NOAA TECHNICAL MEMORANDUM NWS NSSFC-23

SEVERE LOCAL STORM WARNING VERIFICATION: 1988

Leo A. Grenier, John T. Halmstad
and Preston W. Leftwich, Jr.
National Severe Storms Forecast Center
Kansas City, Missouri 64106

June 1989

U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Weather Service

National Weather Service
National Severe Storms Forecast Center

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ABSTRACT. Tornado and severe thunderstorm warnings are issued by local offices of the National Weather Service. Routine verification of these warnings is accomplished at the National Severe Storms Forecast Center. This report highlights verification procedures and summarizes national, regional and local verification results for the year 1988.

Stations in the Central and Southern regions again issued most of the warnings and experienced most of the severe local storm events. On a national scale, verification scores improved slightly. Continued improvement in the False Alarm Ratio and the Critical Success Index are evident. After a slight decrease in the Probability of Detection in 1987 it also resumed an upward trend.

1. INTRODUCTION

Severe local storm warnings are issued to the public by more than 200 local offices of the National Weather Service (NWS). These warnings, which are typically based on radar information and/or storm spotter reports, alert the public to an existing tornado or severe thunderstorm. Each designated area of warning responsibility is composed of counties in the vicinity of the local office. Locations of these offices and their areas of responsibility are contained in Operations of the National Weather Service (NWS, 1985). Routine verification of all tornado and severe thunderstorm warnings issued by NWS offices is accomplished at the National Severe Storms Forecast Center (NSSFC) in Kansas City, Missouri. This report summarizes these verification results for the year 1988. Detailed evaluation of results, such as comparisons among individual offices, is beyond the scope of this report.

2. VERIFICATION PROCEDURES

Severe local storm warning verification began at the NSSFC in 1979. Pearson and David (1979) and Kelly and Schaefer (1982) analyzed warning verification back to 1976. In 1982 the NWS formulated a National Verification Plan (NWS, 1982) to provide guidelines for verification of all products issued to the public. The severe local storm warning verification

effort at the NSSFC is an integral part of this national program. Monthly and year-to-date summaries are now routinely provided to national and regional headquarters and to local offices.

The two elements necessary for verification are: (1) issued warnings and (2) event reports. Initially, both warnings and event reports are collected in real time from the Automation of Field Operations and Services (AFOS) computer system. Information concerning events are extracted from surface observations, warning messages, local storm reports (LSR), statements, pilot reports and state weather summaries. Additional reports may be received via telephone conversations or newspaper articles. These reports form a "rough log" of severe local storm events.

Each week, listings of warnings and event reports that have been logged and processed at the NSSFC are transmitted via the AFOS system to local offices for review. Roles of these warning and event summaries in the verification process are discussed in detail by Leftwich and Lee (1984), and updated by Grenier and Halmstad (1986). After reviewing these summaries, local offices send any warning corrections to the Verification Section at the NSSFC. The events list is an aid for the Warning Preparedness Meteorologist (WPM), at each local forecast office, to use in preparing "Storm Data and Unusual Weather Phenomena" (Form F-8). These F-8 reports are the sole source of all event reports used for official verification, with one exception; real-time surface aviation observations (SAO's) containing severe weather reports may be retained in the smooth log. After all forms of information have been compiled, the resulting "smooth log" and warning file provide data bases for official verification.

To qualify as a severe local storm event, a report must satisfy one of the criteria given in Table 1. General guidelines on event reporting may be found in Grenier and Halmstad (1986). For verification purposes, multiple reports of non-tornadic events occurring within 10 statute miles and 15 minutes of each other and in the same county are recorded as one event. All distinct tornadoes are retained as separate events.

Table 1
Criteria for Severe Local Storm Events
Used in Warning Verification

a. Tornado - a rotating circulation touching the ground and associated with a thunderstorm.

b. Hail equal or greater than 3/4 inch (1.9 cm) in diameter.

c. Thunderstorm wind gust of at least 50 knots (93 km/h).

d. Thunderstorm wind damage.

A detailed examination and comparison of ALL severe local storm events versus "SIGNIFICANT" severe local storm events may be found in Hales (1987).

"Significant" severe local storm events are identified using the criteria defined in Table 2. Because of the interest in, and demand for, significant event statistics, significant severe local storm events are identified on all monthly and annual summaries.

Table 2
Criteria for
"SIGNIFICANT" Severe Local Storm Events

a. Tornado - F2 or greater intensity on FPP scale, (Fujita,1981).

b. Wind gusts - 65 knots (121 Km/h) or greater.

c. Hail - 2 inches (5.1 cm) in diameter or greater.

d. Wind damage - $50,000 damage or greater. (Non-agricultural)

e. All events resulting in 1 or more deaths, or 3 or more injuries.

Even though a severe local storm may occur in a particular county, sparseness of population may decrease the chances that an event is reported. Schaefer and Galway (1982) addressed biases reflected in the tornado climatology across the United States. Hales and Kelly (1985) discussed possible effects of variations in reporting of hail and thunderstorm wind gust events upon verification results. Recently, Doswell and Burgess (1988) noted several problems relating to the F-scale rating system and the occurrence of very long track tornado events. Results of these studies demand that caution be exercised in directly comparing verification results between local offices, and regions that have different population densities or different meteorological regimes.

Once data have been compiled, various verification statistics are computed. Primary statistics are the Probability of Detection (POD), False Alarm Ratio (FAR), and Critical Success Index (CSI) that were adapted from those described by Donaldson et al. (1975). Adaptations were necessary because the statistics described by Donaldson et al. considered point forecasts, but warnings are area forecasts.

Any event that occurs both within a county for which a warning was issued and during the valid period of the warning is a "warned event". Thus, one warning can cover many events. Any type of severe local storm event (Table 1) can verify either type (tornado or severe thunderstorm) warning. The POD, which is a measure of the correctness of the warnings in time and space, is computed as follows:

$$\text{POD} = \frac{\text{number of warned events}}{\text{total number of events.}} \qquad (1)$$

In current verification procedures, the county is the basic unit of area. A warning that covers three counties is counted as three "warned

counties". At least one severe event occurring during the valid period of a warning in a warned county produces a "verified county". In order to obtain complete verification of a warning, at least one severe event must occur in each warned county. From these values, the FAR is computed (as a measure of overwarning) as follows:

$$FAR = 1 - \frac{\text{number of verified counties}}{\text{number of warned counties.}} \qquad (2)$$

These two statistics are combined to form the CSI as follows:

$$CSI = [(POD)^{-1} + (1-FAR)^{-1} - 1]^{-1}. \qquad (3)$$

For the CSI, higher values represent better skill, with a maximum possible value of "1". When either the FAR is "1" or the POD is "0", the CSI is undefined. The CSI, which is the same as the Threat Score, is the ratio of successful predictions to the number of events and false alarms. A graphical explanation of the CSI is given in Appendix B.

