NOAA Technical Memorandum NWS ER 80

RELATIONSHIP OF WIND SHEAR, BUOYANCY, AND RADAR TOPS TO SEVERE WEATHER 1988

Hugh M. Stone
National Weather Service Eastern Region
Garden City, New York

Scientific Services Division
Eastern Region Headquarters
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Hugh M. Stone
National Weather Service Eastern Region
Garden City, New York

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PREFACE

This publication is an extension of a 1987 study which investigated the relationship of stability and wind shear to severe weather occurrences in the eastern United States (NOAA Tech. Memo. NWS ER-75). The data base has been expanded in 1988 to include 14 stations in the Midwest for the purpose of investigating possible geographic differences in this relationship. An investigation of radar top penetration of tropopause and equilibrium level versus the occurrence of severe weather is also included in the present study.

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Hugh M. Stone

Eastern Region Headquarters
National Weather Service, NOAA
Garden City, New York

I. INTRODUCTION

Numerical and observational studies have indicated that wind shear is an important factor in determining the type of convection that develops in an unstable atmosphere, and it appears to be a useful indicator of whether or not convection will produce severe weather. In 1987 shear and stability data for the eastern United States were correlated with severe weather occurrences during the spring and summer seasons (Stone, 1988). Statistically significant correlations were found for various measures of both shear and stability. The 1987 study has been continued in 1988 to obtain more data for the eastern United States and also includes a sample from fourteen stations in the Midwest (Fig.1). Computations are done seperately for the Midwest and eastern areas to investigate possible geographic differences in the influence of shear and stability.

As in 1987, various shear and buoyancy parameters computed from 1200 UTC raobs are correlated to the occurrence or non-occurrence of afternoon (18Z-24Z) severe weather. Point biserial correlations are computed the same as in 1987. All shear and buoyancy computations are unchanged with one exception: previously the positive energy area B+ was computed using the parcel with maximum wet bulb potential temperature in the lowest 150mb of the atmosphere, i.e., the same parcel as used for the energy index computation. In this study, B+ is computed using a saturated parcel ascending from the convective condensation level (CCL), and represents the positive buoyancy of an undiluted parcel ascending from the CCL to the equilibrium level (EL). This conforms to the practice of most other researchers, so that these results may be more legitimately compared to theirs. This same parcel is used for the equilibrium level computation, which usually results in a higher EL than in previous years. B+ is also usually larger than before, which in turn effects the Bulk Richardson Number (BRN).

All data used in this study are obtained automatically by a data collection program, which extracts operationally available data from the AFOS circuit. Some data were lost due to missing or incomplete raobs, radar reports, and severe weather statistics, but the principal data loss was due to computer malfunction that occasionally prevented the program from running automatically. This was a frequent occurrence on weekends. A very poor sample was obtained in 1988 with only 39 percent of the potentially available data collected, compared to 73 percent in 1987.

II. SUMMARY OF 1987 RESULTS

In the East significant correlations were obtained between various measures of stability and the occurrence of afternoon severe weather. The role of wind shear was insignificant until the data were stratified. When correlations were computed using only the unstable data (EI>0), significant results were obtained for the various shear parameters, with the best correlations for the vector product shears VS5, VS10, and VS15, which represent shears from the surface to 5, 10, and 15 thousand feet above ground level, respectively. Correlations for VS15 were only slightly better than VS5 and VS10, indicating that the most important shear is found in the lowest five thousand feet of the atmosphere. During the summer season, the situation changed completely, with all measures of shear becoming virtually uncorrelated to severe weather. This seasonal variation of the influence of shear was also found by Schaefer and Livingston (1988). Their results show that springtime tornadoes mostly occurred in a strong wind shear environment with varying degrees of instability, while summer tornadoes generally occurred with weak shear but high instability.

III. 1988 RESULTS

EAST

As in previous years, significant correlations are obtained between severe weather and the various measures of stability. Combined data for the three month period April, May, and June showed little difference between EI, EI+, and B+ correlations. The EI+ correlation of .337 was slightly better than the other two (Table 1).

Unfortunately, the relationship between shear and severe weather seems to have vanished in the 1988 spring season. Significant correlations could not be obtained through any type of stratification. The reason for this is not known. The spring season of 1988 was cool with stable conditions prevailing much of the time, which delayed the onset of severe weather until later in the season than in 1987. The 500mb height anomalies were negative over most of the east throughout spring, Fig. 2. In 1987 500mb anomalies were near normal except April, when strong negative anomalies occurred, however, our data collection in 1987 did not begin until April 22. These factors may have had an influence on the deterioration of the shear relationship, also, using a sample with only 39 percent of the potential data, may be damaging.

