NOAA Technical Memorandum NWS SR-119

AN EVALUATION OF SEVEN STABILITY INDICES AS PREDICTORS OF CONVECTION IN SOUTH TEXAS

Thomas M. Hicks, James D. Schumacher, and Gary K. Grice
WSFO San Antonio, Texas

Scientific Services Division
Southern Region
Fort Worth, Texas
August 1986

UNITED STATES DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary /
National Oceanic and Atmospheric Administration
John V. Byrne, Administrator /
National Weather Service
Richard E. Hallgren, Director

ABSTRACT

Stability indices from four upper air stations are compared as predictors for the occurrence of convection (VIP 3 or greater) reported by three radar sites in South Texas for the months of June through October, 1984. The EII Index (now called EI by Stone, 1984b, 1985,1986) was found to be slightly better in predicting the occurrence of convection and showed significant potential in segregating potentially severe events from the more benign cases. Thresholds (60% confidence levels) are presented for the individual indices for the occurrence of convection which can be of use to the operational meteorologist. Although the stability indices showed merit in predicting the occurrence of convection, little correlation existed for predicting the areal coverage of convection.

1. INTRODUCTION

Since the advent of the radiosonde and its routine use in obtaining upper air data, various indices have been formulated as quick and simple means of estimating the instability of the atmosphere. Such indices have been introduced mainly as aids in connection with particular forecasting techniques or studies. The stability indices have the advantage of ease of computation, flexible choice of the layer most pertinent to the particular problem or area, and a numerical form convenient for ready use in objective studies.

Although stability indices have been used for over 30 years, little information is available which describes how well these indices depict areas of actual conditional instability. More importantly, very little is available on studies which relate possible thresholds to convection. Showalter (1953) and Galway (1956), in their original papers, suggested limiting values for convection for the Showalter and Lifted Indices respectively. A NOAA publication (NOAA, 1977) related differing values of the K Index to thunderstorm frequency and probability and Miller (1972), in his well known check list, suggested the relative importance of the Lifted Index and Total Totals Index to severe weather.

Such guidelines are important to the forecaster for pinpointing areas of potential convection. However, experience over the years has shown that thresholds for the same stability index can vary considerably across the United States. Also, one index may be a very good predictor in one part of the country and a poor predictor in another area. David and Smith (1971) evaluated seven stability indices as predictors of severe thunderstorms and tornadoes for the eastern half of the United States and found the Showalter Index to be the best predictor. Bryan (1967) and Hambridge (1967) examined the value of the K Index in predicting convection in the southern and western United States respectively and Johnson (1982) evaluated 14 stability indices. The purpose of this study is to examine the value of seven stability indices as predictors for convection in South Texas.

2. EXPLANATION OF INDICES

The seven indices investigated in this study were:

1. Showalter Index
2. Lifted Index
3. Total Totals Index
4. Sweat Index

5. K Index
6. EI1 Energy Index
7. EI2 Energy Index

The two energy indices were developed by Stone (1984a, 1984b) and will be described later. Although many are familiar with most of the above indices, short descriptions will be provided. More detailed descriptions can be found in the referenced literature.

Perhaps the earliest index was the algebraic difference between the 500 mb and 850 mb thermal fields (more recently known as the Vertical Totals). The advantage was graphical subtraction could be quickly and easily performed with the resulting field an indication of instability. The main disadvantage was the vertical moisture profile was not considered.

The **Showalter Index** was developed in the early 1950s as a measure of the local static stability of the atmosphere, expressed as a numerical index. This index is calculated by raising an air parcel from 850 mb (higher levels are frequently used over higher terrain) dry-adiabatically to the point of saturation (lifted condensation level or LCL), then wet-adiabatically to 500 mb. At the 500 mb level, the temperature of the parcel is compared to that of the environment; the magnitude of the index is the difference between the two temperatures. If the parcel is colder than the new environment, the index is positive; if warmer, the index is negative.

Since the Showalter Index compares conditions at only two levels of the atmosphere, it can be difficult to use on a detailed synoptic time and space basis when, as often happens, there is an inversion or rapid drop of moisture which passes through the 850 mb level between stations or between two successive sounding times. The Showalter Index can be advantageous at certain times, such as when considering the stability above a shallow front.

Because of the limitations of the Showalter Index, the **Lifted Index** was developed by Joseph G. Galway in the mid 1950s. The Lifted Index uses a parcel of air with the moisture content equal to the mean mixing ratio of the lowest 3000 feet (or 100 mb) of the sounding and the temperature equal to the forecast maximum surface temperature. This parcel is lifted dry-adiabatically to the point of saturation (lifted condensation level or LCL), and wet-adiabatically to 500 mb. The 500 mb temperature of the parcel is algebraically subtracted from the ambient 500 mb temperature to calculate the Lifted Index. Lifted Index values are usually algebraically less than Showalter Index values.

The **Total Totals Index** has proven useful in locating potential areas of thunderstorm development. The Total Totals Index is the combined Cross Totals and Vertical Totals or:

Total Totals = (850 mb temp + 850 mb dew point) - 2(500 mb temp)

The Total Totals Index must be used with careful attention to either the Cross Totals or the low-level moisture since large Total Totals may exist due to the temperature lapse rate with little supporting low-level moisture. However, in South Texas, this is seldom the case.

The Severe WEAther Threat Index or **SWEAT Index** is defined by the following:

$$SWEAT = 12D + 20(T-49) + 2f_8 + f_5 + 125(S+0.2)$$

where D = 850 mb dew point, T = Total Totals Index, f_8 = 850 mb wind speed, f_5 = 500 mb wind speed, S = sin(500 wind dir - 850 mb wind dir)

Since the SWEAT Index was derived as an aid to forecasting severe thunderstorms, certain restrictions apply with respect to the various parameters. However, since this study examined the index as a predictor of only significant convection, the restrictions were not applied.

