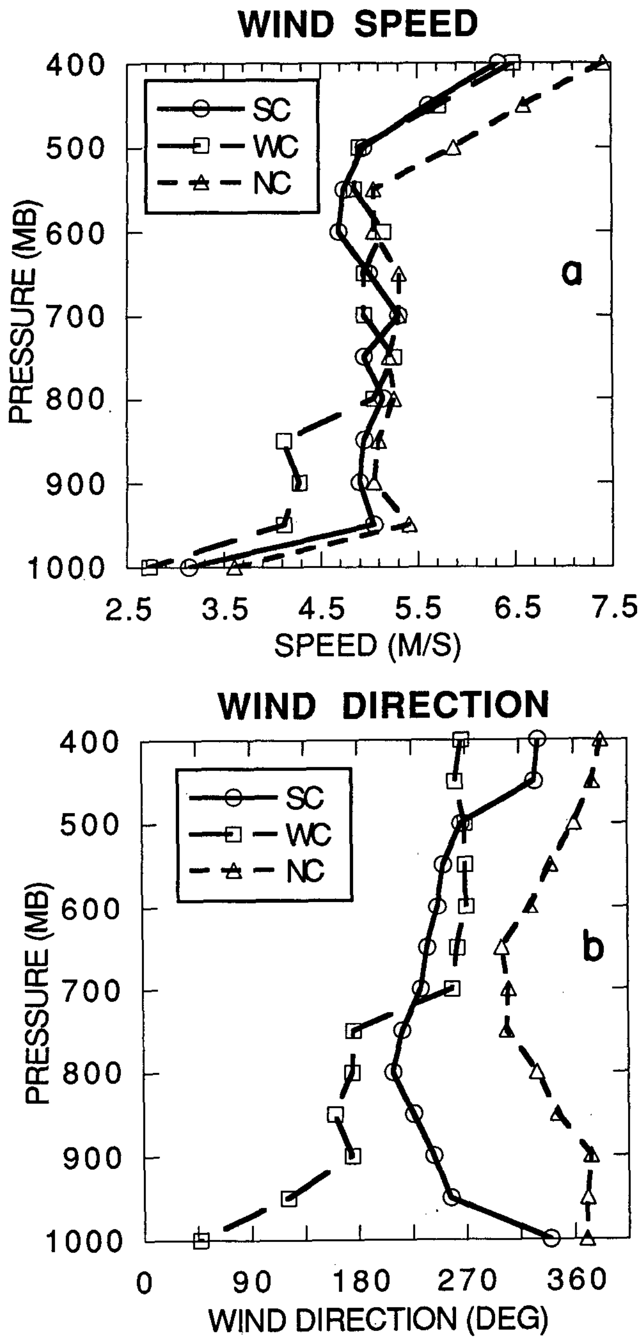

FIG. 5. Vertical profiles of (a) mean wind speed (m s^{-1}) and (b) vector mean wind direction (deg) for three categories of convection.

c. Stability

We calculated various stability indexes to determine which is most helpful in predicting convection over the Florida Panhandle. Those investigated were the total totals (TT) index, Showalter index (SI), K index (KI), lifted index (LI), and surface-based lifted index (SLI). Upper-air data used in the calculations were from 0800 EDT soundings at either AQQ or TLH.

The TT index is defined (Sadowski and Rieck 1977) as

$$TT = (T_{900\,\mathrm{m}} + TD_{900\,\mathrm{m}}) - 2T_{500\,\mathrm{mb}}, \qquad (1)$$

where T is temperature and TD is dewpoint temperature. Mean and median values for TT (Table 1) are very similar for the three categories. Frequency distributions (not shown) also reveal little difference between categories. Thus, the TT index is not a useful indicator for summertime convection over the Florida Panhandle. One should note that the original definition of TT (Miller 1972) used the 850-mb level (approximately 1.5 km) instead of 900 m. However, this choice would make little difference in our findings since Fig. 4 showed that moisture contrasts among the convection categories were similar at both 900 (approximately 1 km) and 850 mb. Moreover, a deep layer of moist air is required for thunderstorm development over the Florida Panhandle, and this depth is not assessed by the TT index.

