NOAA TECHNICAL MEMORANDUM NWS ER-69

A COMPARISON AMONG VARIOUS THERMODYNAMIC PARAMETERS FOR THE PREDICTION OF CONVECTIVE ACTIVITY PART II

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December 1985

PREFACE

This publication is a continuation of the study originally reported in NOAA Technical Memorandum NWS ER-68, which investigated the correlation of various stability parameters to thunderstorm and severe weather occurences during a six month period, April to September 1984.

The same data were collected again for the corresponding period of 1985 and statistics were computed with very similar results to the 1984 period. The experiment was carried into the second year, because the 1984 sample was rather small and we were not sure that our conclusions were really valid.

The 1984 and 1985 data have been combined for the statistical summary presented here. A total of 2389 cases are now included in the sample.

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I. INTRODUCTION

A multitude of stability indices and thermodynamic parameters are now available for use in forecasting convection and severe weather. The performance of the more commonly used stability indices is well known, but the behavior of some of the more recently developed parameters has not previously been tested. A statistical comparison of the effectiveness of several of these parameters for forecasting various types of convection will be presented here.

The parameters which we have tested are not really new but are based on principles that have been used subjectively in forecasting for many years. We are now able to deal with them in a quantitative manner due to the computer capabilities of the AFOS system. All of these parameters may be computed with the RANP applications program (Stone, 1984a).

The subjective evaluation of positive and negative energy areas from a raob plotted on a thermodynamic diagram, has been quantified in the computation of the energy index (Stone, 1983,1984a,b). The energy index (EI1) is computed by selecting a parcel of air with maximum wet bulb potential temperature in the lowest 150 mbs of the raob and raising it to the 400 mb level, while entraining (Austin, 1948) environmental air at a rate that provides a 60 percent increase in mass over a 500 mb ascent. The EI1 is computed by integrating positive and negative energy areas as the parcel ascends.

The amount of solar heating needed to initiate convection based on the 1200 GMT sounding is estimated by the energy area between the temperature trace and the dry adiabat through the convective condensation level (Haltiner and Martin, 1957) to the surface. We shall designate this quantity as ETCCL. It may also be computed for the 0000 GMT sounding and may be interpreted as a measure of low level stability inhibiting surface based convection.

The concept of potential instability may also be considered in forecasting convection. If wet bulb potential temperature decreases with height through an atmospheric layer and that layer is lifted until saturation occurs, then the lapse rate through the layer will be unstable for saturated air. A crude measure of potential instability, which we will call DMAX, is defined as the depth (in millibars) of the deepest potentially unstable layer in the atmosphere. Of course this neglects the amount of lift required to attain saturation, but is considered as a possible predictor of convection.

These three parameters are compared to three traditional stability indices, the lifted index (LI), K index (KI), and Showalter index (SWI). The VIP level reported in the MDR portion of radar observations is used as a measure of the intensity of convection. Point biserial correlation coefficients were computed between the various stability parameters and the occurrence or non-occurrence of various radar VIP levels and similar correlations were computed for severe weather. Finally the relationship between heights of radar tops and the occurrence of severe weather was examined. Correlation coefficients were computed for radar top heights above ground level, above tropopause level, and above equilibrium level.

II. DATA COLLECTION AND ANALYSIS

Data were collected over the 1984 and 1985 convective seasons (April through September) at nine locations in the eastern United States where radiosonde observations are colocated with network radar observations. The following observation sites were used:

PWM	Portland, ME
ACY	Atlantic City, NJ
HAT	Cape Hatteras, NC
CHS	Charleston, SC
BUF	Buffalo, NY
PIT	Pittsburgh, PA
BNA	Nashville, TN
AHN	Athens, GA
AYS	Waycross, GA

Radar VIP levels within a 125 nautical mile radius of the observing station were used as a measure of the intensity of convection. Since most convection occurs between the hours of 1800 GMT through 0600 GMT, parameters based on the 1200 GMT raobs are correlated with the occurrence of various radar VIP levels during the six hour period 1800 GMT to 2400 GMT, and parameters from 0000 GMT are correlated with various radar VIP levels during the period 0000 GMT to 0600 GMT.

Over the two six month periods, 1111 cases were collected for the 1200 GMT raob time and 1278 cases for the 0000 GMT time. This is approximately 36 percent of the potentially available data. Only data that were operationally available on the AFOS circuit were used. No attempt was made to retrieve data that were missing for any reason. The greatest data loss occurred because <u>all</u> radar observations for the two six-hour time periods, 1800 to 2400 GMT and 0000 to 0600 GMT, were required to be available. A single missing or improperly coded radar report resulted in the rejection of that case. Other data were lost due to missing radiosonde observations, missing severe weather statistics, and occasional computer failures which prevented the data collection program from operating.