The **K Index** is a measure of thunderstorm potential based on the vertical temperature lapse rate, the moisture content of the lower atmosphere, and the vertical extent of the moist layer. The combination of these parameters to yield the K Index is performed as follows:

K = (850 temp - 500 temp) + 850 dew point - 700 dew point depression

K values are primarily applicable to the prediction of air mass thunderstorms. The K Index is also an important index for forecasting heavy rains (Belville *et al.*, 1978; Mortimer *et al.*, 1980; Grice and Maddox, 1986). When computing the K Index, caution should be exercised when the 850 mb level is near the surface.

One common feature of the above indices is the use of data from selected levels of the raob sounding. These stability indices were designed prior to the development of the computer when ease of computation was an important consideration. However, anomalous data at any of the levels can yield misleading values and the atmospheric structure between those levels is ignored.

With the general availability of computer power today, reliance on indices incorporating information from just a few levels in the atmosphere is no longer necessary. The Energy Index developed by Stone (1984a, 1984b) is a measure of the change in kinetic energy of a parcel of air as it moves upward through the atmosphere, entraining environmental air as it ascends. All significant levels of the raob sounding (to 400 mb) are utilized in the computation of the energy change.

The procedure selects the parcel in the lowest 150 mb of the raob sounding with the greatest wet bulb potential temperature. This parcel is used because it is usually most unstable with respect to vertical displacements in the atmosphere, i.e. the parcel can make the ascent to the upper levels of the atmosphere with the maximum energy released or the minimum energy required for forced lifting.

The parcel is raised to the 400 mb level (for the EI1 Index; Stone now refers to this as the EI Index) or the equilibrium level (for the EI2 Index) while entraining (Austin, 1948) environmental air at a rate that provides a 60 percent increase in mass over a 500 mb ascent. The energy indices are computed by integrating positive and negative energy areas as the parcel ascends and expressed as joules $kg^{-1}/10$. The EI2 is no longer routinely calculated from upper air sounding data, but the index was included in this study for comparison.

3. PROCEDURE

Three basic questions were addressed in this study:

1. Do the stability indices possess merit as predictors for the occurrence of convection?

2. Do the stability indices possess merit as predictors of areal coverage by convection?

3. Do thresholds exist for the indices which can aid the forecaster in predicting convection?

To answer these questions, data from three radar sites in South Texas (Fig. 1) and data from four upper air stations in South Texas and southwest Louisiana were utilized for the five month period June through October, 1984. Since the radar stations and upper air stations are not collocated (with the exception of Brownsville), the radar umbrellas were subjectively divided into sections considered representative of the upper air soundings from neighboring stations. For example, part of the radar coverage from Hondo, Texas, was considered representative of upper air data from Del Rio and part representative of upper air data from Victoria. Although such an assumption is not always valid on a day-to-day basis, for an extended period it is likely representative. The stability indices were those printed on the AFOS generated upper air soundings.

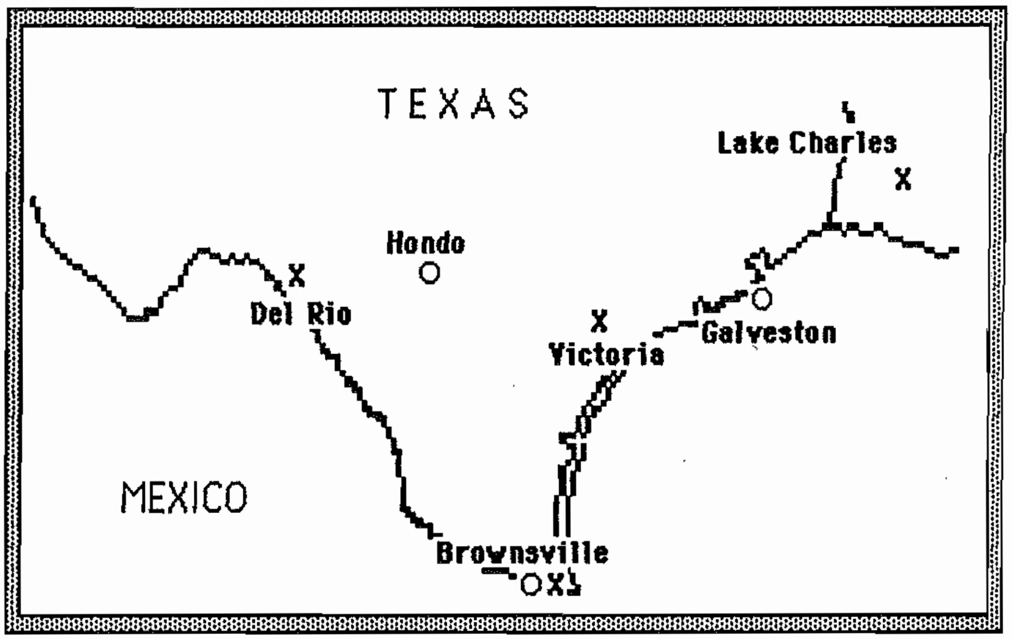


FIGURE 1. Locations of upper air stations (denoted by X's) and radar stations (denoted by circles) used in study.

Hourly MDR values (Moore and Smith, 1979; Smith, 1980) of VIP 3 and higher were plotted for each radar station for the four month period. These data were expressed in terms of percent coverage of values VIP 3 and higher for the radar sections considered representative of stability indices of neighboring upper air stations. The information was then segregated into twelve hour time periods following the upper air soundings.

The final data package for each radar section consisted of stability indices (from the appropriate neighboring upper air station) and percent coverage for MDR values of VIP 3 and higher (for the 12 h period following the upper air sounding). The stability indices were compared to the radar coverage to determine if the indices were reliable predictors of convection in South Texas.

4. RESULTS

The climate of South Texas varies considerably from west to east. Annual rainfall along the Rio Grande River is less than 20 inches with parts of Southeast Texas receiving over 50 inches a year. Topography also varies from over 2000 feet in the Texas Hill Country to sea level along the Texas coast.