The Significant Probability of Detection (PODS) is calculated in exactly the same way as the POD. However, only those events that meet the "significant" criteria in Table 2 are used.

$$PODS = \frac{\text{number of warned significant events}}{\text{total number of significant events}}$$

Two additional statistics, Percent Verified (PV) and Verification Efficiency (VE), provide additional information concerning verification of warnings. The Percent Verified (PV) is defined as:

$$PV = \frac{\text{number of verified counties}}{\text{number of warned counties}} \times 100 \qquad (4)$$

The PV is also equivalent to 100(1-FAR). Values range from "0" to "100". Verification Efficiency represents an average of the POD and PV, and provides a straightforward measure of combined success in verifying warnings and covering events with valid warnings. It is calculated as

$$VE = 0.005\ (PV + 100 \cdot POD) \qquad (5)$$

and ranges from "0" to "1".

3. NATIONAL STATISTICS

Table 3 summarizes warning verification data for the contiguous United States during 1988. A total of 8,593 counties were warned via warning messages, and 7,253 severe local storm events were reported. The number of counties warned is a record low, 800 fewer than the previous record low of 9,409 in 1987. This appears to be a result of both more efficient warning procedures and a quiet severe weather year. Tornadoes totaled 702, well below the 30 year average of 778 and 7,253 total events was the lowest since 1982. It is also the second successive year, the only 2 years on record, in which no tornadoes were reported during April in Oklahoma. Nationwide,

approximately 58% of the severe local storm events occurred in warned counties, and at least one event was observed in 43% of the warned counties. The resulting national CSI was .33 with a VE of .51. Significant events comprised 13% of the severe local storm event total, and 50% of the significant events occurred in warned counties.

Table 3
National Severe Local Storm Warning
Verification Data: 1988

Counties Warned	8,593
County Warnings Verified	3,675
Severe Local Storm Events	7,253
Warned Events	4,232
FAR	.57
POD	.58
CSI	.33
% Verified	43
VE	.51
Significant Event Data	
Severe Local Storm Events	910
Warned Events	448
PODS	.50

Figures 1a, b, c, and d show the distributions of some of these station statistics. Only those stations that issued at least one warning or had one event occur in their area of responsibility were included in the raw distribution. Because stations with minimal activity tend to fall into the extremes of the raw distribution, the data have been "smoothed" using the following criteria.

(1) FAR...contains only those stations that issued 6 or more warnings for the year.

(2) POD...contains only those stations that had 6 or more severe events occur in their area of responsibility.

(3) CSI...contains only those stations that meet the criteria in (1) or (2).

(4) PODS..contains only those stations that had 3 or more significant severe weather events in their area of responsibility.

A comparison of the raw distribution to the smooth distribution is shown in Figures 1a, b, c and d respectively. Median values are also shown for both the raw and smooth distributions of the FAR, POD, CSI and PODS.

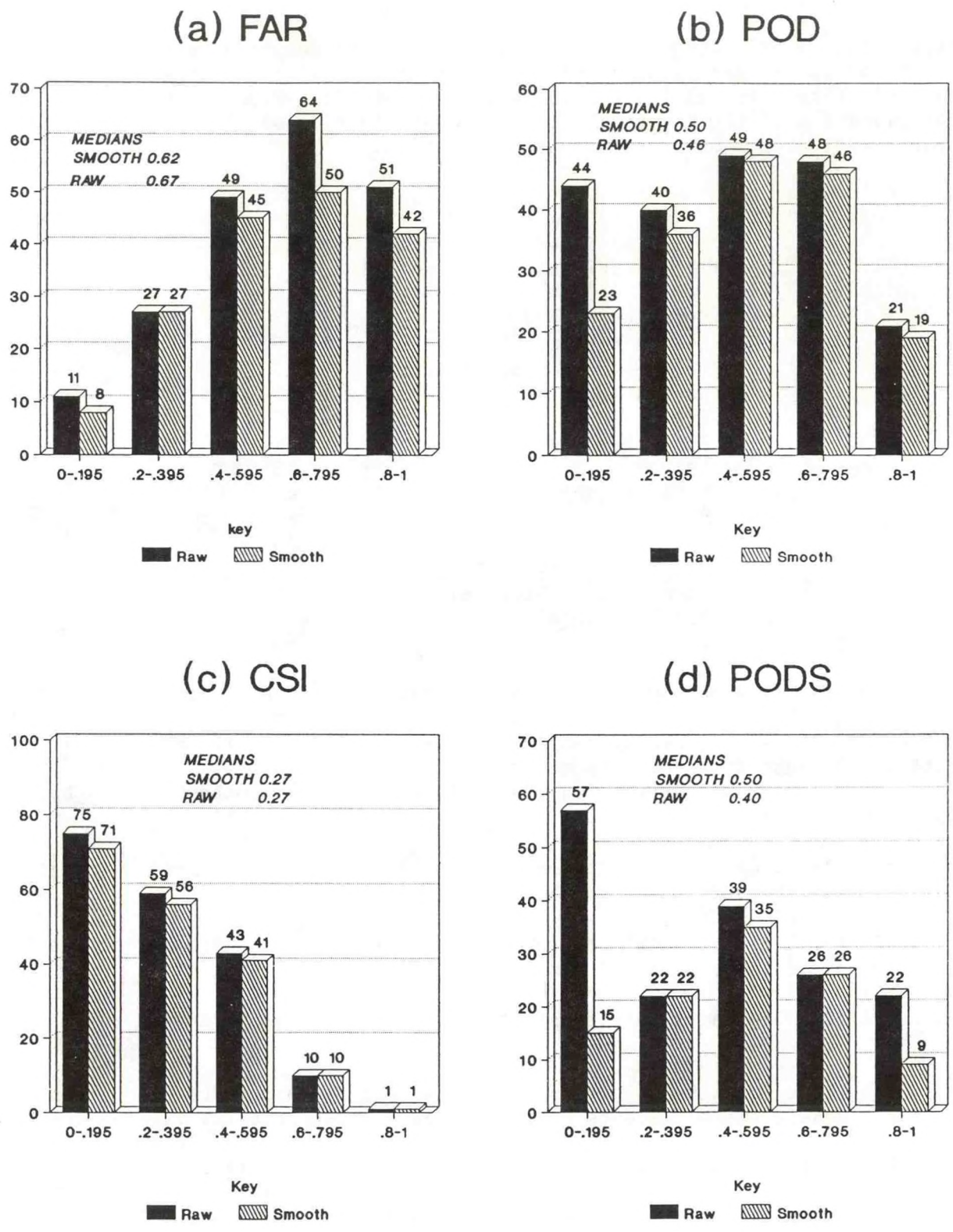

Figure 1. Frequency distributions of severe local storm warning verification statistics for 1988.

Figure 2 depicts the trend in national statistics since 1978, the first full year in which warnings were gathered. The 1987 and 1988 statistics might make us believe that we have reached a statistical plateau. All curves show significantly slower changes in the past two years than in previous years. This may be at least partially due to quieter than normal severe weather years.