During the summer season the relation of severe weather to wind shear remained insignificant, and the relation to buoyancy parameters weakened (Table 1) with B+ having the best correlation of .253.

MIDWEST

The springtime relationship of various measures of stability to severe weather is the same as in the East. EI+ with a correlation of .328 is slightly better than the other stability parameters.

Some measures of wind shear during the spring show significant correlation to severe weather in the Midwest with the best results from the vector product shears (Table 1). Significant correlation is obtained without stratifying the data into stable and unstable sets, and stratification does not improve the correlation. The relationship of severe weather to vector product shear is similar to that found in the East in 1987. VS5, VS10, and VS15 all show significant correlation with VS5 slightly better than the rest. The speed shears SS5, SS10, and SS15 are not as good as the vector product shears and the shear used in the BRN is virtually uncorrelated. In 1987 in the East, it was found that this relationship vanished in July for the summer season. The 1988 Midwest data shows good correlations of vector product shear VS5 for April and May, but in June it deteriorates completely (Fig.3).

During the summer the relation between severe weather and wind shear deteriorates as expected. The correlation to the VS5 shear, .129, is just barely significant. The correlation to the various buoyancy parameters are also weak, with the best correlation only .219 for B+.

IV. MEAN HODOGRAPHS

The springtime data were stratified by month for both the East and Midwest and mean hodographs computed for severe weather days and non-severe weather days. Hodographs are from the 1200 UTC raobs with wind levels interpolated to exactly one thousand foot intervals above ground level from the surface to 16 thousand feet. Results are shown in Fig. 3, Midwest on the left and East on right.

MIDWEST

The distinctive severe weather hodograph with strong speed and direction shear in the lowest 5 thousand feet is clearly seen in the Midwest during April and May and differs sharply from the mean hodograph on non-severe weather days. Monthly mean values of VS5, SS15, EI, B+, and EI+ for severe and non-severe weather days are shown on each hodograph along with correlations of each to severe weather occurrence. The VS5 shear in April has correlation .267 and in May .325, both significant and comparable to the correlation of the buoyancy parameters EI, EI+, and B+. Mean values of VS5 on severe weather days was 32 in April and 30 in May, while on non-severe weather days the mean of VS5 was 10. This difference in shear is also readily seen in the hodographs. Shear correlations deteriorate rapidly in June, even becoming negative, and hodographs for severe and non-severe days appear similar. Correlation with buoyancy parameters remain satisfactory through June.

EAST

In the East shear correlations are poor for all three months. The mean hodographs for severe weather days in April and May lack the distinctive shape of the Midwest hodographs. Despite the fact that the severe and non-severe hodographs differ in shape, correlations to all shear parameters in April and May are very poor. In June severe and non-severe hodographs are not much different, with poor shear correlations. Correlations with the buoyancy parameters are good in early spring then gradually deteriorate with time.

V. RADAR TOPS VERSUS SEVERE WEATHER

Traditionally radar tops have been compared to the height of the tropopause to indicate the possibility of severe weather with a thunderstorm (Darrah, 1978). The greater the penetration of the tropopause, the greater the likelihood of severe weather, with severe weather generally occurring as the tops diminish. More recently it has been suggested that the equilibrium level EL is the proper level for assessing the potential for severity (Burgess and Davies-Jones, 1979, Doswell, et.al., 1982). Another possibility is to compare tops to the maximum parcel level (MPL), which is where the negative energy area above the EL balances the positive area below; this is the theoretical limit to the height a parcel may attain as it loses all buoyancy.

In this study EL, MPL, and Tropopause are determined from the 1200 UTC soundings; these values are subtracted from maximum radar tops during the afternoon period 18Z-24Z and correlated with afternoon severe weather occurrences. Likewise, 0000 UTC sounding data are used for correlation between maximum radar tops and severe weather during the evening 00Z-06Z. Data from both time periods are combined and only cases with MDR values of 3 or greater are used in the statistical analysis. Due to the small sample size, data from the Midwest and East are also combined.

The results for spring and summer are shown in Table 2. The spring data shows that the best correlation to severe weather (.458) is obtained from tops above ground level. Tops referenced to tropopause level yield a correlation of .400, and referenced to EL only .262. Tops referenced to MPL are worst with coefficent of .165, which is not statistically significant at the one percent level.

The relation of severe weather to radar tops deteriorates in the summer with the best correlation only .249 for tops referenced to tropopause height. This is slightly better than correlation to tops above ground level. Correlations with tops referenced to EL and MPL are not statistically significant.

