Some Trends in Forecast Skill at the National Severe Storms Forecast Center

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Abstract

Tornado watch and severe local storm outlook verification statistics reveal the trends in forecast skill at the National Severe Storms Forecast Center. The skill level of the outlook has been steadily increasing since 1973. The percentage of watches verifying has been gradually increasing since 1970. While the probability of detection for tornadoes has decreased slightly since 1974, this appears to be highly correlated with the number of outbreak tornadoes reported in a given year. During significant tornado days, a much higher degree of skill is exhibited for both outlooks and watches. Factors influencing the results are discussed, including the impact of snoptic scale operational numerical prediction models on the severe local storm forecasting process.

1. Introduction

Since the implementation of numerical weather prediction techniques 20 years ago, a steady increase has been noted in the accuracy of forecasts of synoptic scale systems (Fawcett, 1977; Shuman, 1978). The skill in predicting the 36 h circulation pattern at 500 mb has roughly doubled since the 1950s. Beginning with the first operational primitive equation model (Shuman and Hovermale, 1968) similar improvements in forecasting the sea level pressure patterns have occurred.

However, there is evidence that the quality of operational public forecasts is not improving (Pierce, 1976; Cook and Smith, 1977), and may even be somewhat declining (Snellman, 1977). Forecasting experiments at several universities provide similar results (Sanders, 1973; Bosart, 1975). It appears that the numerical guidance has improved at a faster rate than the man-made forecasts have. Further, these studies tend to confirm the contention of Brown and Fawcett (1972) that "the better the numerical prognosis, the more difficult it is to improve manually with any degree of success."

Most of the previous studies have focused on general forecasting, especially temperature and precipitation forecast trends. This paper will examine the level of skill demonstrated at the National Severe Storms Forecast Center (NSSFC) in forecasting severe local storms, including outbreaks of tornadoes.

2. The forecast program at NSSFC

The Severe Local Storms (SELS) Unit at NSSFC has responsibility for issuing severe local storm outlooks and severe thunderstorm and tornado watches for the contiguous United States. The outlooks are issued twice daily at 0830 and 1500 GMT for the period lasting until 1200 GMT the next day. They specify areas and densities of expected severe thunderstorm occurrences (tornadoes, waterspouts, large hail, damaging wind gusts, and extreme turbulence). Also, since 1974, an afternoon outlook has been issued between 1 February and 31 August.

A graphic version of the 0830 GMT outlook is transmitted daily on the national facsimile circuit between 1 February and 31 August and whenever severe local storms are forecast between 1 September and 31 January. A narrative version of all outlooks is transmitted via the Radar Report and Warning Coordination Circuit (RAWARC) to all National Weather Service (NWS) offices. The outlooks provide preliminary guidance on expected severe local storm development and are used by Weather Service Forecast Offices in preparing state, zone, and local forecasts. The severe local storm outlooks constitute the first step in the NWS Severe Local Storms Forecast Program.

The second step is the severe local storm watch. Watches, unlike the outlooks, are issued when needed (not at regularly scheduled times). The average watch is valid for approximately 6 h and covers a rectangular area of ~65 000 km² (25 000 mi²). Watches may be issued several hours prior to the expected onset of severe convection; the average lead time, however, is around 30 min.

The watch is formulated to notify NWS offices, disaster preparedness and storm spotter groups, law enforcement agencies, and the general public to be prepared to implement safety precautions should a warning be issued. NSSFC transmits the watch to the local NWS offices, where additional dissemination occurs. A detailed discussion of the NWS's Severe Local Storm Warning and Disaster Preparedness Program can be found in Mogil and Groper (1977).

To accomplish the severe local storm forecasting mission, members of the SELS staff have a number of techniques to aid in the forecast process. Prognostic guidance from the National Meteorological Center (NMC) includes output from primitive equation numerical models such as the Limited Area Fine Mesh (LFM) (Gerrity, 1977). Short range (2–6 h) severe local storm probabilities (Charba, 1979), as well as medium range (12–36 h) probabilities (Reap and Foster, 1977) are produced using the classical statistical method and the method of Model Output Statistics (MOS) (Glahn and Lowry, 1972). Medium range severe local storm probabilities are also produced at NSSFC (David, 1974).

Diagnostic aids include computer plotted surface weather maps from which detailed mesoanalyses are made (Magor, 1958, 1959, 1971; House, 1964; Mogil, 1978). Upper air maps are also computer plotted and analyzed twice daily. Requests for special rawinsonde observations can be made when widespread severe local storms are anticipated.

Several derived meteorological quantities unique to NSSFC are also available. These include objective analyses of 500 mb absolute vorticity and vorticity advection (which are not influenced by first guess fields), upper tropospheric mean divergence (McNulty, 1978a), and automated analyses of upper air soundings (Prosser and Foster, 1966), including airmass stability (Galway, 1956). Low level properties include surface moisture convergence (Hudson, 1971), surface geostrophic winds (Sangster, 1960), and hourly tendencies of temperature, dewpoint, and altimeter setting (i.e., Carr, 1955; Mogil, 1975).