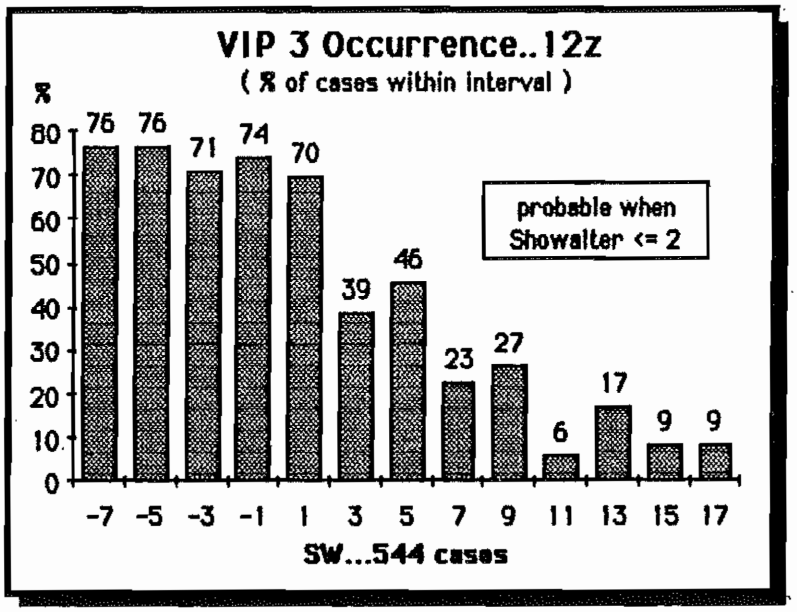
The threshold for most stability indices vary with both the climate and topography. In maritime type climates, convection frequently occurs with more stable indices than observed with drier climates. Since one major component of most indices is the low level thermal and moisture fields, higher elevation stations frequently exhibit more unstable indices.

In this study the threshold for convection for the seven indices varied only slightly across South Texas. Consequently, the data from all stations were combined and are displayed in Figures 2 through 8.

Figures 2 through 8 show the occurrence (in percent) of convection (VIP 3 or greater) for the individual stability intervals. Convection was considered probable (shown on the individual figures) when 60 percent of the events (within the stability interval) experienced convection. In considering Figs. 2 through 8, an ideal predictor of convection would be an index which exhibits discrete break points. One example would be a break point for the occurrence or nonoccurrence of convection; another could include several thresholds coincident with discrete probabilities. Indices with continuous distributions are of lesser value to the forecaster due to the difficulty in determining significant thresholds; of course, every index falls between the two extremes.

Although the distributions varied between the indices and between 1200 GMT and 0000 GMT for the same index, it appears (subjectively) that the EI1 and Total-Totals indices showed significant break points for both time periods. The distribution for the Lifted Index at 0000 GMT also shows significant thresholds but the graph at 1200 GMT provides little information. In fact, with regard to threshold values, the Showalter Index appears to offer more forecast information than the Lifted Index.

Showalter Index



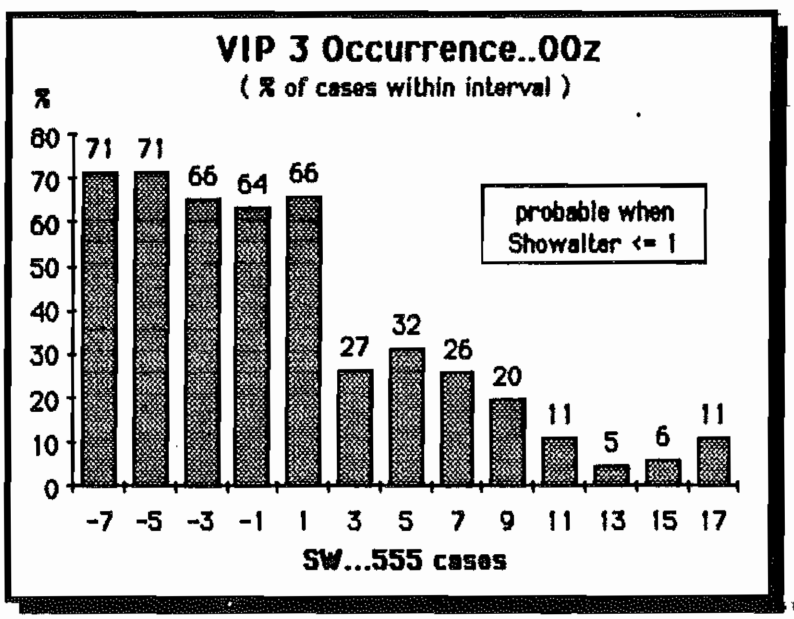
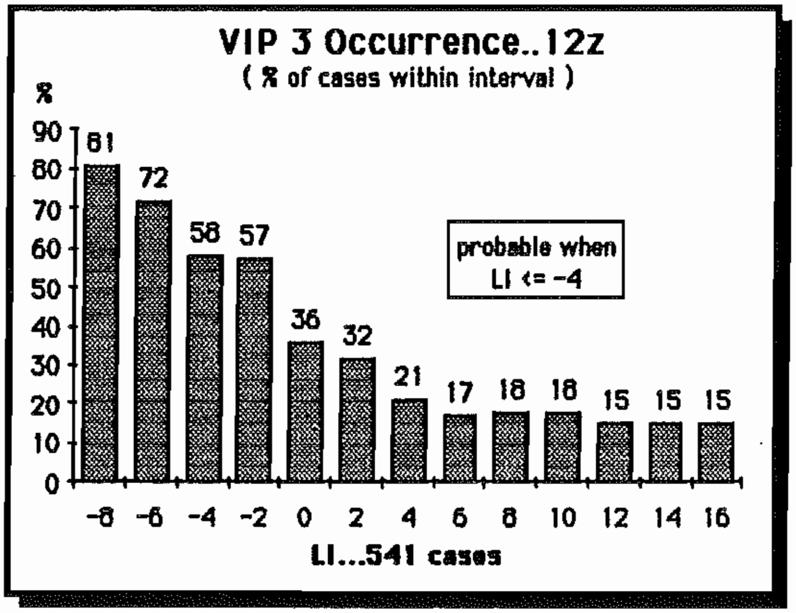


FIGURE 2. The occurrence of convection (percent) at all stations with the Showalter Index.