Histograms of relative frequency of springtime severe weather occurrence versus radar top heights referenced to various levels are shown in Fig.4. This shows that the greater the penetration of the tropopause or EL, the more likely that severe weather is associated with the storm. Almost all severe weather events are accompanied by tops that penetrate the EL and penetration of the EL results in severe weather approximately 27 percent of the time. Tops referenced to MPL show the highest relative frequency of severe weather for tops at the MPL to six thousand feet above the MPL. Theoretically tops should not exceed MPL, but in our sample 37 percent of the tops do exceed this level. Both MPL and EL vary with time, and both are highly sensitive to the selection of a representative parcel for convection. The parcel originating from the CCL, which is estimated from the 1200UTC sounding, is not always a representative parcel for afternoon convection.

The summer histograms of frequency of severe weather occurrence versus tops are shown in Fig.5. There is a tendency for high tops to be associated with severe weather, but the relationship is not as clear as in the springtime (Fig.4).

The above results indicate that there is no level that is good for referencing radar tops for determining the likelihood of severe weather with a storm. The higher the radar top, the more likely that a storm will be a severe weather producer. The location of the tropopause or equilibrium level is immaterial. These are the same results as obtained in the East during the spring and summer of 1984 and 1985 (Stone, 1985), however, at that time EL was computed in a non-standard way.

VI. CONCLUSIONS

Differences in results for shear from the eastern data between 1987 and 1988 illustrate the danger in drawing conclusions from a single year of data. Shear correlations became insignificant in the East in 1988, but a significant relationship appears to be valid in the West. Several more years of complete data are probably needed to establish whether or not there are real differences between the wind shear relationships valid for the East and Midwest, and to explain the inter-annual variation that may occur. Therefore, the following conclusions, except number 1, are tentative and subject to change:

1. Buoyancy is clearly related to the development of severe weather, and the relationship is valid irrespective of geographical location.

2. The relationship of wind shear to severe weather seems to be weaker than that of buoyancy both East and Midwest, but is stronger in the Midwest than in the East.

3. The shear relationship is apparently more important in the spring season than in the summer months.

4. Of the various measures of shear, the vector product shear appears to have to best relation to severe weather, probably because it accounts for the turning of the wind with height.

5. The most important shear occurs in the lowest 5 thousand feet of the atmosphere. Correlations to severe weather of VS5, VS10, and VS15 are all about the same.

6. The shear used in the BRN is poorly related to severe weather, therefore, BRN itself is not useful as an indicator of severe weather.

The data from which these conclusions are drawn consists of all possible cases of operationally available data that could be saved automatically by the computer. This may be a virtue since it eliminates all subjectivity in selecting the sample, but it also results in lower correlations. Many cases were recorded where instability and shear were very favorable for convection at 1200 UTC in the morning, but a complete change of airmass occurred by afternoon with instability being replaced by stability and a completely different wind shear. It would be clear to a forecaster that there is no possibility of severe weather in this circumstance, but our data collection program saves the data irrespective of synoptic conditions.

The most important factor in determining whether or not severe weather will occur is the dynamic forcing available. Wind shear and buoyancy determine the atmospheric response to whatever dynamic forcing is being imposed. For example, favorable buoyancy and shear may provide an environment for the development of severe weather with relatively weak dynamics, whereas, stronger dynamics are required to trigger severe convection when buoyancy and shear are not so favorable. This important factor has not been considered in the present study.

Despite the neglect of the change of synoptic situation between morning and afternoon and the neglect of dynamic triggering mechanisms, we still obtain statistically significant correlations of buoyancy and shear to the occurrence or non-occurrence of severe weather. This indicates that buoyancy and shear are both important factors in the development of severe weather. The change in buoyancy during the day is more easily estimated than the change in wind shear. With the advent of the NEXRAD and wind profiler systems, we will be able to monitor the diurnal variation of shear and it will likely assume a more important role as a predictor of severe weather than at the present time.

Recent studies indicate that the effects of wind shear and stability can be successfully combined into a single parameter that is useful as an indicator for severe weather potential. One such parameter called the Storm Severity Index (SSI) has been used to discriminate the potential for severe versus non-severe storms in Quebec (V. Turcotte and D. Vigneoux, 1987). An index called the Shear/Energy Index (SEI) has recently been developed at the National Severe Storms Forecast Center (Preston and Wu, 1988) which shows skill at discriminating F-scale values for tornadoes, high F-scale tornadoes being associated with high SEI values.

We have not been able to combine shear and stability into a single useful parameter for assessing potential for severe weather. The difficulty is apparently caused by a lack of a subjective screening to eliminate non-representative soundings from our data collection. Our current procedure, which is completely automated, allows us to identify the most useful measures of shear and stability, but even our best correlations are relatively low. Further progress will require a subjective screening of the data to assure that shear and stability are extracted only from the same air mass that produces the storms.