A colocated Satellite Field Services Station provides high resolution enhanced infrared and visible satellite pictures at frequent intervals, plus specialized interpretation of the imagery. These data can provide important information needed to evaluate and update the numerical guidance (Ferguson and Mathews, 1978; Hales, 1978). An image analyzer computer system provides continuous movie loops of the satellite imagery to aid the interpretation process.

Finally, the National Aviation Severe Weather Radar Analysis Unit at NSSFC provides hourly analysis of weather radar data in the contiguous United States. This unit has ably assisted SELS for many years (Darrah, 1978), and has often been invaluable in recognizing convection which may be associated with severe local storms.

3. Tornado watch statistics

Galway (1967) presented verification statistics for the period 1952–66. This evaluation has been continued and Fig. 1 presents tornado watch verification for the period 1967–77. A tornado occurring within the watch area during the valid time of the watch is considered to

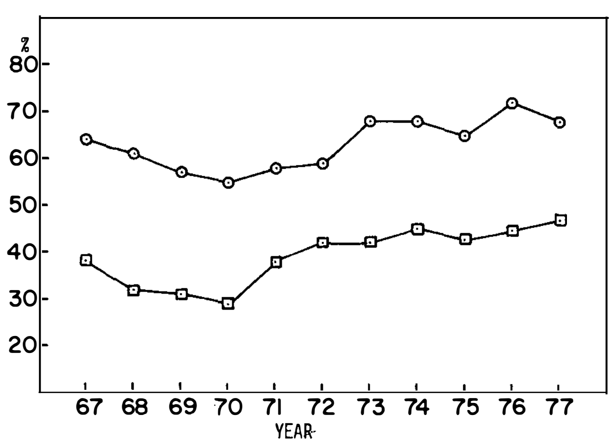

FIG. 1. Percentage of tornado watches verifying (squares). Close reports included in top graph (circles).[2]

[2] Lines connecting points on all graphs are intended to facilitate the visual interpretation of the data, rather than to suggest continuous data.

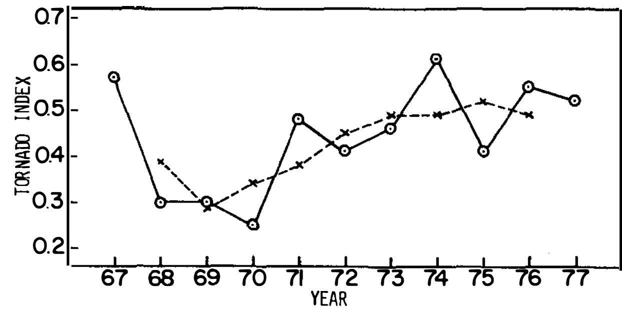

FIG. 2. Tornado index (circles) and three year running average (crosses).

verify the watch. (Note that neither large hail nor damaging thunderstorm wind gusts verify a tornado watch.) A general increase in skill is apparent during the 11-year period. The percentage of watches verifying rises from around 30% in the late 1960s to over 40% during most of the 1970s. When tornadoes close to the watch area are included, a much higher number of watches verify, rising to around 65% since 1973.

We have shown that the percentage of tornado watches verifying has increased during the 1970s. This implies that the forecasters are exhibiting better recognition of tornado-producing synoptic patterns. Further evidence of the improvement in watch verification is illustrated by the tornado index (Fig. 2). The tornado index is the number of tornadoes per unit area of ~26 000 km² (10 000 mi²) per unit time (6 h) that occur within valid watches. A tornado index of 1.0 is obtained when one tornado is reported inside of a watch of 10 000 mi² area valid over a 6 h period. The three year running average smoothes out variations in the index caused in part by climatological variations from year to year. Since 1969, the running average shows a general increase in skill.

The probability of detection (POD) is simply the percentage of tornadoes occurring within valid watch areas, and is shown in Fig. 3. Since 1968, yearly POD values have ranged from around 0.20 to 0.35, with a wide variation often found from year to year. However, a generally increasing trend is present. When tornadoes close to the

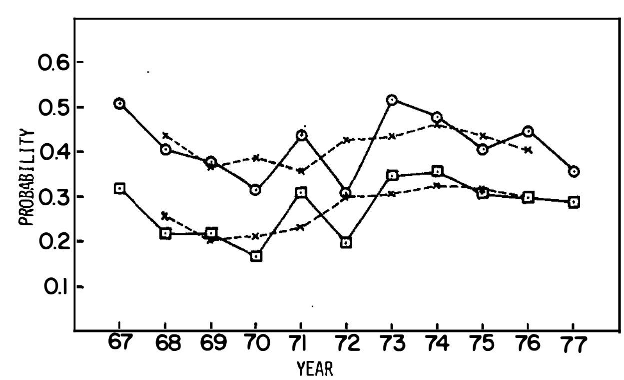

FIG. 3. Probability of detection for tornadoes (squares) and three-year running average (crosses). Close reports included in top graph (circles).

watch area are considered, the POD rises significantly, averaging around 0.42.