Lifted Index



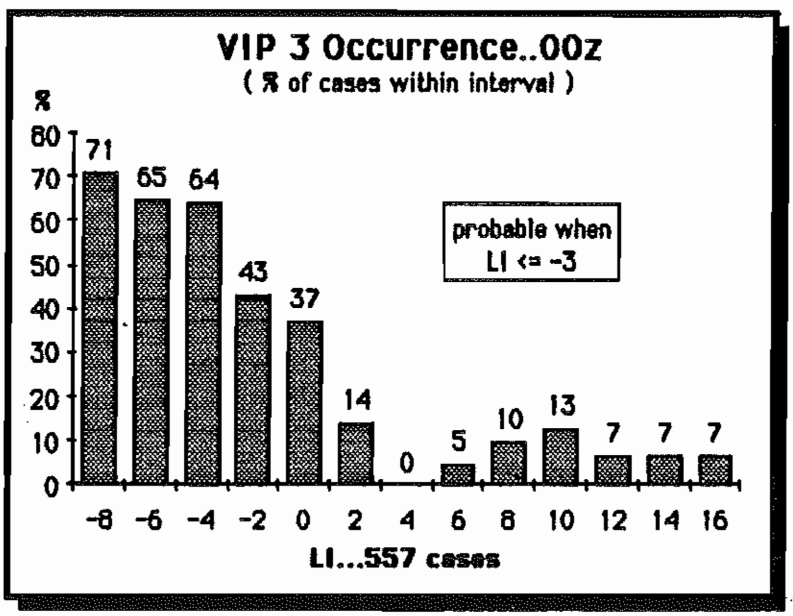
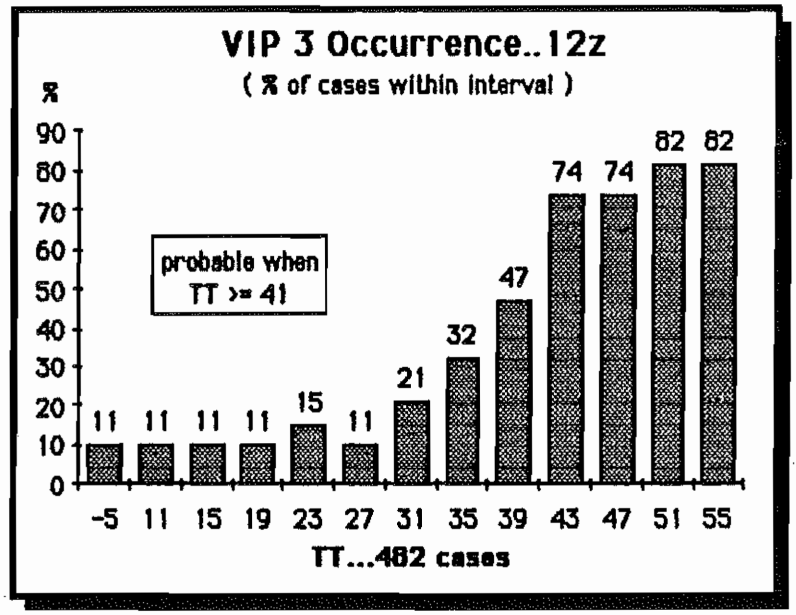


FIGURE 3. As in Fig. 2 except for the Lifted Index.

Total-Totals



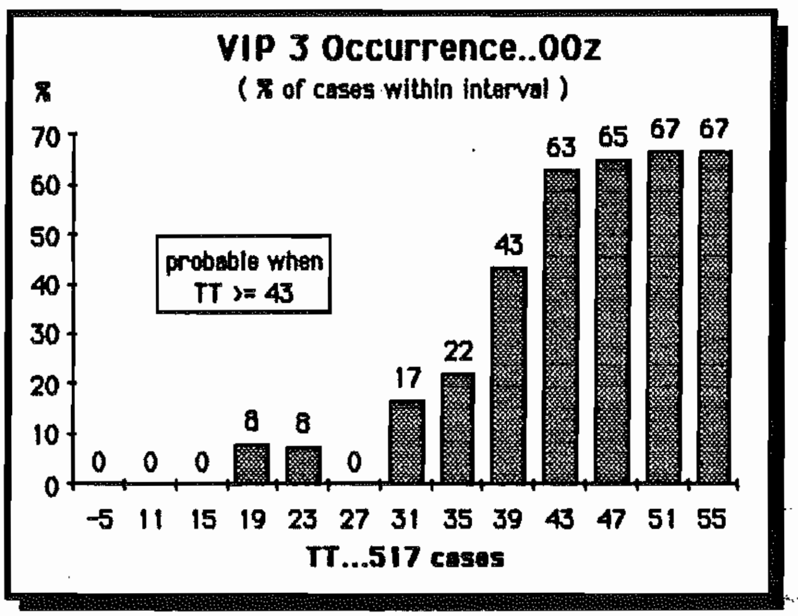
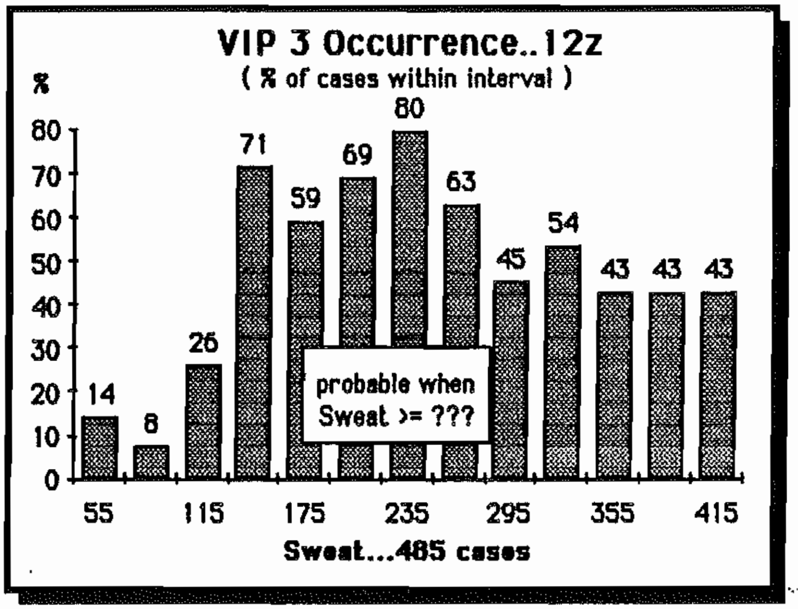