Tropopause and standard level heights were extracted from the mandatory level radiosonde reports. Tropopause and equilibrium levels were converted from pressure units to height units by interpolations using the height of the standard pressure levels.

The occurrence of severe weather events for each six hour period within 125 nautical miles of each of the nine stations was also recorded. This information was obtained from the "Tornado and Severe Thunderstorm Reports - Preliminary List" compiled by the National Severe Storms Forecast Center (NSSFC) in Kansas City, Mo. and distributed daily via AFOS.

III. RESULTS

Point biserial correlation coefficients were computed for three overlapping categories of VIP levels: VIP≥1, VIP≥3, and VIP≥5. The results are shown in the first three columns of Table 1. It can be seen that EI1 has slightly better correlations than any of the standard indices for all three categories of VIP level. Highest correlations were computed for VIP≥3, which is generally considered the lowest VIP level associated with thunderstorms. At this VIP level EI1 has the best correlation, LI second best, and K index the worst of the standard indices. The parameters ETCCL and DMAX have relatively low correlations of -.4423 and .3810 respectively. A multiple correlation coefficient combining EI1, ETCCL, and DMAX was computed with the result .6590, an insignificant improvement over the coefficient of .6510 for EI1 by itself.

Histograms of the relative frequency of occurrence of VIP≥3 versus the various 1200 GMT stability indices are shown in figure 1. At the top of each bar in the histograms there are two numbers, the lower number is the total number of cases in the interval and the upper number represents the number of cases where VIP level 3 or greater was observed. A large number of cases in each interval is desirable for a reliable relative frequency, but this is not always possible for the extremes of the distribution. For example, in Fig. 1.A., the histogram of EI1, a 100 percent relative frequency is shown for EI1 in the range of 100 to 150, but there is only a single case in that range. With a larger sample, negative cases would surely be found where VIP level was less than 3 in that interval. Likewise, in Fig. 1.B., the histogram for LI, a relative frequency of 75 percent is shown for the range of LI from -8 to -12, but there are only four cases in that range interval with one negative case; with a larger sample, the relative frequency would likely exceed 90 percent. In all the histograms, relative frequencies for ranges which contain a very small sample are unreliable.

Stability values that are exactly on a range interval end point are counted in the interval to the left, e.g., in Fig. 1.B. lifted index interval -4 to 0 actually includes -3, -2, -1, and 0. A lifted index of -4 would be counted in the -8 to -4 interval.

VIP level 3 is usually associated with thunderstorms, so the probability of afternoon thunderstorm development may be estimated using the histograms of Fig. 1. A histogram is most useful when the relative frequency decreases rapidly as stability increases. If the relative frequency decreases slowly, this means that a large portion of the observations are clustered around the 50 percent frequency, and this provides little useful information. A large number of observations with very high or very low frequency of occurrence is a much more useful distribution.

For example, Fig. 1.A. shows the relative frequency of thunderstorms for various ranges of EI1. By grouping various ranges of EI1 together, we can establish some rough thresholds, for the development or suppression of thunderstorms. If we consider those cases where EI1>0 (27 percent of sample), we see that the relative frequency of occurrence is about 90 percent, for EI1≤-100 (29 percent of sample) the relative frequency is 7 percent. For the intermediate range, -100<EI1≤0 (43 percent of sample) stability is not very helpful since the relative frequency is 52 percent. In this case other factors influencing thunderstorm development must be carefully considered.

Similar thresholds can be established for any of the other stability indices, but the results will not be quite as useful as the energy index because the correlation coefficients with VIP≥3 are not as good as EI1. K index, Fig. 1.D., shows a 100 percent frequency for K greater than 36, but this rarely occurs; 47 cases out of a total sample of 1111 cases.

The correlations for ETCCL and DMAX are rather poor and their histograms reveal little useful information. Relative frequencies for the 0 to 40 range of ETCCL are only 66 percent. DMAX is poor with a very large percentage of the sample clustered in the 30 to 70 percent relative frequency range.

The correlations for the various VIP categories versus the stability parameters from the 0000 GMT raobs are shown in Table 2. In this case VIP occurrences in the time period 0000 to 0600 GMT are used. For this set of data, EI1 provides the best correlations for VIP≥3 and VIP≥5, but K index is best for VIP≥1. K index was also better than LI or SWI for the 1200 GMT data of Table 1. The K index is sensitive to mid level (700 mb) moisture, while the LI and SWI are effected only by the moisture of the parcel and not the environmental moisture. This is probably the reason for the better correlation of K with the lower VIP levels 1 and 2, since a deep moist layer in the atmosphere is more likely to result in many convective elements with low radar VIP levels rather than a few convective elements with higher VIP levels. The

EIl index is also sensitive to environmental moisture, because of the entrainment process used in the computation.