During 1988, 702 tornadoes caused 32 fatalities and 688 injuries in the United States. The fatalities and injuries totals are significantly higher than the 1986 record lows of 15 and 536 respectively, while the tornado count is lower. However, all current year totals are well below the 30 year annual averages of 778 tornadoes, 83 fatalities, and 1656 injuries. As shown in Table 4, 41 percent of all tornado fatalities and 62 percent of all tornado injuries occurred within a valid severe local storm warning. Severe thunderstorm wind gusts caused another 23 fatalities and 342 injuries. Of these, 30 percent of the fatalities and 36 percent of the injuries occurred within a warned area.

Table 4
Severe Local Storm-Related Fatalities and Injuries
Relative to Valid Warnings: 1988

	Tornado		Severe Thunderstorm	
	Fatalities	Injuries	Fatalities	Injuries
Total Number	32	688	23	342
Within Valid Warnings	13	427	7	122
% Within Warnings	41	62	30	36

Figure 3 shows the number of event reports received in three categories for a 30 year period. While the number of tornadoes has remained relatively steady, the number of wind/hail reports and the total events have generally been increasing. Since 1978, the total number of severe events has approximately doubled. Originally, a severe event was identified as a duplicate if it met the following criteria; (1) it was in the same county, (2) it was within 10 statute miles and 15 minutes of another reports, (3) it was the same type of non-tornadic phenomena, i.e. hail or wind (Leftwich and Lee, 1984). It was later decided that a severe wind and severe hail report from the same severe thunderstorms were basically duplicates. In an effort to eliminate previously retained duplicate reports the "same type" requirement was dropped at the beginning of the 1986 severe weather year (Grenier and Halmstad,1986). It appears that we have reached a plateau in the 7000 - 8500 report range, with a decrease in both of the past 2 years. Possible causes for the declines in 1987 and 1988 are the extremely quiet severe weather years along with the revised definition of a severe event.

The lack of reports impacts the CSI scores as presented in Figure 2. It has long been known that the CSI exhibits a bias such that the score will flutuate in concert with the frequency of events (Gilbert,1884). Thus, if the CSI remains constant or increases as the number of reports decreases, the actual skill has increased. This is exactly what has happened since 1986.

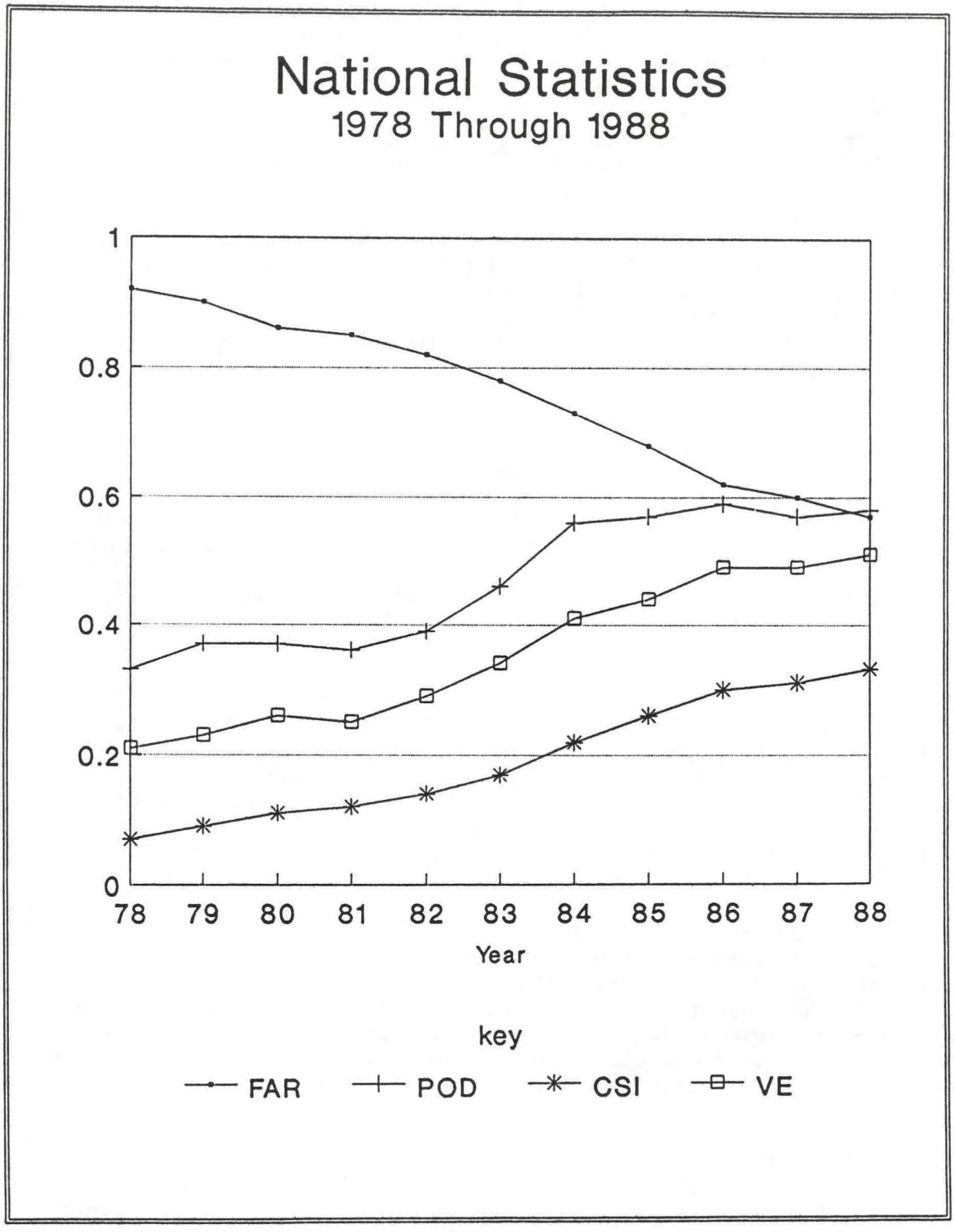

Figure 2. Severe local storm warning verification.