FIGURE 4. As in Fig. 2 except for the Total Totals Index.

Sweat Index



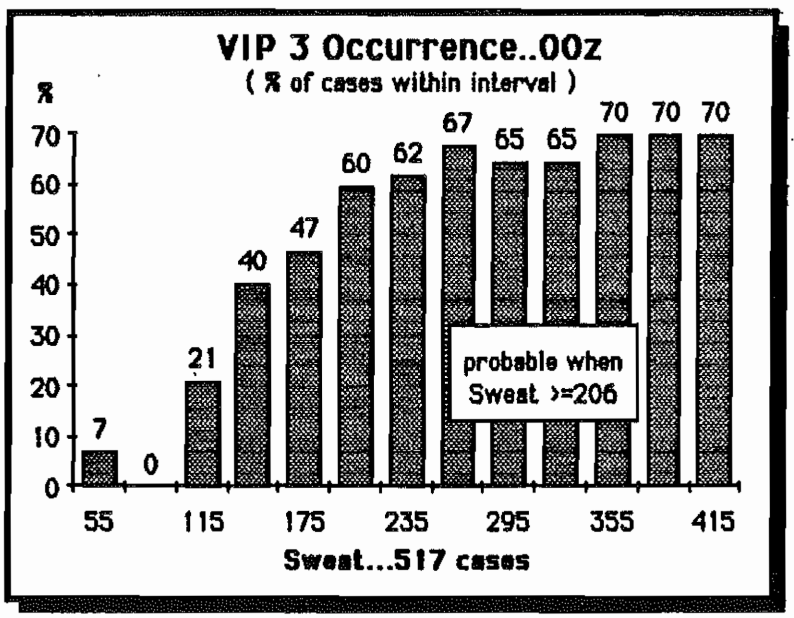
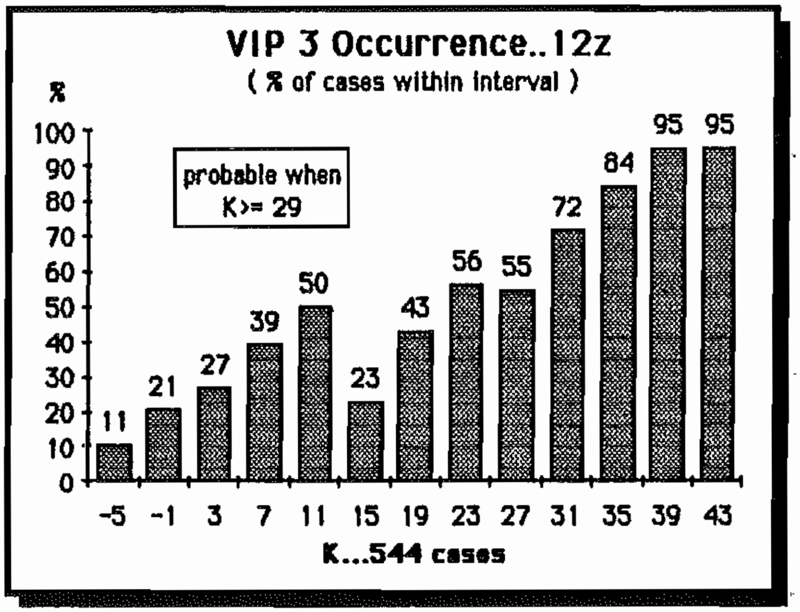


FIGURE 5. As in Fig. 2 except for the Sweat Index.