Correlation coefficients of Table 2 (0000 GMT data) are generally lower than the coefficients of Table 1 (1200 GMT data). This is probably due to the fact that stability indices from the 1200 GMT data are representative of the preconvective state of the atmosphere, while indices based on the 0000 GMT data frequently have already been influenced by ongoing convective activity. It is fortunate that better correlations are obtained from the 1200 GMT data, since the need to evaluate stability is more important at that time rather than the evening after convection has usually already begun.

The corresponding histograms of relative frequency for the various stability indices are shown in figure 2. For this set of data the energy index obviously provides the most useful histogram with an upper threshold of EIl>50 (9 percent of sample) providing a relative frequency of about 88 percent and a lower threshold of EIl≤-50 (42 percent of sample) yielding a relative frequency of about 9 percent. The middle range, -50<EIl≤50 (48 percent of sample), gives a relative frequency of 58 percent. Similar but less useful thresholds could be obtained for LI, K, and SWI. Histograms of ETCCL and DMAX (Figs 1.E. and 1.F.) are nearly useless, but one interesting feature can be seen in the ETCCL histogram. A range of -40 to 0 is shown that contains 49 cases, which implies a low level superadiabatic lapse rate, but the relative frequency is only 41 percent. Many of these cases probably occured on dry sunny days with strong surface heating but insufficient moisture to support thunderstorm development. Again the multiple correlation coefficient combining EIl, ETCCL, and DMAX showed no significant improvement over the correlation for EIl alone.

The correlations of severe weather occurrences with various values of the stability indices were also computed and are shown in the last column of Table 1 (1200 GMT data) and Table 2 (0000 GMT data). Eighty four severe weather cases were recorded during the 1800 to 2400 GMT period and 39 cases for the 0000 to 0600 GMT period. The more rare an occurrence of some phenomenon, the more difficult it is to establish a good correlation with a predictor. This is readily apparent in both Tables 1 and 2, as the correlation coefficient for all the stability indices declines steadily going from column 2 to column 4; VIP≥5 is more difficult to correlate than VIP≥3 and severe weather correlations are worst of all.

For the period 1800 to 2400 GMT using stability indices from 1200 GMT, the best correlation with severe weather was obtained from LI, which was slightly better than SWI and EIl. All of the indices have poor correlations and the worst are ETCCL and DMAX. Similar results were obtained for the 0000 to 0600 GMT time period shown in Table 2, which shows SWI slightly better than EIl and LI, but all correlations are worse than the preceding time period.

Relative frequency histograms for severe weather occurrences in the 1800 to 2400 GMT time period are shown in Fig. 3. They are not very useful. There is a relative frequency of 22 percent for SWI≤3, 21 percent for LI≤-4, and 18 percent for EI1>50. The development of severe weather is strongly dependent on the proper moisture stratification and appropriate dynamic forcing. Some degree of instability is needed, but it is clearly not the controlling factor.

The best correlations of severe weather were with radar top heights. This is shown in Table 1 (1800 to 2400 GMT) and Table 2 (0000 to 0600 GMT). Radar tops have traditionally been compared to tropopause height to assess their potential for severe weather (Darrah, 1978). Tropopause penetration has been shown to be a better predictor of severe weather west of the Appalachians and not well related east of the Appalachians. More recently it has been suggested that equilibrium level (EL) is the physically meaningful level for assessing the severity of storms (Burgess and Davies-Jones, 1979, Doswell, et al., 1982). The correlation coefficients as shown in Table 1 and Table 2 do not confirm the value of the equilibrium level as a reference point for radar tops in forecasting severe weather. For the 1800 to 2400 GMT period, height of radar tops above EL had a correlation of .2421 with severe weather occurrence, while height of radar tops above tropopause had a correlation of .3551 and correlation with radar tops above ground level was virtually the same .3539. Table 2 for the 0000 to 0600 GMT time period shows a similar relationship but lower correlations.

Histograms of relative frequency of occurrence of severe weather for radar tops above EL, above tropopause level, and above ground level are shown in Figures 4A, 4B, and 4C respectively. The afternoon time period is on the left side of the figure and the evening on the right. These relative frequencies cannot be considered very reliable due to the relatively small sample, especially for those cases with very high tops. Remember that severe weather occurrences were tabulated from the "Tornado and Severe Thunderstorm Reports - Preliminary List" compiled by NSSFC, which does not have complete data; also, many severe weather events are never reported because they occur in sparsely populated areas. Despite these deficiencies, the data indicates that high radar tops have a high frequency of severe weather, and there seems to be no clear advantage in referencing the tops to any particular level, either tropopause or equilibrium level. Fig. 4.A. does show that nearly all severe weather occurrences are accompanied by radar tops exceeding the EL, but there are many more cases where tops exceed EL and severe weather is not observed.