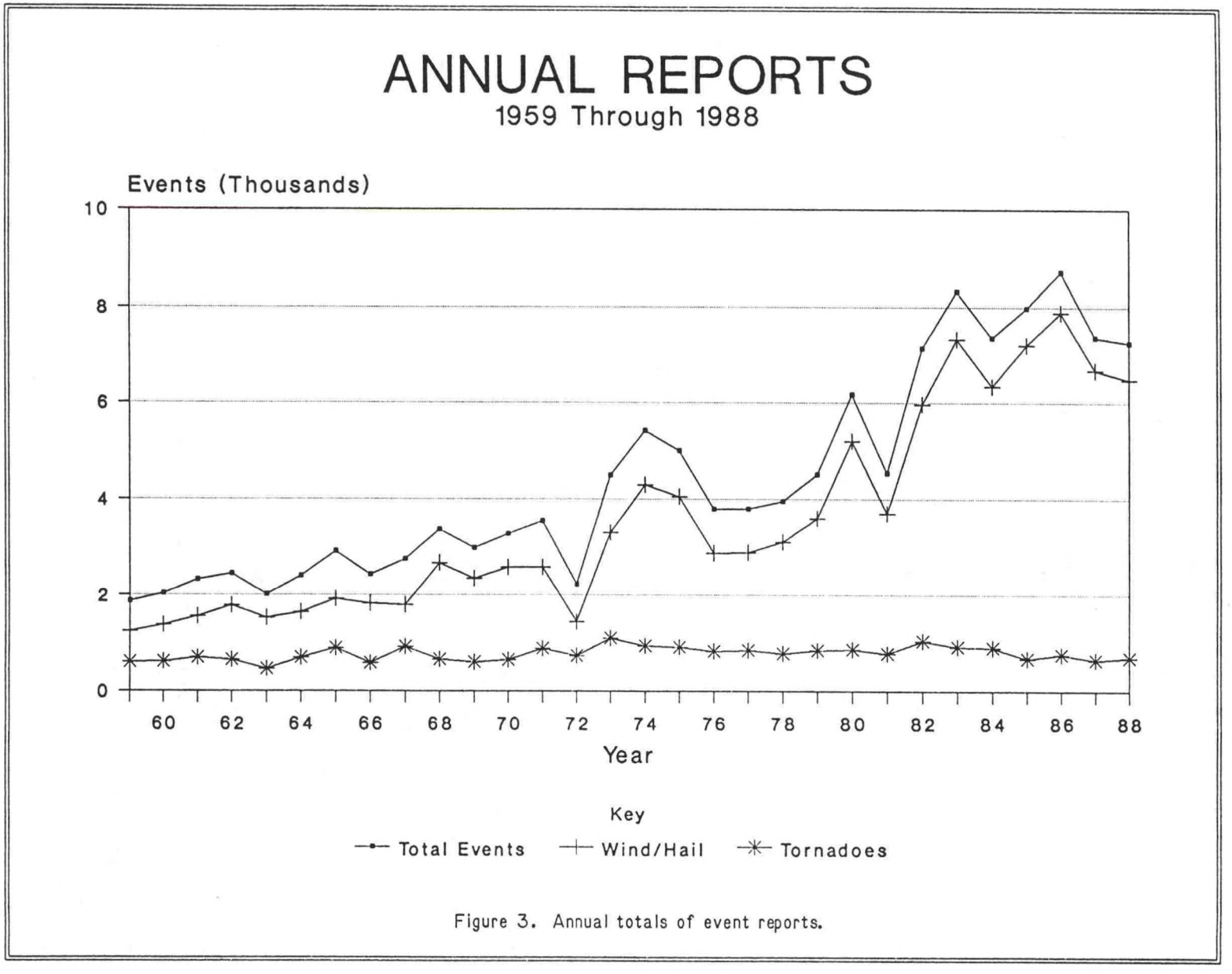

Figure 3. Annual totals of event reports.

4. REGIONAL STATISTICS

Table 5 summarizes warning verification data for the four contiguous NWS regions. Maps depicting the states included within each region are contained in Operations of the National Weather Service (NWS, 1985). As in previous years, severe local storm events were more numerous in the Central and Southern Regions than in the other two regions. This is in agreement with the climatologies by Kelly et al. (1978) and Kelly et al. (1985). Accordingly, these regions typically issue more warnings. Consistent percentage contributions of each region to the national totals for each variable are noted again during 1988. For example, the Southern region issued 46.6% of the county warnings during 1988. This region also had 50.3% of the verified counties, 41.6% of the severe events and 48.2% of the warned events. While Southern Region had 12% more severe events than Central Region, the latter had a 3% higher total of significant severe events.

Table 5

Regional Severe Local Storm Warning Verification Data: 1988
Numbers in parentheses are percentages of national totals for each item.

	Central	Eastern	Southern	Western
Counties Warned	2862 (33.3)	1452 (16.9)	4007 (46.6)	272 (3.2)
County Warnings Verified	928 (25.3)	861 (23.4)	1848 (50.3)	38 (1.0)
Severe Local Storm Events	2235 (30.8)	1752 (24.2)	3019 (41.6)	245 (3.4)
Warned Events	1069 (25.3)	1082 (25.6)	2040 (48.2)	41 (0.9)
FAR	.68	.41	.54	.86
POD	.48	.62	.68	.17
CSI	.24	.43	.38	.08
% Verified	32	59	46	14
VE	.40	.61	.57	.15
Significant Event Data				
Severe Local Storm Events	349 (38.4)	196 (21.5)	322 (35.4)	43 (4.7)
Warned Events	168 (36.7)	99 (21.6)	183 (40.0)	8 (1.7)
PODS	.48	.51	.57	.19

5. LOCAL STATISTICS

Appendix A lists severe local storm warning verification data for local NWS offices. Station names for the call-letter identifiers are listed in Appendix A of Operations of the National Weather Service (NWS, 1985). This list includes those offices that either issued at least one severe local storm warning or recorded at least one severe local storm event within its area of responsibility during 1988. A warning is counted for the office issuing that warning. A severe local storm event is counted for the office in whose area of responsibility that event occurs. As an example, office A issues a warning for a county in the area of responsibility of office B.

Then, three severe local storm events occur in that county during the valid period of the warning. Office A is credited with a warned county, and office B is credited with three warned events. This accounting procedure can result in an office that issues no warnings having a POD greater than zero in Appendix A.

From one office to another there are often wide variations in numbers such as warnings issued and severe local storm events. Computed statistics reflect differences in both severe local storm reporting and meteorological regimes, as well as the warning skills of the forecasters. As stated previously, these factors demand that caution be exercised in any comparisons of verification results with those of other offices.

6. SUMMARY

All verification of tornado and severe thunderstorm warnings issued by local NWS offices is accomplished at the National Severe Storms Forecast Center. Monthly and year-to-date reports containing summaries of all warnings and events and various verification statistics are provided for national, regional and local use. This report documents national, regional and local verification results for the year 1988.

Since 1978, verification statistics have shown continued improvement with only minor POD deviations in 1981 and 1987. The Central and Southern regions contribute most of the warnings and observed events in national totals. Varying population density and differing meteorological regimes are among many factors that influence verification results. Any direct comparisons of verification statistics with those of other regions or local offices require caution.

7. ACKNOWLEDGMENTS

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8. REFERENCES

Charba, J.P. and W.H. Klein, 1980: Skill in precipitation forecasting in the National Weather Service. Bull. Amer. Meteor. Soc., 61, 1546-1555.

Donaldson, R.J., R.M Dyer and M.J. Kraus, 1975: An objective evaluator of techniques for predicting severe weather events. Preprints, Ninth Conference on Severe Local Storms (Norman, OK), Amer. Meteor. Soc., Boston, MA, 395-402.

Doswell, C.A., III and D.W. Burgess, 1988: On some issues of United States tornado climatology. Mon. Wea. Rev., 116, 495-501.