K Index



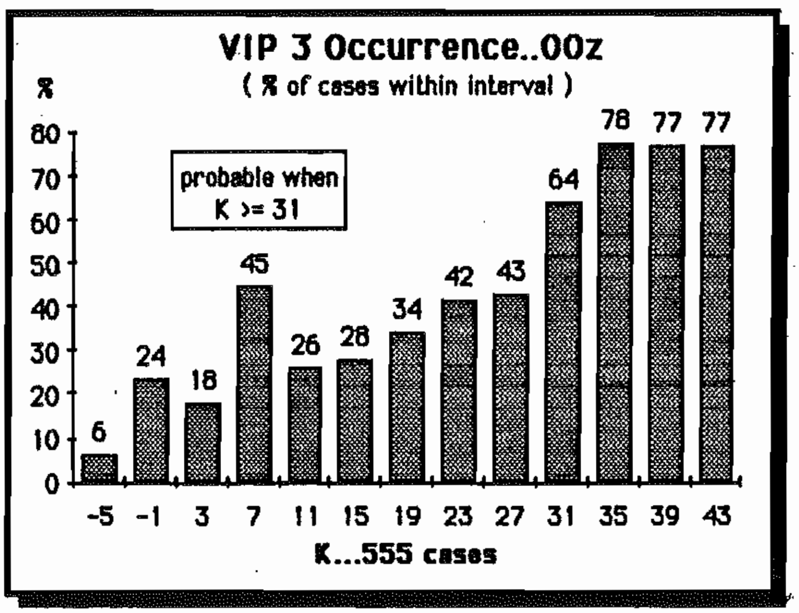
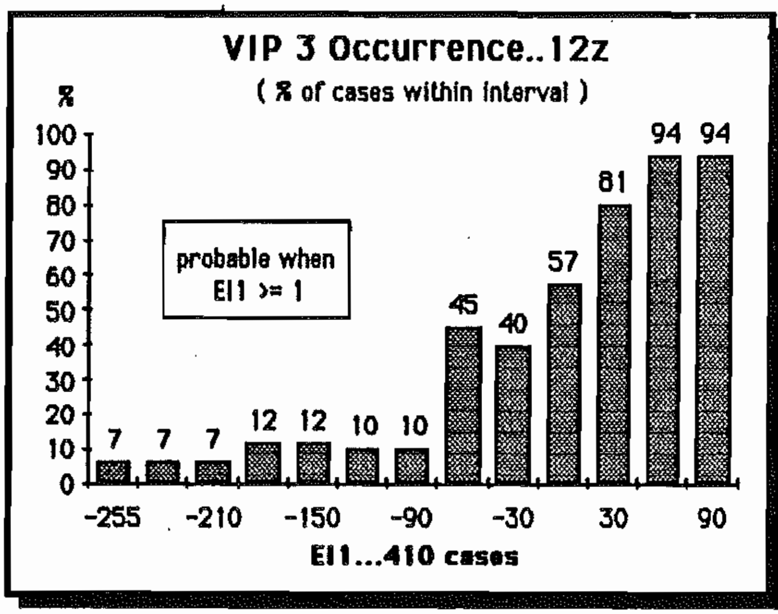


FIGURE 6. As in Fig. 2 except for the K Index.

EI1 Index



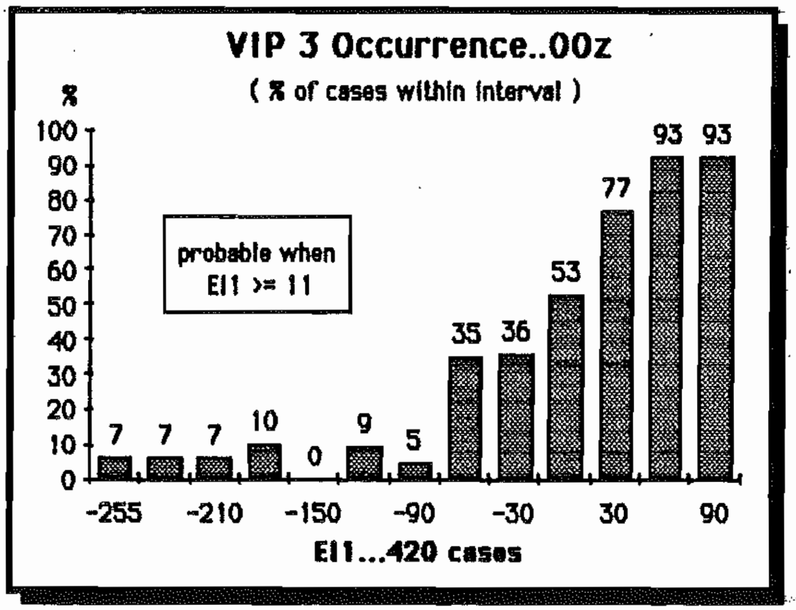
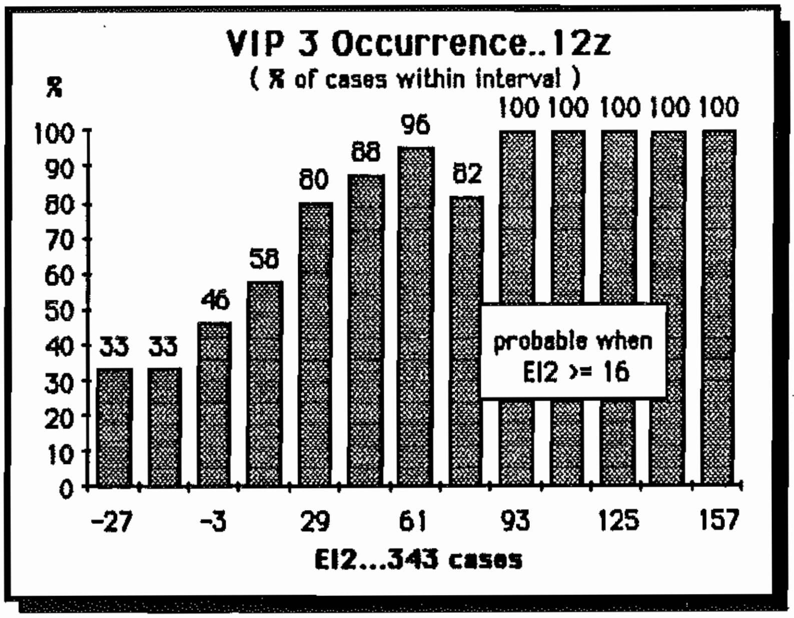


FIGURE 7. As in Fig. 2 except for the EI1 Index.