The remaining four stability indexes exhibit varying degrees of success in predicting thunderstorms. Frequency distributions as well as mean and median values are presented here. Later sections use statistical methods to quantify the usefulness of each index.

The KI (George 1960) considers thunderstorm potential based on temperature lapse rate, moisture content of the lower troposphere, and vertical extent of that moisture. It is defined as

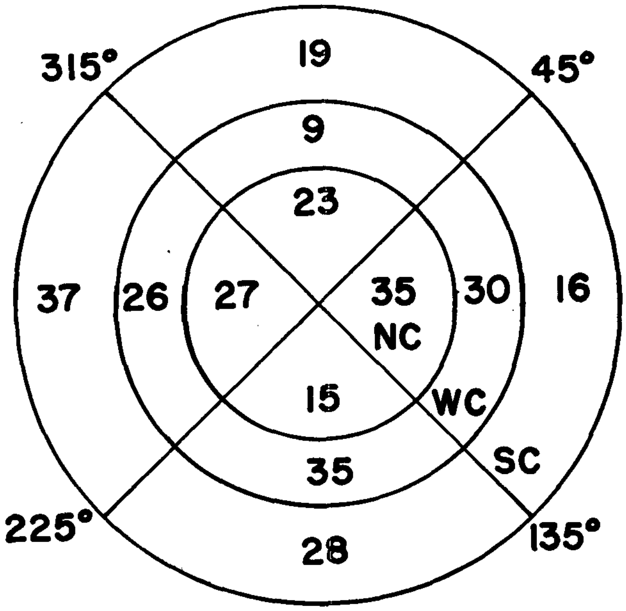

FIG. 6. Percentage of cases when the 850-mb wind direction is from northerly, easterly, southerly, or westerly quadrants. The inner circle represents the no convection category, the middle circle the weak convection group, and the outer circle the strong convection category.

TABLE 1. Statistics on the stability indexes. Values are in degrees Celsius.

Index and category	Mean	Median	Standard deviation
Total totals			
strong convection	43.8	44.0	3.2
weak convection	43.5	44.0	3.7
no convection	42.0	43.0	4.3
K index			
strong convection	29.2	30.0	5.9
weak convection	29.4	31.0	7.8
no convection	22.4	25.5	10.2
Showalter index			
strong convection	0.4	0.4	2.5
weak convection	0.5	−0.3	2.6
no convection	1.7	1.4	3.2
Lifted index			
strong convection	−3.9	−4.1	1.9
weak convection	−3.0	−2.8	2.0
no convection	−2.0	−2.8	3.1
Surface lifted index at 0900 EDT			
strong convection	−6.1	−6.3	1.9
weak convection	−4.7	−4.8	1.8
no convection	−3.5	−4.0	3.1
Surface lifted index at 1100 EDT			
strong convection	−6.5	−6.5	1.8
weak convection	−5.2	−5.4	2.1
no convection	−3.7	−4.8	3.0

$$\mathrm{KI} = (T_{850\,\mathrm{mb}} - T_{500\,\mathrm{mb}}) + \mathrm{TD}_{850\,\mathrm{mb}} - \mathrm{TDD}_{700\,\mathrm{mb}}, \qquad (2)$$

where TDD is dewpoint depression. The KI often is considered useful for predicting thunderstorms in areas of weak synoptic-scale influence (Sadowski and Rieck 1977). The KIs exceeding 28°C generally indicate a strong likelihood of convective activity. Current results indicate that the KI is a better indicator of convective activity than is the TT index. Mean and median values for the SC and NC categories (Table 1) differ by 6.8° and 4.5°C, respectively. The three distributions show distinct, separate peaks (Fig. 7a), although the maximum for the WC group does not lie between those of the SC and NC categories.

The SI (Showalter 1953) is computed by raising a parcel at 850 mb dry adiabatically until saturated, and then moist adiabatically to 500 mb. The parcel's 500-mb temperature then is subtracted from the observed environmental value. Negative SIs are associated with thunderstorm activity, with heavy thunderstorms likely for values less than −3 (Sadowski and Rieck 1977). Current results (Table 1, Fig. 7b) indicate that SC days often are associated with positive SIs. There are only small differences (about 1°C) between the three categories of mean and median values, and the distributions are quite similar.