There is some diurnal variability of the tropopause level and even more for the EL. However, we have tried to lessen this variability of the EL by computing it with a parcel that has maximum wet bulb potential temperature in the lowest 150 millibars of the atmosphere. This procedure usually selects a parcel well above the usual morning inversion of the 1200 GMT sounding, which decreases the variability between 1200 GMT and 0000 GMT.

We have not yet considered the performance of the EI2 index. This index is computed similarly to EI1, except the upper limit of integration is the EL rather than the 400 millibar level. EI2 is not always defined, since it requires some positive energy area in the troposphere to locate the EL, and this may not exist under very stable conditions. To compute the correlation coefficients for EI2 all cases of missing EI2 were removed from the sample, which resulted in a decrease in sample size from 1111 cases down to 690 cases for the 1200 GMT data, and decrease from 1278 to 936 cases for 0000 GMT data. The comparison of correlation coefficients for EI1, EI2, and EL are shown in Table 3 for both the afternoon and evening time periods. The correlations of EI2 with both radar VIP$\geq$3 and severe weather are much worse than the EI1 correlations. The corresponding histograms were also compared and it was found that EI2 provided no information that was not already apparent from the EI1 histograms. The last line of Table 3 shows that thunderstorms and severe weather events are fairly well correlated with the height of the EL. The correlations were not as good as EI1, but considerably better then EI2.

The poor performance of EI2 is probably related to the vertical distribution of positive and negative energy areas encountered during the computation of the indices. Recall that the vertical integration of energy areas for EI1 index arbitrarily terminates at the 400 millibar level, but the EI2 integration terminates at the EL, which may be either above or below the 400 mb level. An EL below 400 mb is a common occurrence in the summer. When the EL is very low, EI2 is representative of stability over a shallow depth of atmosphere and may have a positive value, while EI1 , which represents stability over a large depth, is strongly negative. The positive correlation of EL with thunderstorms and severe weather in Table 3 means that convection is most likely with a high EL. A large degree of instability indicated by EI2 below a low EL is, therefore, not usually favorable for the development of convection. The same positive energy area extending through a large depth of atmosphere is much more likely to result in convection.

With a high EL it is possible to get a fairly large positive value of EI2, with most of the positive energy area above the 400 mb level, and a rather low value of EI1. If the positive area is too high in the atmosphere with a large negative area below it, this is not conducive to the development of convection, since a rising parcel will probably not be able to reach the positive area.

Since problems with EI2 exist for both high and low equilibrium levels, it does not appear to be a very useful measure of stability. EI1 seems to be successful since it integrates energy areas over a sufficiently large depth of the lower troposphere, which is the important region of the atmosphere for initiating convection.

IV. CONCLUSIONS

Stability indices based on the 1200 GMT raob data are better correlated with the development of afternoon convection than the 0000 GMT stability indices with evening convection. This is fortunate since the assessment of stability prior to the beginning of convection is more important in forecasting than stability measurements after the convection has already begun, which is usually the case by 0000 GMT.

The correlation coefficients of Table 1 and the frequency histograms of Fig. 1, both indicate that the EI1 index is somewhat better than the lifted, K, or Showalter index in forecasting afternoon convection. Many times the choice of stability index is immaterial, indications are similar for all of them, but on some occasions the EI1 index points the correct way, while one or more of the others is misleading.

The use of the parameters ETCCL and DMAX in forecasting does not seem to be justified. Their performance singly is inferior to any of the other indices and when used in combination with the EI1 index there is no significant increase in performance as determined by multiple correlation computations. Likewise, the EI2 index does not appear to be a useful predictor of either convection or severe weather since it has correlation coefficients much lower than any of the other stability indices.

The performance of all stability indices is poor with regard to severe weather prediction. As mentioned before, rare events are difficult to predict, and severe weather is relatively rare compared to the common thunderstorm. Severe weather is more dependent on appropriate dynamical forcing than other types of convection, so the role of instability, although important, is not the dominant factor.

Our sample size for severe weather events is not very large, but the data indicates that neither tropopause level nor equilibrium level is significant for referencing radar tops for severe weather forecasting. Correlations of severe weather events to height of radar tops above ground level are about as good as correlations to radar tops referenced to the tropopause and better than correlations of tops referenced to equilibrium level.

This study has demonstrated a small but significant advantage of the EI1 over the standard stability indices for predicting general thunderstorm activity. It seems likely that an even greater advantage would be realized, if the positive and negative components of EI1 are considered seperately, since a large negative energy area in the lower atmosphere will suppress convection, even though the integrated energy EI1 is positive.