Finally, we have shown that the traditional comparison of radar tops to tropopause level, and more recently to EL, for the assessing the possibility of severe weather is not a useful technique. The best correlation to severe weather is obtained from height of radar tops above ground level, without reference to any particular level. The higher the top the more likely that it is associated with severe weather. This is true for both the Midwest and the East.

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Table 1

Point biserial correlation coefficients between various stability and wind shear parameters from 1200GMT raobs and severe weather observed during the period 1800-2400GMT. "F" denotes that coefficient is statistically significant at the one percent level.

	SPRING (Apr, May, Jun)		SUMMER (Jul, Aug, Sep)	
	MIDWEST	EAST	MIDWEST	EAST
No. Cases	506	559	482	557
EI	.323 F	.318 F	.185 F	.157 F
EI+	.328 F	.337 F	.172 F	.198 F
EI-	.289 F	.294 F	.169 F	.134 F
B+	.320 F	.322 F	.219 F	.253 F
B-	-.003	.046	.052	.014
BRN	.052	.157 F	.066	.014
SHR	.015	-.068	-.079	.011
SS5	.125 F	-.013	.098	.126 F
SS10	.111	-.038	.089	.090
SS15	.124 F	-.026	.096	.067
VS5	.197 F	.042	.129 F	.104
VS10	.195 F	.027	.113	.092
VS15	.187 F	.032	.108	.082

Table 2

Point biserial correlation coefficients between heights of radar tops and occurrence of severe weather during spring (Apr, May, Jun) and summer (Jul, Aug, Sep) 1988. Reference levels (EL, TROP, & MPL) from 1200GMT raobs for correlation to severe weather occurrence during 1800-2400GMT period, and from 0000GMT raobs for correlation to severe weather during 0000-0600GMT period.