EI2 Index



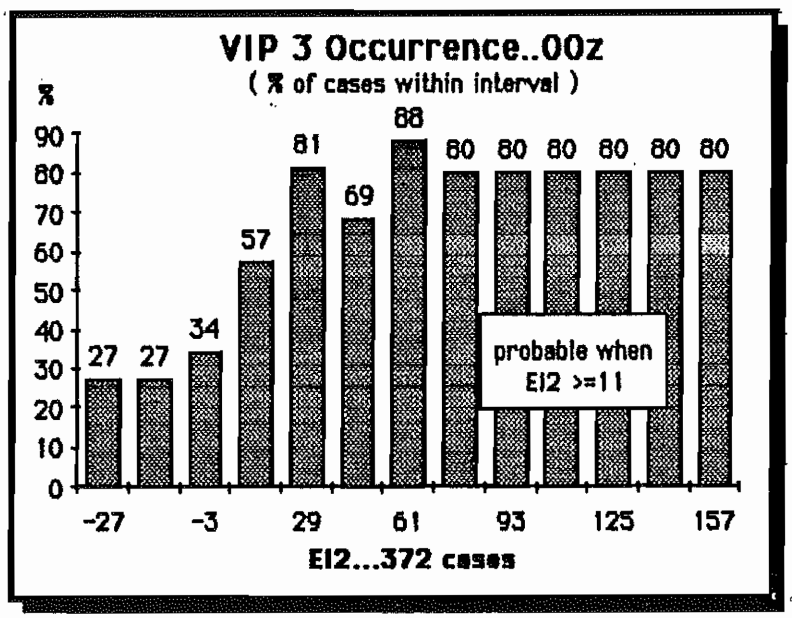


FIGURE 8. As in Fig. 2 except for the EI2 Index.

The graph for the K Index likely reflects the main purpose of this index as a predictor of air mass type convection. Incremental increases in mid level moisture (since this if frequently the more dominating factor with the K Index) likely result in slightly higher probabilities of convection. The preference of this data sample to the late summer and early fall months may also affect the distribution of the K Index.

It is interesting to note that with most of the stability indices, the distributions at 0000 GMT acquired more of a tendency to exhibit pronounced threshold values. This is likely the result of the atmosphere being well mixed in the lower levels; however, the 0000 GMT data were less accurate predictors (see Table 1).

The merit of the stability indices as predictors of convection is shown in Table 1. The thresholds of confidence (60% or greater) from Figs. 2 through 8 were used as predictors for the occurrence and nonoccurrence of convection for the individual events with the results listed in Table 1. Although the comparisons differed between occurrence and nonoccurrence of convection and between 1200 and 0000 GMT, the EI1 Index was the best overall predictor for both time periods. This is not unexpected since the EI1 incorporates positive and negative energy areas to 400 mb whereas the remaining indices (with the exception of the EI2 Index) incorporate information at only a few selected levels. The EI2 Index also performed well but the EI1 was the overall winner.

Due to the limited data sample, it is unlikely significant comparisons can be made among the indices although the EI1 does appear to be slightly better. However, Table 1 does show that the selected thresholds (60 % confidence level) for the individual indices can be used as predictors of convection in South Texas. Using the threshold values could aid the forecaster in segregating the occurrence and nonoccurrence of convection.

Table 2 stratifies the indices with respect to potentially severe thunderstorms (cloud tops over 50 thousand feet) for each station. Considering all stations the EI1 appeared best at segregating potentially severe thunderstorm events from the more benign cases. The average EI1 for potentially severe cases was 26 compared to 13 for the less severe events. No other index in this study exhibited this characteristic.

Although the stability indices were found to be of value in forecasting the occurrence or nonoccurrence of convection, they provided no significant information on the areal coverage of convection. Figure 9 shows the individual plots of Total-Totals versus percent coverage of VIP 3 or

Table 1
Stability Index Comparison

Ranked by Percent of Correct Forecasts using Threshold

Index	**12z** Threshold*	Vip3 >= 0% Fcst	Vip3 >= 0% Obsvd	Vip3 >= 0% % cor	Vip3 = 0% Fcst	Vip3 = 0% Obsvd	Vip3 = 0% % cor	cases	total % cor
EI1	>= 1	209	169	81%	201	134	67%	410	**74%**
Total-totals	>= 41	332	241	73%	150	110	73%	482	**73%**
Showalter	<= 2	346	250	72%	198	142	72%	544	**72%**
K	>= 29	246	198	80%	298	190	64%	544	**71%**
EI2	>= 16	178	147	83%	165	89	54%	343	**69%**
Lifted	<= -4	278	201	72%	263	160	61%	541	**67%**
Sweat	uncertain	--	--	--	--	--	--	485	--

Index	**00z** Threshold*	Vip3 >= 0% Fcst	Vip3 >= 0% Obsvd	Vip3 >= 0% % cor	Vip3 = 0% Fcst	Vip3 = 0% Obsvd	Vip3 = 0% % cor	cases	total % cor
EI1	>= 11	165	129	78%	255	172	67%	420	**72%**
EI2	>= 11	186	141	76%	186	122	66%	372	**71%**
Showalter	<= 1	336	223	66%	219	163	74%	555	**70%**
K	>= 31	235	172	73%	320	213	67%	555	**69%**
Lifted	<= -3	347	226	65%	210	152	72%	557	**68%**
Total-totals	>= 43	308	201	65%	209	146	70%	517	**67%**
Sweat	>= 206	256	166	65%	261	166	64%	517	**64%**

* Threshold implies 60% or greater confidence that Vip3 will occur.

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greater (for the 12 h period following the upper air sounding) for Brownsville. This particular station and index was selected as somewhat representative and shows that although some increase in areal coverage accompanied more unstable Total-Total values, the correlation was not encouraging. Although a correlation did exist, the areal coverage was highly variable for any given index value. This same pattern existed for the other stations and other indices.

Table 2
Stability vs. Potentially Severe Thunderstorms
(and geographic area)

Index		DRT	BRO	VCT	LCH	All
		Avg Index values (00z & 12z)				
EI1	Vip3 > 0%	14	16	17	3	**13**
	Max Top > 500	*	29	28	22	**26**
Showalter	Vip3 > 0%	-2	-1	0	1	**0**
	Max Top > 500	-4	-1	0	-1	**-1**
EI2	Vip3 > 0%	24	19	31	23	**27**
	Max Top > 500	*	37	36	31	**34**
K	Vip3 > 0%	33	29	29	27	**29**
	Max Top > 500	30	32	30	31	**31**
Total-totals	Vip3 > 0%	47	44	44	43	**44**
	Max Top > 500	51	45	44	45	**45**
Lifted	Vip3 > 0%	-4	-5	-4	-3	**-4**
	Max Top > 500	-6	-5	-6	-5	**-5**
Sweat	Vip3 > 0%	261	210	219	200	**219**
	Max Top > 500	317	226	223	211	**224**

* fewer than 5 cases

Notes:

1. EI1 dramatically higher for tops over 50,000 feet
2. Typically more unstable for convection in DRT area
3. 1099 cases used in study
4. Vip 3 or greater occurred in 585 cases.
5. Max tops over 50,000 feet occurred in 155 cases.