Fujita, T.T., 1981: Tornadoes and Downburst in the Context of Generalized Planitary Scales. Journal of Atmospheric Sciences, Amer. Meteor. Soc., Boston, MA, 38, 1511-1534.

Gilbert, G.F., 1884: Finleys Tornado Predictions. American Meteorology Journal, 1, 166-172.

Grenier, L.A. and J.T. Halmstad, 1986: Severe Local Storm Warning Verification Preliminary Procedures, NOAA Technical Memorandum NWS NSSFC-12, National Severe Storms Forecast Center, Kansas City, MO, 10 pp.

Hales, J.E., 1987: An Examination of the National Weather Service Severe Local Storm Warning Program and Proposed Improvements, NOAA Technical Memorandum NWS NSSFC-15, National Severe Storms Forecast Center, Kansas City, MO, 32 pp.

_____, and D.L. Kelly, 1985: The relationship between the collection of severe thunderstorm reports and warning verification. Preprints, Fourteenth Conference on Severe Local Storms (Indianapolis, IN), Amer. Meteor. Soc., Boston, MA, 13-16.

Kelly, D.L., and J.T. Schaefer, 1982: Implications of severe local storm warning verification. Preprints, Twelfth Conference on Severe Local Storms (San Antonio, TX), Amer. Meteor. Soc., Boston, MA, 459-462.

_____, _____, and C.A. Doswell, 1985: Climatology of non-tornadic severe thunderstorm events in the United States. Mon. Wea. Rev., 113, 1997-2014.

_____, _____, R.P. McNulty, C.A. Doswell, and R.F. Abbey, 1978: An augmented tornado climatology. Mon. Wea. Rev., 106, 1172-1183.

Leftwich, P.W. and L.C. Lee, 1984: Severe local storm warning and event summaries available in AFOS. NOAA Technical Memorandum NWS NSSFC-6, National Severe Storms Forecast Center, Kansas City, MO, 10 pp.

National Weather Service, 1985: Operations of the National Weather Service. U.S. Dept. of Commerce, NOAA, 237 pp.

_____, 1982: National Verification Plan. U.S. Dept. of Commerce, NOAA, 81 pp.

Pearson, A.D. and C.L. David, 1979: Tornado and severe thunderstorm warning verification. Preprints, Eleventh Conference on Severe Local Storms (Kansas City, MO), Amer. Meteor. Soc., Boston, MA, 567-568.

Schaefer, J.T. and J.G. Galway, 1982: Population biases in tornado climatology. Preprints, Twelfth Conference on Severe Local Storms (San Antonio, TX), Amer. Meteor. Soc., Boston, MA, 51-54.

Appendix A

Severe Local Storm Warning Verification for NWS Offices: 1988

* * * KEY FOR COLUMN HEADINGS * * *

STN = STATION CALL LETTERS
WRND CNTYS = WARNED COUNTIES
VERF CNTYS = VERIFIED COUNTIES
TOT EVNTS = SEVERE LOCAL STORM EVENTS
WRND EVNTS = WARNED EVENTS
SIG EVNTS = SIGNIFICANT EVENTS
FAR = FALSE ALARM RATIO
POD = PROBABILITY OF DETECTION
PODS = PROBABILITY OF DETECTION (SIGNIFICANT EVENTS ONLY)
CSI = CRITICAL SUCCESS INDEX
VE = VERIFICATION EFFICIENCY

EASTERN REGION

STN	WRND CNTYS	VERF CNTYS	TOT EVNTS	WRND EVNTS	SIG EVNTS	FAR	POD	CSI	VE	PODS
ABE	12	12	16	14	1	0.000	0.875	0.875	0.938	1.000
ACY	28	21	30	24	2	0.250	0.800	0.632	0.775	0.500
ALB	90	71	165	104	30	0.211	0.630	0.539	0.710	0.467
AVL	36	24	31	24	1	0.333	0.774	0.558	0.720	0.000
AVP	7	4	11	5	1	0.429	0.455	0.339	0.513	0.000
BDL	7	3	11	3	5	0.571	0.273	0.200	0.351	0.400
BDR	0	0	1	0	0	0.000	0.000	0.000	0.000	
BGM	35	26	54	33	6	0.257	0.611	0.504	0.677	0.667
BKW	1	0	1	0	0	1.000	0.000	0.000	0.000	
BOS	16	10	22	15	7	0.375	0.682	0.484	0.653	0.714
BTV	34	26	51	33	10	0.235	0.647	0.540	0.706	0.500
BUF	33	25	51	34	1	0.242	0.667	0.549	0.712	0.000
BWI	7	3	14	3	2	0.571	0.214	0.167	0.321	0.500
CAE	126	61	118	73	7	0.516	0.619	0.373	0.551	0.429
CAK	13	11	13	11	2	0.154	0.846	0.733	0.846	0.500
CAR	2	1	5	3	2	0.500	0.600	0.375	0.550	1.000
CHS	28	21	49	33	1	0.250	0.673	0.550	0.712	1.000
CLE	29	20	35	21	5	0.310	0.600	0.472	0.645	0.400
CLT	44	21	49	22	1	0.523	0.449	0.301	0.463	1.000
CMH	17	9	25	9	6	0.471	0.360	0.273	0.445	0.500
CON	27	21	44	30	16	0.222	0.682	0.571	0.730	0.437
CRW	14	4	8	4	1	0.714	0.500	0.222	0.393	1.000
CVG	12	2	11	2	2	0.833	0.182	0.095	0.174	0.000
DAY	15	8	9	8	1	0.467	0.889	0.500	0.711	1.000
EKN	13	5	10	6	0	0.615	0.600	0.306	0.492	

ERI	39	22	26	21	0	0.436	0.808	0.497	0.686	
EWR	3	0	0	0	0	0.000	0.000	0.000	0.000	
GSO	82	51	78	55	7	0.378	0.705	0.494	0.664	0.714
GSP	38	26	65	34	6	0.316	0.523	0.421	0.604	0.667
HAR	38	36	60	48	0	0.053	0.800	0.766	0.873	
HAT	43	12	36	12	10	0.721	0.333	0.179	0.306	0.200
HTS	9	4	10	4	1	0.556	0.400	0.267	0.422	0.000
ILG	9	4	10	6	2	0.556	0.600	0.343	0.522	1.000
ILM	69	32	47	33	11	0.536	0.702	0.388	0.583	0.636
IPT	14	12	26	23	0	0.143	0.885	0.771	0.870	
LYH	4	1	11	5	0	0.750	0.455	0.192	0.352	
MFD	5	3	5	3	0	0.400	0.600	0.429	0.600	
NYC	27	9	29	12	0	0.667	0.414	0.226	0.374	
ORF	14	9	21	9	7	0.357	0.429	0.346	0.536	0.429
ORH	7	5	15	10	4	0.286	0.667	0.526	0.690	1.000
PHL	46	25	54	36	8	0.457	0.667	0.427	0.605	0.500
PIT	54	42	83	74	5	0.222	0.892	0.711	0.835	0.600
PVD	3	0	0	0	0	1.000	0.000	0.000	0.000	
PWM	18	15	37	26	8	0.167	0.703	0.616	0.768	0.375
RDU	125	57	118	65	15	0.544	0.551	0.332	0.503	0.467
RIC	8	5	20	6	3	0.375	0.300	0.254	0.463	0.333
ROA	26	10	18	7	0	0.615	0.389	0.240	0.387	
ROC	15	13	20	15	1	0.133	0.750	0.672	0.808	0.000
SYR	18	10	37	16	4	0.444	0.432	0.321	0.494	0.000
TOL	24	10	26	12	4	0.583	0.462	0.280	0.439	0.750
WBC	57	29	51	28	2	0.491	0.549	0.359	0.529	0.000
YNG	12	8	15	8	0	0.333	0.533	0.421	0.600	
VQN	...NO SEVERE ACTIVITY...									
CHH	...NO SEVERE ACTIVITY...									
PKB	...NO SEVERE ACTIVITY...									
RDG	...NO SEVERE ACTIVITY...									