	SPRING	SUMMER
No. Cases	222	253
TOP	.458 F	.222 F
TOP-EL	.262 F	.155
TOP-TROP	.400 F	.249 F
TOP-MPL	.165	.136

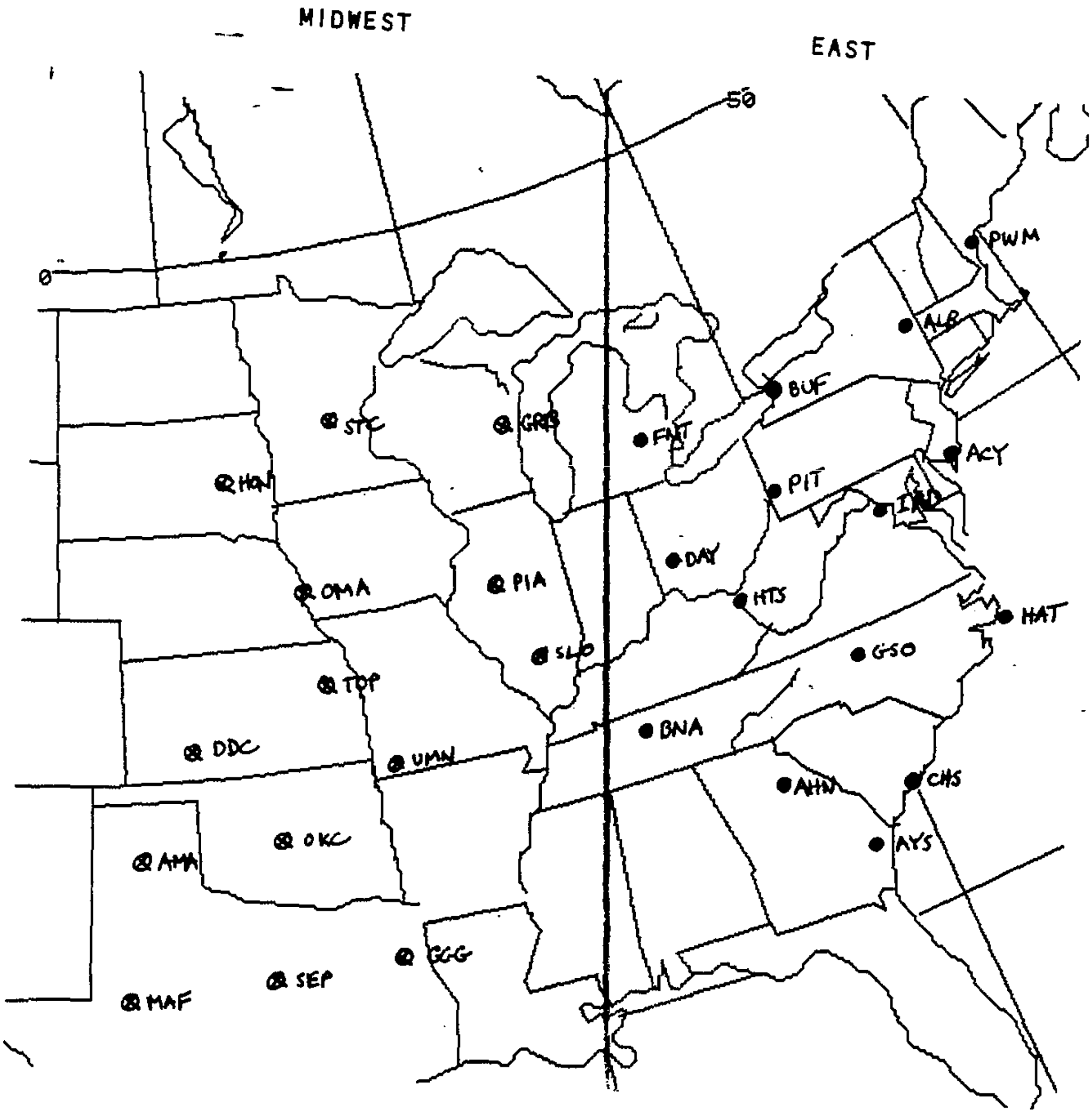

Fig.1. Raob stations used for stability and wind shear computations.