The LI (Galway 1956) was calculated using the mean temperature and dewpoint in the lowest 100 mb of each sounding. This mean parcel was lifted from 50 mb above the surface to 500 mb, with the LI then calculated as described for the SI. The LI shows some differentiation between categories (Table 1, Fig. 7c). Mean and median values between the SC and NC groups differ by 1.9° and 1.3°C, respectively, and the frequency distributions contain distinct, separate peaks

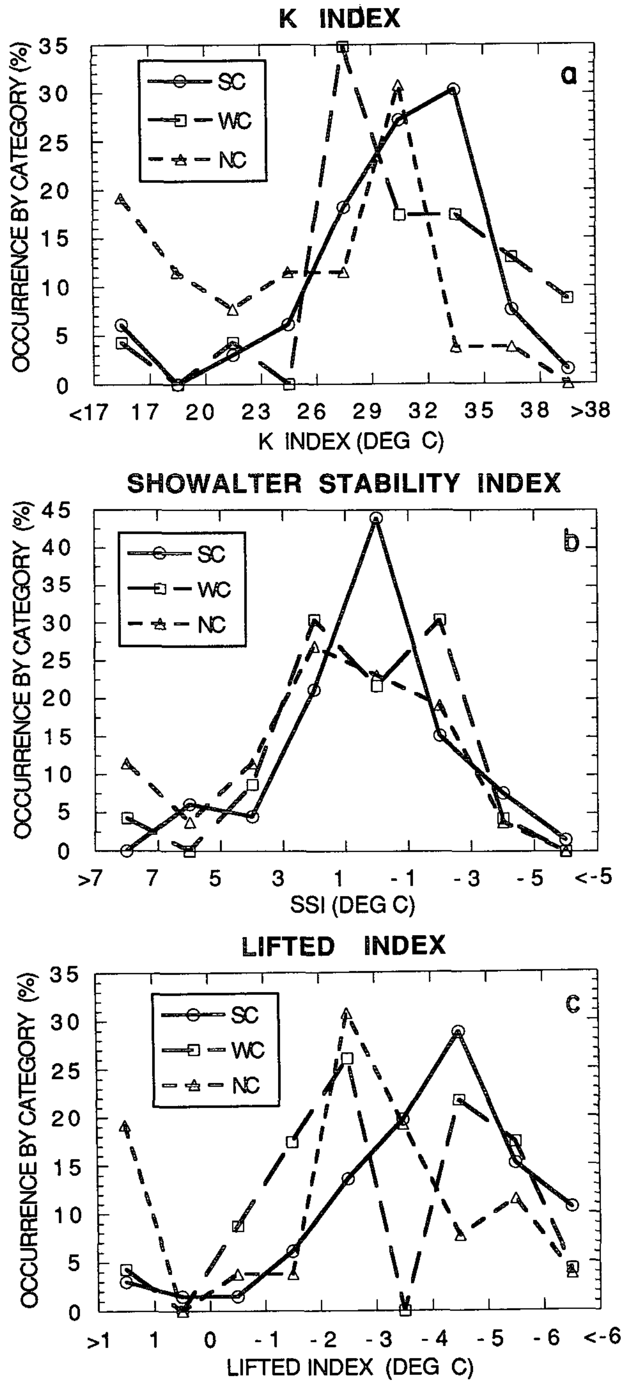

FIG. 7. Distributions of stability values for the three categories of convection: (a) K index, (b) Showalter index, and (c) lifted index. Corresponding statistical data are given in Table 1.

for the NC and SC groups. The WC distribution is bimodal, with maxima between the other categories.

The surface-based LI uses the latest hourly surface temperature and dewpoint data together with either an observed or model-derived 500-mb temperature (Hales and Doswell 1982; Sanders 1986). Thus, the SLI is more time and location specific than the traditional LI, which employs more widely spaced data, both spatially and temporally. The surface-defined parcel is lifted to 500 mb, with the SLI computed as described earlier for the LI. Since surface conditions are assumed to represent those of the entire boundary layer, the SLI is not suitable for early-morning conditions when there has been little mixing.