Finally, the variation with time of stability has not been considered at all in this study and must be accounted for subjectively by the forecaster. This along with a consideration of moisture distribution and dynamical forcing is a necessity for a good prediction of convection.

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Table 1. Point biserial correlation coefficients for 1800 GMT to 2400 GMT. Stability indices, equilibrium level, and tropopause height at 1200 GMT. Radar tops from 1800-2400 GMT. Sample size is 1111. Best correlations are underlined.

	VIP≥1	VIP≥3	VIP≥5	Severe weather
Energy Index 1	.5505	.6510	.4492	.2125
Lifted Index	-.4615	-.6247	-.4417	-.2158
K Index	.5309	.5272	.3768	.1603
Showalter Index	-.4997	-.5856	-.4261	-.2148
ETCCL	-.4269	-.4423	-.2602	-.1106
DMAX	.2801	.3810	.2594	.0915
Radar Tops - Equilibrium Level				.2421
Radar Tops - Tropopause				.3551
Radar Tops				.3539

Table 2. Point biserial correlation coefficients for 0000 GMT to 0600 GMT. Stability indices, equilibrium level, and tropopause height at 0000 GMT. Radar tops from 0000-0600 GMT. Sample size is 1278. Best correlations are underlined.

	VIP≥1	VIP≥3	VIP≥5	Severe Weather
Energy Index 1	.5112	.5886	.3997	.1513
Lifted Index	-.3989	-.5327	-.3764	-.1473
K Index	.5503	.5337	.3223	.1258
Showalter Index	-.4525	-.5160	-.3537	-.1588
ETCCL	-.4176	-.3747	-.2126	-.0814
DMAX	.2070	.3144	.2191	.0768
Radar Tops - Equilibrium Level				.1421
Radar Tops - Tropopause				.2502
Radar Tops				.2596

Table 3. Point biserial correlation coefficients for stability indices from 1200 GMT (1800-2400 GMT) and 0000 GMT (0000-0600 GMT). Sample size reduced to 690 and 936 cases for the respective time periods to eliminate cases where EI2 not defined. Correlation with VIP≥3 and severe weather (SV WX).

	1200 GMT		0000 GMT	
	VIP≥3	SV WX	VIP≥3	SV WX
EI1	.5668	.1938	.5702	.1335
EI2	.3289	.1451	.3751	.1145
EL	.5086	.1903	.5310	.1326

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VIP≥3 (1800-2400 GMT)