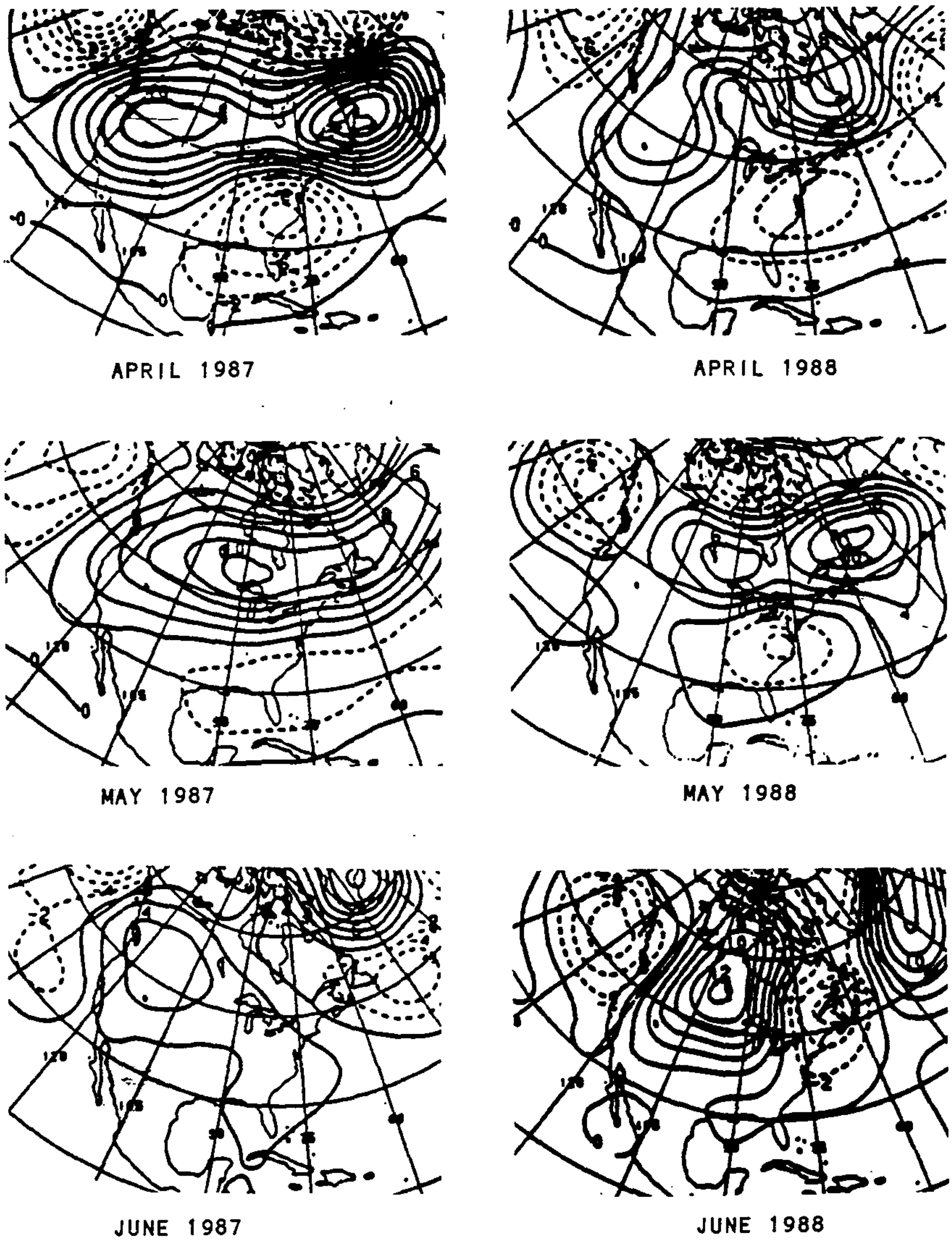

Fig.2. Monthly 500MB geopotential height anomalies for the spring season of 1987 and 1988. Base period is 1955 to 1978. Contour interval 2dm. Negative contours are dashed. From: Climate Analysis Center, NMC.