5. CONCLUDING REMARKS

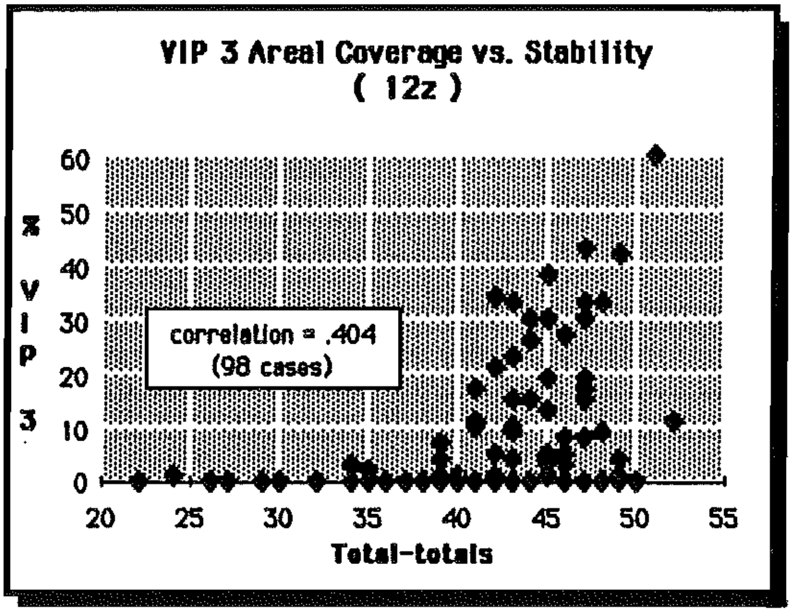
Although the data in this study are limited to a five month period during summer and early fall, the results basically agree with those of Stone (1985, 1986). Overall, the EI1 appears to have significant potential as a predictor for thunderstorms. This index proved best at predicting convection and also exhibited considerable potential towards segregating the potentially severe thunderstorm events from the more benign cases. However, this study suggests that most of the indices examined can successfully be used in predicting convection.

One index should never be considered apart from the others since each index can provide important information to the forecaster on the conditional instability of the atmosphere. For example, the K Index may have only limited value in the prediction of severe weather but is a very good tool in anticipating heavy rains. The lifted Index provides considerable information regarding severe weather but can be meaningless when forecasting convection during an overrunning situation. Each index must be considered in the context of the weather problem of the day.

Perhaps the significance of this study are the thresholds for the individual indices. It is quite likely these indices are applicable for maritime climates along the Gulf Coast; however based on the accompanying figures and the small data sample, the threshold values should be used with caution. They can be used, however, as starting points for additional local studies.

It should be obvious that very unstable indices will not necessarily be harbingers of convection. Stability indices were developed only as alerting devices and serve to alert the forecaster of areas with the potential for convection. The meteorological conditions (including vertical soundings) of these areas should be closely examined for factors which may alter the vertical structure of the atmosphere. The message of Beebe and Bates (1955) is still true that, in forecasting convection, the effort of the weather analyst/forecaster must be directed towards finding where upward vertical motion will occur in regions of moist, stratified air. Consequently, the vertical atmospheric structure is only part of the solution. It is important that the forecaster develop a four-dimensional (current structure plus temporal evolution) mental picture of the meteorological situation (Maddox, 1979; Doswell, 1982) and that he/she have a good physical understanding of the mechanisms that act to produce convection.

BRO Total-totals



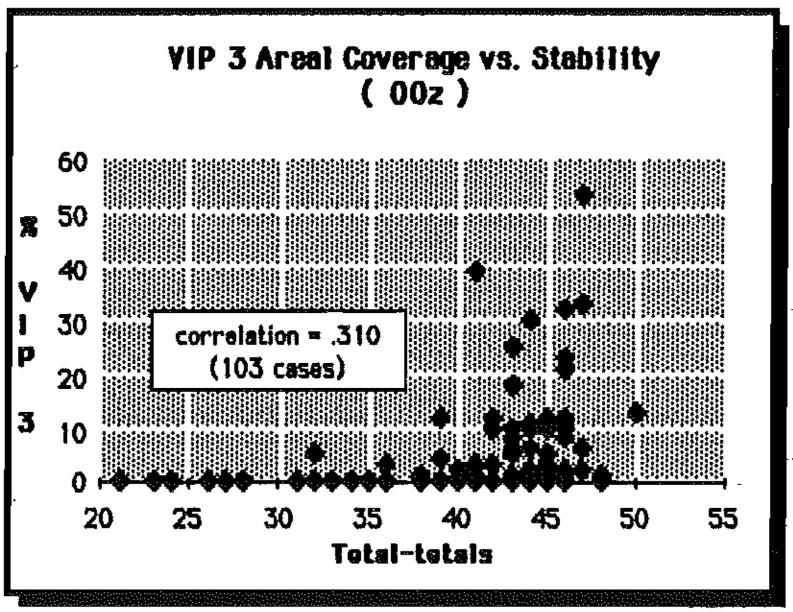


Figure 9 Areal coverage of convection (percent) for Brownsville, Texas, with the Total Totals index.

ACKNOWLEDGMENTS

Hugh Stone provided considerable information on the energy indices. His help is greatly appreciated. The authors would also like to thank Jimmy D. Ward for his assistance and encouragement.

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