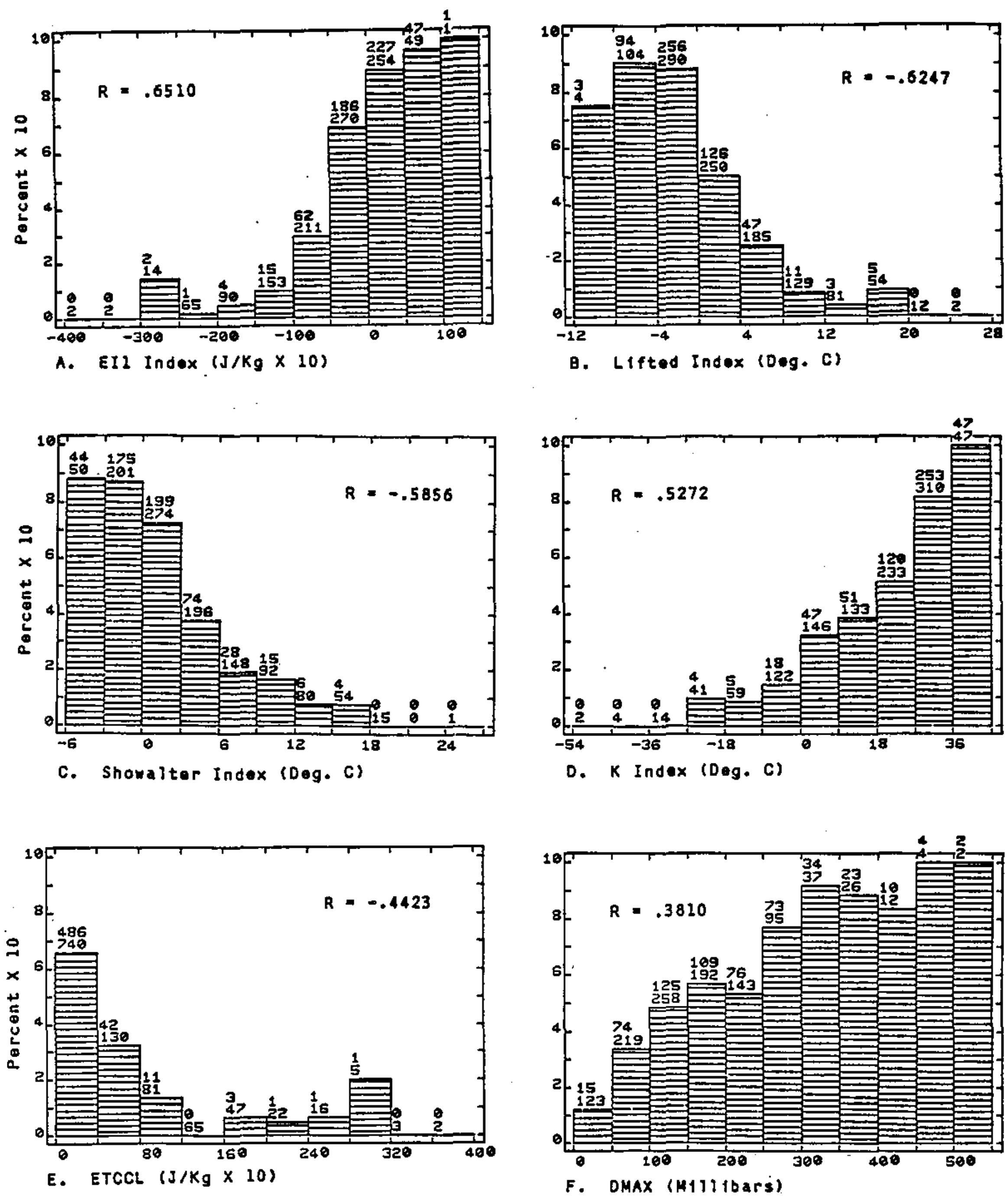


Fig. 1. Histograms of relative frequency of occurrence of VIP level 3 or greater (1800-2400 GMT) for various stability parameters computed from 1200 GMT raob data. Top number above each bar is number of occurrences of VIP≥3; bottom number is number of cases in the interval. Total number of cases is 1111. Correlation coefficient (R) is given for each histogram.