We calculated SLIs at various times during the morning using observed 0800 EDT 500-mb temperatures (either at AQQ or TLH). Since conditions at 500 mb typically change little during the mornings of synoptically quiescent days, it was not necessary to incorporate forecast temperatures. Surface data at TLH were used both years since it is the only panhandle station that is sufficiently inland to be unaffected by the advancing sea breeze during the morning.

Table 1 and Fig. 8 show results of the SLI calculations at 0900 and 1100 EDT (1300 and 1500 UTC). Differences between mean SLI values of the NC and SC categories are slightly greater at 1100 EDT (2.8°C) than at 0900 EDT (2.6°C). Conversely, median values for these two categories differ slightly less at 1100 EDT than at 0900 EDT. The SC distribution has a better-defined peak at 1100 EDT than at 0900 EDT. Although the NC distribution is relatively broad at each time, the profiles are oriented toward less negative values than are those for the SC group. The statistical evaluation of these differences (described later) will show that the SLI at 1100 EDT has the highest correlation with observed weather in the dependent sample.

Surface temperatures and dewpoints at TLH were averaged at hourly intervals to investigate causes for the SLI differences between 0900 and 1100 EDT. During the morning, when the SLIs were calculated, average temperatures (Fig. 9a) varied little between categories. The SC days become relatively cool during the afternoon due to the evaporative cooling and increased cloud cover associated with the storm activity. Surface dewpoints for each category decreased during the morning due to vertical mixing (Fig. 9b), but there are important differences among the categories. Specifically, mean dewpoints on the mornings of NC days are approximately 2°C cooler (drier) than those on SC days. Thus, the morning surface dewpoint may be useful for assessing the potential for afternoon deep convection. Sanders (1986) has shown that SLI changes are more influenced by surface dewpoints than surface temperatures.

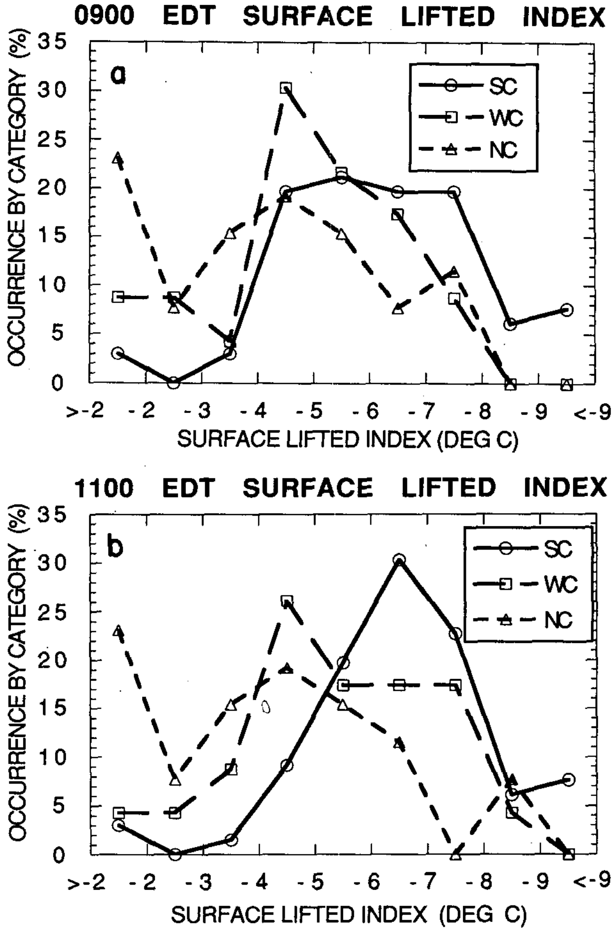

FIG. 8. As in Fig. 7 but for the surface-based lifted index at (a) 0900 EDT and (b) 1100 EDT. Statistical data are given in Table 1.