CENTRAL REGION

STN	WRND CNTYS	VERF CNTYS	TOT EVNTS	WRND EVNTS	SIG EVNTS	FAR	POD	CSI	VE	PODS
ABR	49	15	33	19	3	0.694	0.576	0.250	0.441	0.333
ALO	14	6	28	6	11	0.571	0.214	0.167	0.321	0.091
ALS	0	0	3	0	0	0.000	0.000	0.000	0.000	
APN	45	8	20	9	0	0.822	0.450	0.146	0.314	
ARB	3	0	0	0	0	1.000	0.000	0.000	0.000	
BFF	62	15	30	12	6	0.758	0.400	0.178	0.321	0.500
BIS	63	31	64	36	17	0.508	0.562	0.356	0.527	0.588
CHI	70	13	53	14	13	0.814	0.264	0.122	0.225	0.538
CNK	28	18	31	18	1	0.357	0.581	0.439	0.612	0.000
COS	18	9	26	12	4	0.500	0.462	0.316	0.481	0.250
COU	100	50	71	59	12	0.500	0.831	0.454	0.665	0.750
CPR	21	3	19	3	3	0.857	0.158	0.081	0.150	0.333
CYS	39	13	31	17	4	0.667	0.548	0.262	0.441	0.750

DBQ	5	3	32	20	9	0.400	0.625	0.441	0.612	0.778
DDC	9	7	19	8	1	0.222	0.421	0.376	0.599	0.000
DEN	127	30	82	32	11	0.764	0.390	0.173	0.313	0.545
DLH	77	11	48	16	6	0.857	0.333	0.111	0.238	0.333
DSM	95	31	97	31	37	0.674	0.320	0.193	0.324	0.405
DTW	60	20	63	21	5	0.667	0.333	0.200	0.333	0.400
EVV	23	18	20	18	1	0.217	0.900	0.720	0.841	0.000
FAR	161	53	94	60	22	0.671	0.638	0.277	0.484	0.682
FNT	11	3	18	3	1	0.727	0.167	0.115	0.220	0.000
FSD	85	8	22	6	5	0.906	0.273	0.075	0.183	0.400
FWA	72	27	48	33	8	0.625	0.687	0.320	0.531	0.625
GJT	1	0	6	0	1	1.000	0.000	0.000	0.000	0.000
GLD	30	20	46	22	3	0.333	0.478	0.386	0.572	0.333
GRB	41	16	34	18	14	0.610	0.529	0.290	0.460	0.286
GRI	58	13	28	15	7	0.776	0.536	0.188	0.380	0.143
GRR	31	6	47	7	7	0.806	0.149	0.092	0.171	0.143
HON	31	6	19	5	0	0.806	0.263	0.126	0.226	
HTL	29	6	12	6	0	0.793	0.500	0.171	0.353	
ICT	80	29	70	39	10	0.637	0.557	0.281	0.460	0.500
IND	74	18	67	19	14	0.757	0.284	0.151	0.263	0.429
INL	19	4	8	2	1	0.789	0.250	0.129	0.230	1.000
ISN	12	5	10	6	1	0.583	0.600	0.326	0.508	0.000
JKL	6	1	5	1	1	0.833	0.200	0.100	0.183	0.000
LAN	49	20	48	21	2	0.592	0.437	0.268	0.423	0.000
LBF	28	3	33	3	12	0.893	0.091	0.052	0.099	0.000
LEX	1	0	7	0	3	1.000	0.000	0.000	0.000	0.000
LND	2	2	7	2	1	0.000	0.286	0.286	0.643	0.000
LNK	10	2	7	4	2	0.800	0.571	0.174	0.386	1.000
LSE	6	4	7	5	1	0.333	0.714	0.526	0.690	1.000
MCI	61	23	44	31	2	0.623	0.705	0.326	0.541	0.000
MKE	65	33	63	35	6	0.492	0.556	0.361	0.532	0.500
MKG	14	1	8	1	0	0.929	0.125	0.048	0.098	
MLI	41	16	43	20	16	0.610	0.465	0.269	0.428	0.500
MQT	42	11	24	12	1	0.738	0.500	0.208	0.381	0.000
MSN	35	19	45	26	7	0.457	0.578	0.389	0.560	0.714
MSP	57	17	35	21	9	0.702	0.600	0.249	0.449	0.889
OFK	19	5	13	5	2	0.737	0.385	0.185	0.324	0.000
OMA	85	23	54	25	17	0.729	0.463	0.206	0.367	0.647
PAH	22	9	16	10	0	0.591	0.625	0.328	0.517	
PIA	51	10	32	11	7	0.804	0.344	0.143	0.270	0.286
PUB	18	1	13	1	1	0.944	0.077	0.033	0.066	0.000
RAP	28	8	31	8	9	0.714	0.258	0.157	0.272	0.222
RFD	33	5	20	4	2	0.848	0.200	0.094	0.176	0.500
RST	14	4	16	5	1	0.714	0.312	0.175	0.299	1.000
SBN	61	33	59	38	5	0.459	0.644	0.416	0.593	0.400
SDF	22	5	16	5	0	0.773	0.312	0.152	0.270	
SGF	98	32	61	38	5	0.673	0.623	0.273	0.475	0.400
SHR	0	0	3	0	0	0.000	0.000	0.000	0.000	
SPI	82	18	33	18	8	0.780	0.545	0.186	0.382	0.875
SSM	24	2	5	2	0	0.917	0.400	0.074	0.242	
STC	39	7	19	8	0	0.821	0.421	0.144	0.300	
STL	140	77	112	87	22	0.450	0.777	0.475	0.663	0.636
SUX	15	5	15	5	3	0.667	0.333	0.200	0.333	0.667
TOP	49	16	37	21	4	0.673	0.568	0.261	0.447	0.750
VTN	2	1	5	4	1	0.500	0.800	0.444	0.650	1.000

AIA ...NO SEVERE ACTIVITY...
CIR ...NO SEVERE ACTIVITY...
EEW ...NO SEVERE ACTIVITY...
GCK ...NO SEVERE ACTIVITY...
LIC ...NO SEVERE ACTIVITY...
MMO ...NO SEVERE ACTIVITY...