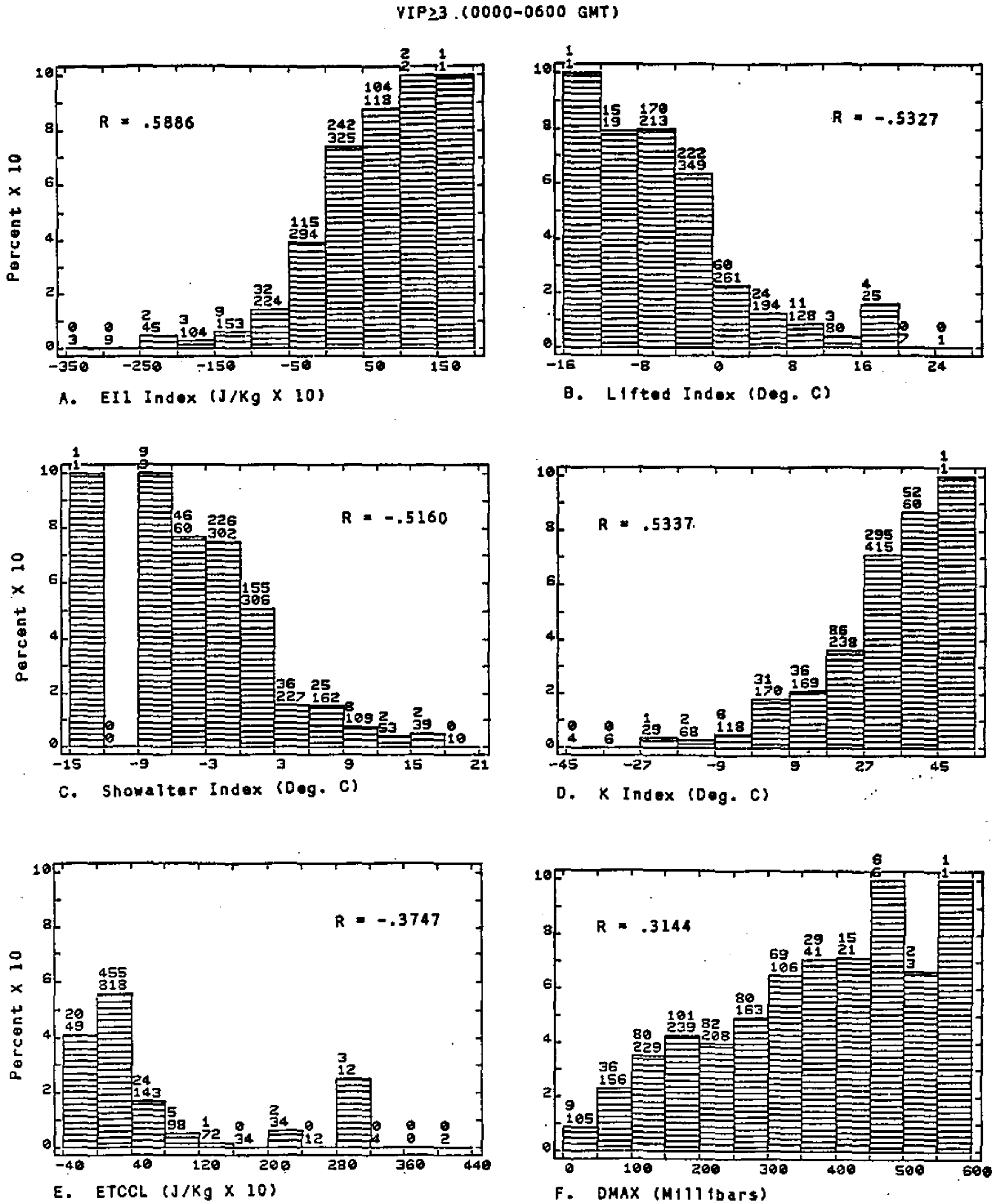


Fig. 2. Histograms of relative frequency of occurrence of VIP level 3 or greater (0000-0600 GMT) for various stability parameters computed from 0000 GMT raob data. Top number above each bar is number of occurrences of VIP≥3; bottom number is number of cases in the interval. Total number of cases is 1278. Correlation coefficient (R) is given for each histogram.

SEVERE WEATHER (1800-2400 GMT)