d. Statistical evaluation of stability-derived forecasts

It is important to determine statistically which stability index best differentiates between SC, NC, and WC days. We used the test statistic (Z_{ab}) described by McClave and Dietrich (1988) for this purpose. It is defined as

$$Z_{ab} = (\bar{X}_a - \bar{X}_b)\left(\frac{s_a^2}{n_a} + \frac{s_b^2}{n_b}\right)^{-1/2}, \qquad (3)$$

where $\bar{X}_a$ and $\bar{X}_b$ are mean stability values for categories a and b, n_a and n_b represent the number of events in each category, and s_a and s_b are corresponding standard deviations. Serial correlation must be included in the significance testing, because one cannot assume that all of the data are independent. Burpee and Lahiff (1984) found that area-averaged rainfall over south Florida was more highly correlated with the previous day's rainfall than with any quantity derived from that day's morning radiosonde release. This suggests that serial correlation may be large. We accounted for serial correlation by using a subset of the original data in the significance tests. Specifically, days composing each convection category were selected so there would be at least a 6-day gap between successive entries. However,

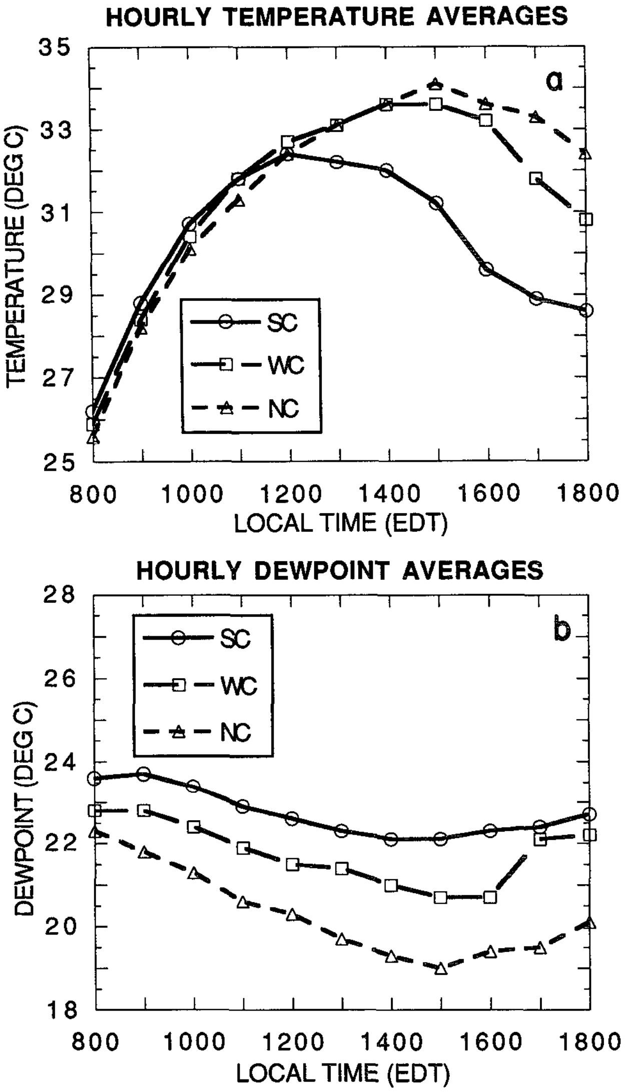

FIG. 9. Averages of hourly (a) temperature and (b) dewpoint temperature at Tallahassee from 0800 to 1800 EDT.

the average gap for the subset ranged from 10 days for the SC category to 16 days for the WC and NC groups. Sample sizes for the subset were reduced to 21 SC days, 12 WC days, and 13 NC days, although means and standard deviations (not shown) differed only slightly from those of the complete dataset (Table 1).

Table 2 gives test statistics for SI, LI, KI, and SLI. The entry Z_{sw} compares stability indexes for the strong and weak categories of convection, while Z_{wn} and Z_{sn} compare the WC and NC, and SC and NC categories, respectively. Larger absolute values of Z represent more significant differences between categories.

Results (Table 2) show that the SLI is the best index for differentiating between strong convection and no convection (Z_{sn}). And, it is better at 1100 EDT than at 0900 EDT. The SLI is not as successful at either time in distinguishing between strong and weak convection and between the weak and no convection categories. The general superiority of the 1100 EDT values over those at 0900 EDT probably is due to the greater mixing that has occurred by the later hour—that is, surface humidity data better represent the entire boundary layer. The midday surface observations included in the SLI almost always yield test statistics that are greater than those of the radiosonde observation-based indexes. For example, both the KI and LI have some ability to differentiate between strong and no convection, although neither is as good as the SLI. Finally, the SI is considerably less useful than the other indexes.