SOUTHERN REGION

STN	WRND CNTYS	VERF CNTYS	TOT EVNTS	WRND EVNTS	SIG EVNTS	FAR	POD	CSI	VE	PODS
ABI	56	29	40	32	5	0.482	0.800	0.458	0.659	0.400
ABQ	11	10	7	2	1	0.091	0.286	0.278	0.597	0.000
ACT	63	37	49	39	6	0.413	0.796	0.510	0.691	0.667
AGS	69	3	12	3	1	0.957	0.250	0.038	0.146	0.000
AHN	25	15	28	17	1	0.400	0.607	0.432	0.606	1.000
AMA	52	11	46	13	7	0.788	0.283	0.138	0.247	0.571
AQQ	0	0	2	0	0	0.000	0.000	0.000	0.000	
ATL	114	41	61	38	7	0.640	0.623	0.295	0.491	0.857
AUS	46	7	18	8	0	0.848	0.444	0.128	0.298	
BHM	180	75	113	82	7	0.583	0.726	0.360	0.571	0.714
BNA	47	13	33	14	5	0.723	0.424	0.201	0.350	0.200
BPT	23	9	14	9	1	0.609	0.643	0.321	0.517	0.000
BRO	6	0	16	0	13	1.000	0.000	0.000	0.000	0.000
BTR	27	11	20	12	6	0.593	0.600	0.320	0.504	0.500
CHA	20	12	20	12	0	0.400	0.600	0.429	0.600	
CRP	43	15	23	14	7	0.651	0.609	0.285	0.479	0.571
CSG	43	29	38	30	3	0.326	0.789	0.572	0.732	0.333
DAB	16	5	11	5	4	0.687	0.455	0.227	0.384	0.500
DRT	11	5	7	6	2	0.545	0.857	0.423	0.656	0.500
ELP	12	3	16	3	2	0.750	0.187	0.120	0.219	0.000
ESF	1	1	3	1	0	0.000	0.333	0.333	0.666	
EYW	6	2	6	3	0	0.667	0.500	0.250	0.417	
FMY	0	0	7	0	1	0.000	0.000	0.000	0.000	0.000
FSM	99	52	81	65	11	0.475	0.802	0.465	0.664	0.727
FTW	318	182	253	207	25	0.428	0.818	0.508	0.695	0.840
GLS	7	1	2	1	1	0.857	0.500	0.125	0.321	0.000
HOU	25	8	20	10	1	0.680	0.500	0.242	0.410	0.000
HSV	44	17	32	20	6	0.614	0.625	0.314	0.506	0.833
JAN	277	136	213	151	28	0.509	0.709	0.409	0.600	0.607
JAX	21	2	11	2	2	0.905	0.182	0.067	0.139	0.000
LBB	64	35	51	35	13	0.453	0.686	0.437	0.617	0.769
LCH	46	8	33	9	7	0.826	0.273	0.119	0.223	0.286
LIT	211	77	168	85	26	0.635	0.506	0.269	0.435	0.577
MAF	46	27	52	34	7	0.413	0.654	0.448	0.620	0.571
MCN	70	65	85	72	3	0.071	0.847	0.795	0.888	0.333

MCO	8	6	11	6	3	0.250	0.545	0.462	0.648	0.667
MEI	105	60	75	58	4	0.429	0.773	0.489	0.672	0.500
MEM	118	30	60	28	10	0.746	0.467	0.197	0.360	0.300
MGM	68	46	81	48	4	0.324	0.593	0.462	0.635	0.500
MIA	14	3	3	0	1	0.786	0.000	0.000	0.107	0.000
MOB	79	44	69	47	3	0.443	0.681	0.442	0.619	0.333
NEW	64	14	32	16	3	0.781	0.500	0.179	0.359	0.000
OKC	444	290	405	328	32	0.347	0.810	0.566	0.732	0.750
PBI	0	0	5	0	1	0.000	0.000	0.000	0.000	0.000
PNS	47	7	16	6	1	0.851	0.375	0.119	0.262	0.000
ROW	7	5	19	17	0	0.286	0.895	0.659	0.805	
SAT	78	15	37	16	12	0.808	0.432	0.154	0.312	0.667
SAV	44	8	22	8	4	0.818	0.364	0.138	0.273	0.500
SHV	353	210	275	229	12	0.405	0.833	0.531	0.714	1.000
SJT	42	14	26	15	4	0.667	0.577	0.268	0.455	0.250
SPS	62	36	58	46	3	0.419	0.793	0.504	0.687	1.000
TBW	100	4	36	5	5	0.960	0.139	0.032	0.089	0.200
TLH	33	2	11	2	5	0.939	0.182	0.048	0.121	0.000
TRI	0	0	4	0	0	0.000	0.000	0.000	0.000	
TUL	139	75	115	92	9	0.460	0.800	0.475	0.670	0.556
TUP	72	33	53	35	14	0.542	0.660	0.371	0.559	0.643
TYS	22	2	11	3	1	0.909	0.273	0.073	0.182	0.000
VCT	9	1	4	1	0	0.889	0.250	0.083	0.181	
AYS	...NO SEVERE ACTIVITY...									
CAO	...NO SEVERE ACTIVITY...									
CKL	...NO SEVERE ACTIVITY...									
GGG	...NO SEVERE ACTIVITY...									
HDO	...NO SEVERE ACTIVITY...									
SEP	...NO SEVERE ACTIVITY...									

WESTERN REGION

STN	WRND CNTYS	VERF CNTYS	TOT EVNTS	WRND EVNTS	SIG EVNTS	FAR	POD	CSI	VE	PODS
BFL	0	0	1	0	0	0.000	0.000	0.000	0.000	
BIL	7	0	11	0	7	1.000	0.000	0.000	0.000	0.000
BOI	9	0	14	0	2	1.000	0.000	0.000	0.000	0.000
EKA	2	0	0	0	0	1.000	0.000	0.000	0.000	
EKO	0	0	2	0	0	0.000	0.000	0.000	0.000	
ELY	2	0	3	0	0	1.000	0.000	0.000	0.000	
FAT	0	0	2	0	0	0.000	0.000	0.000	0.000	
FCA	3	1	3	3	0	0.667	1.000	0.333	0.667	
GEG	3	0	1	0	0	1.000	0.000	0.000	0.000	
GGW	10	1	27	2	10	0.900	0.074	0.044	0.087	0.100
GTF	50	14	33	10	5	0.720	0.303	0.170	0.292	0.800
HLN	3	1	14	3	3	0.667	0.214	0.150	0.274	0.000
HVR	4	1	9	3	3	0.750	0.333	0.167	0.292	0.333
LAS	6	1	5	1	1	0.833	0.200	0.100	0.183	0.000