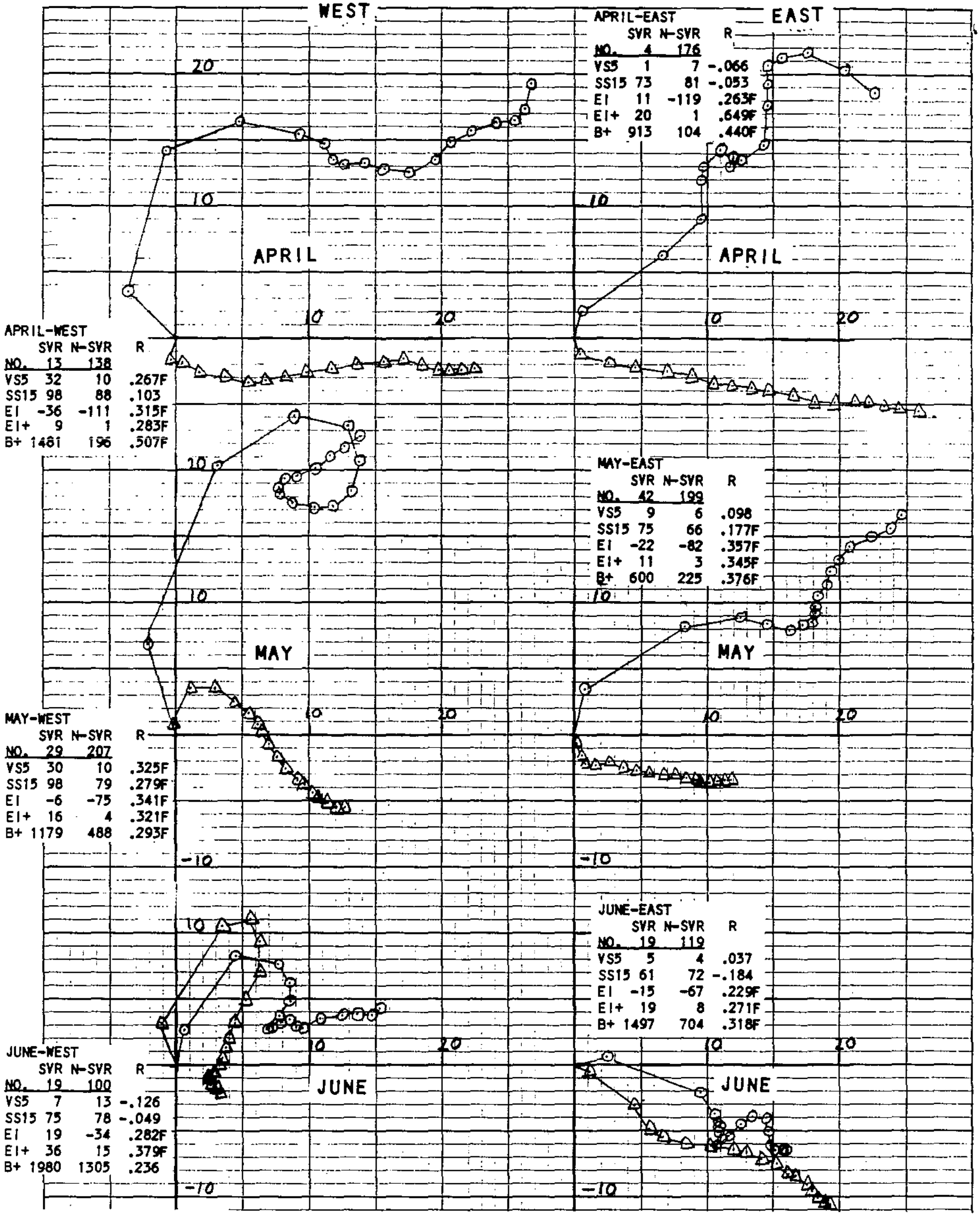

Fig.3. Mean hodographs (1200 UTC) for Midwest and East for spring months of 1988. Severe weather (SVR) hodographs plotted with circles from surface to 16 thousand feet AGL, and non-severe (N-SVR) hodographs plotted with triangles. X and Y axes are U and V wind components, respectively, and units are knots. Accompanying tables show mean values of various shear and stability parameters and correlation coefficients (R). Top line of table (NO.) is number of cases.

SPRING
(Apr, May, Jun)

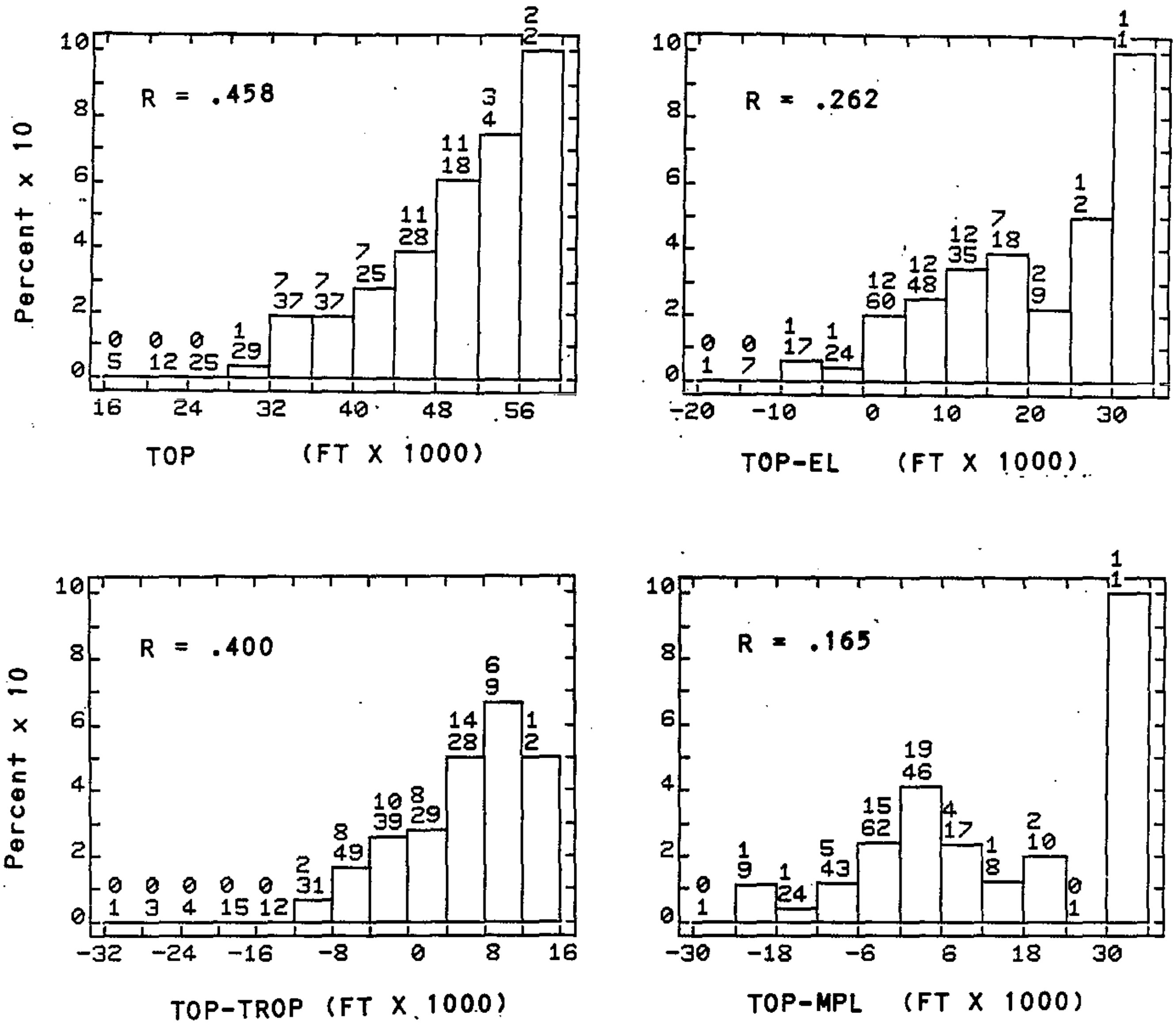

Fig.4. Histograms of relative frequency of occurrence of severe weather for radar tops above various reference levels. "R" on each histogram denotes correlation coefficient. Top number above each bar is number of severe weather occurrences; bottom number is total number of cases in that interval. Data from April, May, June 1988 for both East and Midwest areas; 222 observations total.