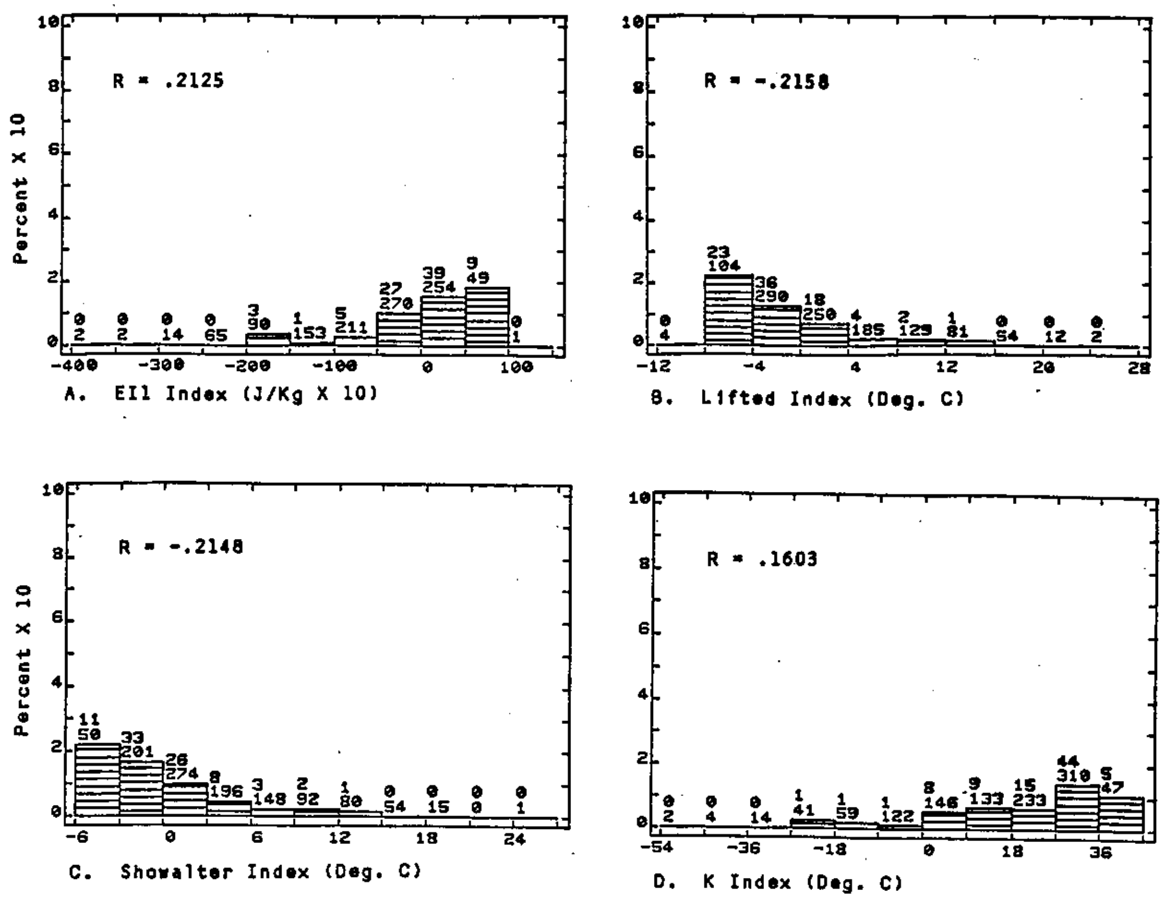
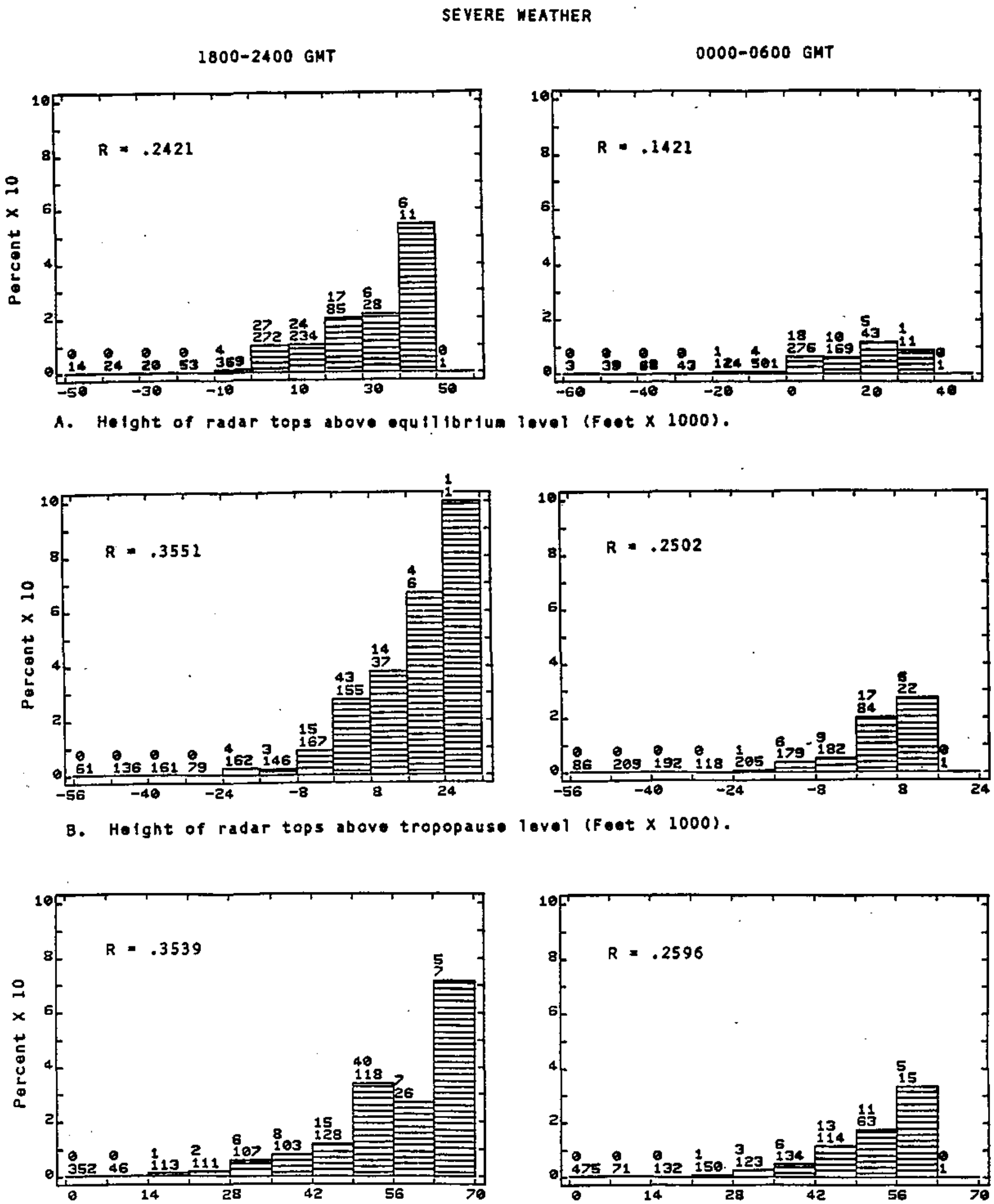


Fig. 3. Histograms of relative frequency of occurrence of severe weather (1800-2400 GMT) for various stability indices computed from 1200 GMT raob data. Top number above each bar is number of severe weather occurence; bottom number is total number of cases in the interval. Total number of cases is 1111.



A. Height of radar tops above equilibrium level (Feet X 1000).

B. Height of radar tops above tropopause level (Feet X 1000).

C. Height of radar tops above ground level (Feet X 1000).

Fig. 4. Histograms of relative frequence of occurrence of severe weather for radar tops above various reference levels. Left side for time period 1800-2400 GMT (1111 cases) and right side for 0000-0600 GMT (1278 cases).