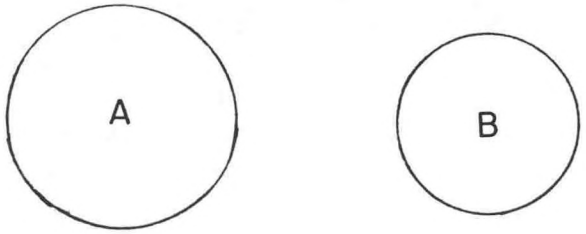
LAX	22	0	4	0	2	1.000	0.000	0.000	0.000	0.000
MSO	16	1	15	1	5	0.937	0.067	0.033	0.065	0.000
PDT	0	0	4	0	0	0.000	0.000	0.000	0.000	
PHX	34	7	23	7	9	0.794	0.304	0.140	0.255	0.333
PIH	11	0	8	0	1	1.000	0.000	0.000	0.000	0.000
RDD	7	0	1	0	1	1.000	0.000	0.000	0.000	0.000
RNO	12	1	8	1	2	0.917	0.125	0.053	0.104	0.000
SAC	6	0	7	0	1	1.000	0.000	0.000	0.000	0.000
SAN	0	0	1	0	0	0.000	0.000	0.000	0.000	
SEA	4	0	2	0	1	1.000	0.000	0.000	0.000	0.000
SFO	3	0	0	0	0	1.000	0.000	0.000	0.000	
SLC	38	7	26	7	3	0.816	0.269	0.123	0.227	0.333
TUS	20	3	14	3	7	0.850	0.214	0.097	0.182	0.143
YKM	0	0	5	0	3	0.000	0.000	0.000	0.000	0.000
YUM	0	0	2	0	1	0.000	0.000	0.000	0.000	0.000
AST	...NO SEVERE ACTIVITY...									
BIH	...NO SEVERE ACTIVITY...									
FLG	...NO SEVERE ACTIVITY...									
INW	...NO SEVERE ACTIVITY...									
IMT	...NO SEVERE ACTIVITY...									
LWS	...NO SEVERE ACTIVITY...									
MFR	...NO SEVERE ACTIVITY...									
OLM	...NO SEVERE ACTIVITY...									
PDX	...NO SEVERE ACTIVITY...									
SMX	...NO SEVERE ACTIVITY...									
WMC	...NO SEVERE ACTIVITY...									

Appendix B

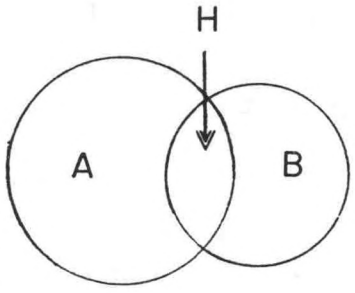
A Graphical Representation of the Critical Success Index

One of the various statistics used to summarize severe local storm warning verification is the Critical Success Index (CSI). The CSI, as defined in Section 2 of this report, is the ratio of successful predictions to the sum of the number of events and false alarms. A graphical representation of this index is helpful in clarifying its meaning and depicting its relationship to the Probability of Detection (POD) and False Alarm Ratio (FAR). Such a graphical illustration has been previously presented for precipitation forecasts (Charba and Klein, 1980).

First, let the number of county warnings issued be represented by the area in circle A. Let the number of severe local storm events be represented by the area of circle B.



Then, the intersection of these two areas, H, represents the number of verified county warnings, or successful predictions. A warning is verified when at least one severe local storm event occurs within the warned county. The area (A-H) represents the number of county warnings that did not verify, or the number of false alarms.



Expressing the definition of the CSI (given above) in terms of the areas in the figures gives

$$CSI = \frac{H}{(A-H)+B} \quad . \qquad (1B)$$

This expression can be rewritten as

$$CSI = [(B+(A-H))/H]^{-1}$$

$$= [(B/H) + (A/H)-1]^{-1} \qquad (2B)$$

With some further manipulation,

$$CSI = [(H/B)^{-1} + (1-(A-H)/A)^{-1} -1]^{-1} \qquad (3B)$$

H/B is equivalent to the POD, and (A-H)/A is equivalent to the FAR.

Substitution into 3B then gives

$$CSI = [(POD)^{-1} + (1-FAR)^{-1} -1]^{-1} \qquad (4B)$$

Thus, the CSI reflects both the POD and the FAR.

No. 8 A Minimum Assumption Tornado Hazard Probability Model. Joseph T. Schaefer, Donald L. Kelly, and Robert F. Abbey, May 1985, 30 p., (PB85 206092/AS).

No. 9 Verification of Severe Local Storm Forecasts Issued by the National Severe Storms Forecast Center: 1984. Preston W. Leftwich, Jr., November 1985, 23 p., (PB86 128105/AS).

No. 10 Severe Local Storm Warning Verification: 1984. Preston W. Leftwich, Jr. and Leo A. Grenier, December 1985, 14 p., (PB86 148244).

No. 11 Severe Thunderstorm Cases of 1985. John E. Hales, Jr. and Hugh G. Crowther, February 1986, 51 p., (PB86 164340/AS).

No. 12 Severe Local Storm Warning Verification Preliminary Procedures. Leo A. Grenier and John T. Halmstad, April 1986, 16 p., (PB86 194362).

No. 13 Verification of Severe Local Storm Forecasts Issued by the National Severe Storms Forecast Center: 1985. Preston W. Leftwich, Jr., November 1986, 9 p., (PB87 137139/AS).

No. 14 Severe Local Storm Warning Verification: 1985. Preston W. Leftwich, Jr. and Leo A. Grenier, December 1986, 16 p., (PB87 137147/AS).

No. 15 An Examination of the National Weather Service Severe Local Storm Warning Program and Proposed Improvements. John E. Hales, Jr., January 1987, 32 p., (PB87 147948/AS).

No. 16 Severe Thunderstorm Cases of July 1985 through June 1986. John E. Hales, Jr. and Hugh G. Crowther, February 1987, 72 p., (PB87 163911/AS).

No. 17 Severe Local Storm Warning Verification: 1986. Leo A. Grenier, John T. Halmstad and Preston W. Leftwich, Jr., June 1987, 19 p., (PB87 195939).

No. 18 Verification of Severe Local Storm Forecasts Issued by the National Severe Storms Forecast Center: 1986. Preston W. Leftwich, Jr., September 1987, 9 p., (PB88 101407).

*U.S.Government Printing Office:1989-657-394/23

No. 19 Severe Thunderstorm Cases of July 1986 through June 1987. John E. Hales, Jr. and Hugh G. Crowther, April 1988, 83 p., (PB88 214085).

No. 20 Severe Local Storm Warning Verification: 1987. Leo A. Grenier, John T. Halmstad and Preston W. Leftwich, Jr., June 1988, 19 p., (PB88 241393).

No. 21 Verification of Severe Local Storm Forecasts Issued by the National Severe Storms Forecast Center: 1987. Preston W. Leftwich, Jr., December 1988, 18 p., (PB89 159719/AS).

No. 22 Severe Thunderstorm Cases of July 1987 thru June 1988. John E. Hales, Jr. and Hugh G. Crowther, April 1989, 98 pp.

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