Although the test statistics (Table 2) indicate the stability indexes that are useful in distinguishing between the three categories of convection, they do not quantify the accuracy of forecasts based on those indexes. Different statistical procedures are required for this purpose. Since many of these methodologies are based on only two possible outcomes—for example, the occurrence or nonoccurrence of a phenomenon—we decided not to have a separate WC category. Mean and median stability values for the WC group (Table 1) often were between those of the SC and NC categories, and the frequency distributions (Figs. 7 and 8) indicated that there was no clear demarcation between the WC and the other two groups. Since 23 days were categorized as WC, we did not wish to exclude them completely. Thus, the choices were to include them with either the SC or NC days. Since the WC category denoted days having only a few small convective cells, representing less than 20% coverage, we chose to combine the WC and NC groups.

Several statistical measures have been used to assess forecast utility. The critical success index (CSI) is a commonly used parameter that combines attributes of both the probability of detection (POD) and the false alarm rate (FAR) (see Schaefer 1990; Watson et al. 1991). However, the CSI is not always the best tool for evaluating forecasts, because it does not give credit for successfully forecasting a nonevent. Schaefer (1990) noted that the CSI overestimates skill, with the mag-

TABLE 2. Test statistics comparing the strong and weak convection categories (Z_{sw}), weak and no convection categories (Z_{wn}), and strong and no convection categories (Z_{sn}). Values with an asterisk are significant at the 90% level. Values with a double asterisk are significant at the 95% level. The effects of serial correlation were considered as described in the text.

Index	Z_{sw}	Z_{wn}	Z_{sn}
SI	0.14	−1.47*	−1.20
LI	−0.55	−1.09	−1.39*
KI	−0.99	2.09**	1.33*
SLI 0900 EDT	−1.66*	−1.44*	−2.37**
SLI 1100 EDT	−0.70	−2.15**	−2.44**

nitude of overestimation increasing with the frequency of the event being forecast.

Because of these limitations of the CSI, we chose to evaluate the success of stability-index-derived convection forecasts using the true skill statistic (TSS) that is described by Watson et al. (1991) and Doswell and Flueck (1989). The TSS is defined as

$$\mathrm{TSS} = \mathrm{POD} - \mathrm{POFD}, \qquad (4)$$

where POFD denotes the probability of false detection. For our application, POD and POFD are defined as

$$\mathrm{POD} = \mathrm{FSCO}/\mathrm{TSCO}, \qquad (5)$$

and

$$\mathrm{POFD} = \mathrm{FSCNO}/\mathrm{TNCO}, \qquad (6)$$

where FSCO represents forecast strong convection days—observed (i.e., correct SC forecasts), TSCO denotes the total of strong convection days—observed (all days in the SC category), FSCNO represents forecast strong convection days—not observed (i.e., incorrect SC forecasts), and TNCO denotes the total of nonconvection days—observed (all days in the combined NC plus WC categories). The TSS has several desirable characteristics. Unlike the CSI, it considers all aspects of 2×2 contingency tables. In addition, it compares actual forecast performance to perfect performance, with a fixed range between -1 and $+1$, where $+1$ indicates perfect forecasts.

Skill in this study is defined relative to persistence. This is consistent with the definition of the American Meteorological Society (1991). Thus, the TSS is a measure of forecast accuracy, not skill. We first computed the TSS using the original dataset described earlier. A later section describes the additional computations that were used to assess skill.

The TSS calculations were made after determining for each index the threshold value that produced the best forecasts. This was an iterative process in which the TSS first was calculated using an initial threshold. That threshold then was changed and the TSS was recalculated. The process was continued until the threshold yielding the greatest TSS was obtained. Table 3 gives these thresholds, contingency tables, and statistics for the various indexes.