SUMMER
(Jul, Aug, Sep)

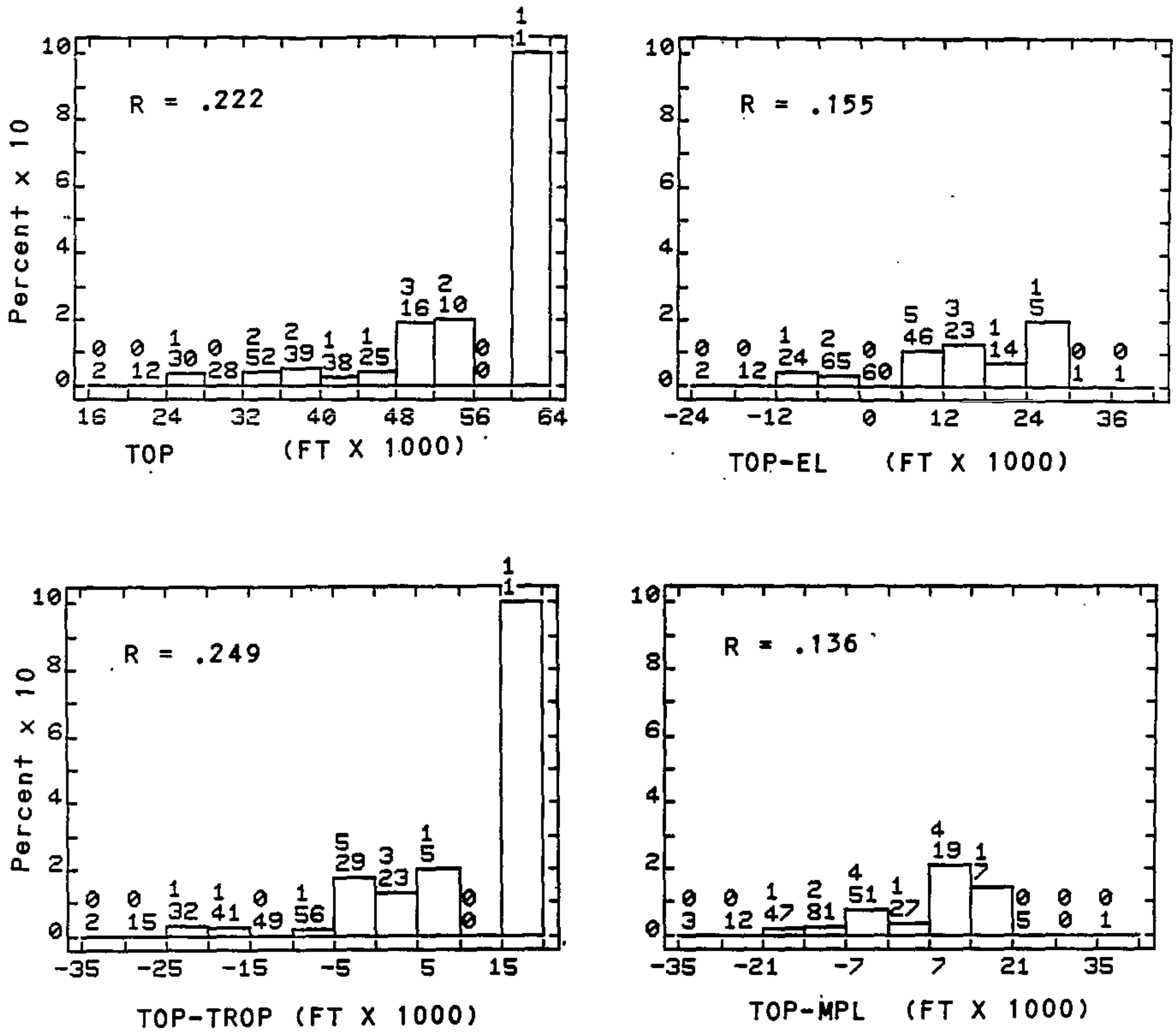

Fig.5. Histograms of relative frequency of occurrence of severe weather for radar tops above various reference levels. "R" on each histogram denotes correlation coefficient. Top number above each bar is number of severe weather occurrences; bottom number is total number of cases in that interval. Data from July, August, September 1988 for both East and Midwest areas; 253 observations total.