The best forecasts (Table 3) are produced using the SLI at 1100 EDT with a threshold of -5.5°C. That is, convection (no convection) would be forecast on days when the SLI is less (greater) than -5.5°C. The TSS score of 0.45 is the greatest of the indexes examined. The table shows that the corresponding POD = 53/66 = 0.80, and POFD = 17/49 = 0.35. Results from additional calculations (not shown) indicate that 76% of days with an 1100 EDT SLI ≤ -5.5°C had subsequent afternoon convection. On the other hand, only 14% of days with an SLI > -4.5°C were accompanied by strong afternoon storms. Thus, the SLI at 1100 EDT also is useful in forecasting the nonoccurrence of thunderstorm activity. Of course, forecasters certainly will consider information other than low-level stability in producing their afternoon convection forecasts.

TABLE 3. Contingency tables for the stability indexes. Threshold values for each index are indicated. POD, POFD, and TSS are probability of detection, probability of false detection, and true skill statistic, respectively.

	Observed category		
Predicted category	SC	WC + NC	Total
Showalter index			
SC (≤2.0°C)	55	32	87
WC + NC (>2.0°C)	11	17	28
Total	66	49	115
POD = 0.83	POFD = 0.65	TSS = 0.18	
K index			
SC (≥25°C)	58	34	92
WC + NC (<25°C)	8	15	23
Total	66	49	115
POD = 0.88	POFD = 0.69	TSS = 0.19	
Lifted index			
SC (≤−3.0°C)	49	21	70
WC + NC (>−3.0°C)	17	28	45
Total	66	49	115
POD = 0.74	POFD = 0.43	TSS = 0.31	
Surface lifted index at 0900 EDT			
WC (≤−5.5°C)	43	13	56
WC + NC (>−5.5°C)	23	36	59
Total	66	49	115
POD = 0.65	POFD = 0.27	TSS = 0.38	
Surface lifted index at 1100 EDT			
SC (≤−5.5°C)	53	17	70
WC + NC (>−5.5°C)	13	32	45
Total	66	49	115
POD = 0.80	POFD = 0.35	TSS = 0.45	

The threshold for SLI at 0900 EDT also is -5.5°C; however, the TSS of 0.38 indicates slightly less successful forecasting, with POD = 0.65 and POFD = 0.27. In this case (not shown), 77% of days with an 0900 EDT SLI ≤ -5.5°C have strong convection during the afternoon. Conversely, only 19% of days with SLI > -3.5°C have strong convection.

The remaining indexes (Table 3) all are based solely on the morning sounding, and their TSS statistics are less than those of the SLIs. While their PODs are relatively large, so are the corresponding POFDs. The conventional LI is the best in this category, with a TSS of 0.31. Approximately 70% of days with an LI ≤ -3°C had strong convection during the afternoon. The Showalter index produces the worst forecasts, with a TSS of 0.18. Its results are not much better than forecasting strong convection every day that gives TSS = 0. Burpee and Lahiff (1984) and Watson and Blanchard (1984) also found that the SI was an ineffective forecasting tool over south Florida.

Additional calculations were needed to assess the forecast skill of the various stability indexes. The objective was to compare the stability-based forecasts with those derived solely from persistence. Since our original dataset spanned two summers and had gaps due to missing observations, we prepared a subset that contained only consecutive days. This allowed 24-h persistence forecasts to be prepared from the earlier day's satellite imagery. The SC, WC, and NC days were defined as before. Results of the persistence forecasts are given in Table 4. The TSS of 0.26 is based on POD = 0.70 and POFD = 0.44.

The data subset used to prepare the persistence forecasts then was used to calculate TSS statistics for the stability-derived forecasts. The threshold stability values used originally (Table 3) were found to be best for the subset as well. TSS statistics for the subset (Table 5) are similar to those for the complete dataset (Table 3). It is important to note that TSS values for the SLI at 1100 EDT (0.46) and at 0900 EDT (0.38) exceed that of persistence (0.26). Thus, these two indexes do possess forecast skill. On the other hand, the lifted, K, and Showalter indexes all produce TSS values less than that of persistence. These indexes do not exhibit forecast skill. Some caution is appropriate here since threshold values of stability, and the skill of the resulting forecasts, were estimated within the sample. We have not yet tested the indexes on independent data but hope to do so during the summer of 1994. Nonetheless, our findings for the Florida Panhandle are consistent with those of Burpee and Lahiff (1984), who found that persistence was an important factor in explaining area-averaged rainfall over south Florida.

4. Summary and conclusions

This study has investigated the preconvective environment of summer thunderstorms over the Florida Panhandle on days when large-scale forcing was not a major influence. GOES 1-km visible imagery was used to subjectively categorize the days as having either strong, weak, or no convection. Mean and difference profiles of various radiosonde-derived parameters were constructed for each category. Several different stability indexes also were calculated each day.

Results showed that midtropospheric humidity and low-level instability are important for thunderstorm development over the panhandle. The average relative humidity of the 500–700-mb layer was approximately 20% greater on strong convection days than on no convection days. This finding agrees with those for south Florida (e.g., Burpee 1979; Lopez et al. 1984; Watson et al. 1991) in showing that a deep layer of humid air is required for summertime thunderstorm development. On the other hand, the mean temperature profile for the strong convection days differed little from that of the no convection days.

TABLE 4. Contingency table for persistence forecasts.

	Observed category		
Predicted category	SC	WC + NC	Total
SC	33	16	49
WC + NC	14	20	34
Total	47	36	83
POD = 0.70	POFD = 0.44	TSS = 0.26	

TABLE 5. Ranked values of the TSS based on a subset of the original dataset used to make persistence forecasts. The extent to which forecast statistics exceed (are less than) those of persistence also is indicated. Threshold values are identical to those in Table 3.

Index	TSS	$\mathrm{TSS} - \mathrm{TSS}_{\mathrm{PERS}}$
Surface LI at 1100 EDT	0.46	0.20
Surface LI at 0900 EDT	0.38	0.12
Persistence	0.26	—
Lifted index	0.25	(0.01)
K index	0.17	(0.09)
Showalter index	0.14	(0.12)

Atmospheric instability, which is heavily influenced by low-level humidity, was found to be an important ingredient for convective activity over the Florida Panhandle. The SLI was the best stability index for predicting afternoon convective development. It allows stability to be computed at a later time than when using the 0800 EDT upper-air soundings. The SLI at 1100 EDT was more accurate than its counterpart at 0900 EDT in predicting afternoon convection. However, both versions of SLI produced forecasts that were more accurate than those based on persistence. Thus, they possessed forecast skill. Since the National Weather Service in Tallahassee typically issues afternoon forecasts at approximately 1130 EDT, forecasters can use the 1100 EDT SLI as last minute additional guidance. The conventional lifted index as well as the K and Showalter indexes had considerably less predictive value. Forecasts based on these indexes were less accurate than those derived from persistence.

Wind direction over the Florida Panhandle also was found to be related to convective activity. On days with strong convection, winds in the lower and midtroposphere tended to be from the southwest. Conversely, the no convection days were characterized by northerly or northwesterly flow. These contrasts were most evident near 850 mb. The results suggest that the added moisture transported off the Gulf of Mexico by prevailing southerly flow has a stronger influence on convective development than the increased low-level convergence caused by the collision of prevailing northerly winds with the southerly flow of the sea breeze.

The factors described above should be helpful in predicting afternoon convective development over the Florida Panhandle on synoptically quiescent days. However, their use will not produce perfect forecasts. It is clear that factors not studied in this research also have an important influence on the presence or absence of thunderstorms. For example, low-level convergence frequently has been shown to be a major influence on convective development over the Florida peninsula (e.g., Ulanski and Garstang 1978; Cooper et al. 1982; Burpee and Lahiff 1984; Watson and Blanchard 1984; Watson et al. 1991). Convergence undoubtedly is important over the panhandle as well since it provides lift to destabilize the atmosphere and begin the convective process. The 1-km GOES imagery used in this research can be used to infer areas of convergence but only after convective clouds have formed. Doppler radar can detect areas of convergence before associated cloud development occurs. The northwest Florida Doppler radar already has been installed, and the Tallahassee site is scheduled to be available by the end of 1994. Forecasters then can combine information from the latest Doppler radar signatures with knowledge about stability and humidity and all other available guidance to produce increasingly accurate and site-specific predictions of thunderstorm activity.

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