Further statistics were compiled exclusively for tornado outbreak days, and are taken primarily from Galway (1978). In this paper, an outbreak is defined in the same way as by Galway (1977), with 10 or more tornadoes occurring in an organized temporal and spatial manner. Thus, the occurrence of 10 or more tornadoes will not by itself constitute an outbreak. The verification was performed on watches issued or in existence during the time span and in the area of the outbreak. In general, more than 60% of the outbreak watches have verified since 1967 (Fig. 4), with an 11-year average of 66%. The POD for outbreak tornadoes oscillates somewhat on a yearly basis; the 11-year average is 0.58 (Fig. 5). It is significant that these results for outbreak days reveal an impressively higher degree of skill when compared to all tornado days.

This increase in skill becomes even more important when considering tornado deaths associated with outbreaks. Since 1967, nearly 70% of all tornado deaths (808 out of 1162) occurred during outbreaks. Thus, the SELS Unit has shown an ability to forecast significant severe local storm episodes.

4. Discussion and evaluation of the watches

The forecasting of relatively rare weather events, such as severe local storms, involves procedures not normally used in other types of forecasting. Similarly, the verification of these forecasts must be processed and interpreted in special ways. When first examining the verification data, it may appear that the level of skill in tornado forecasting is not as high as one might expect. However, it must be remembered that the severe local storm forecaster is dealing with situations in which the climatological chance for positive verification is much lower than is true for other types of forecasting (House, 1963; Galway, 1967; Kessler, 1970).

The complex problem of interpreting the verification results is compounded by a number of interrelated factors influencing the forecast itself. These factors include personnel changes and the associated experience level of the forecasters; data acquisition and display procedures, including remote sensing applications; forecast dissemination procedures; and even varying philosophies pertaining to the optimum watch characteristics. Owing to the highly subjective decision-making process in tornado forecasting, it is impossible to account for every change in skill level demonstrated in the statistics. When feasible, however, possible factors influencing the results will be mentioned.

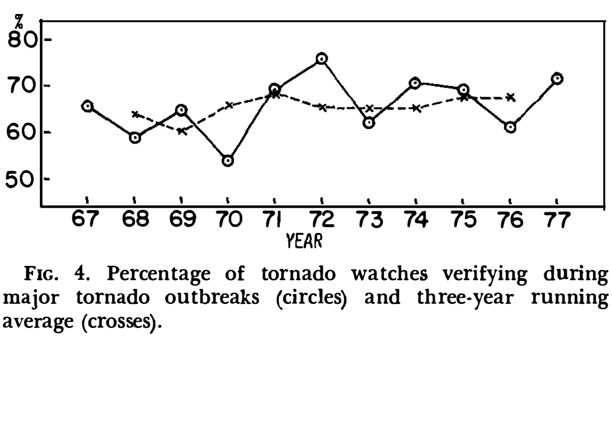

FIG. 4. Percentage of tornado watches verifying during major tornado outbreaks (circles) and three-year running average (crosses).

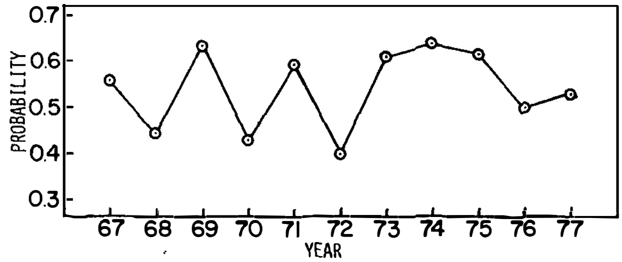

FIG. 5. Probability of detection for tornadoes during major tornado outbreaks.

It can be argued that the larger the watch area, the better chance a watch has to verify. That is, a tornado originally close to a watch spatially could become a "hit" if the size of the watch is increased. In this way, the likelihood of verifying a watch would be proportional to its area. Figure 6 shows that the average area of tornado watches has generally become larger during the 11-year period. This trend agrees with that of the verification percentage (Fig. 1). Note, however, that the trend to larger areas does not affect the tornado index statistics (Fig. 2), since the index is normalized per unit area.

Lead time is defined as $t_i - t_v$, where t_i is the watch issue time, and t_v is the beginning of the valid period of the watch. The greater the lead time, the more uncertainty there can be in the forecast. A watch with a long lead time is likely to be issued prior to the development of convection, whereas a watch with little or no lead time is normally predicted on existing thunderstorm activity.[1]

The yearly average lead time is shown in Fig. 7. Lead times steadily decreased through 1974, with a gradual increase noted the last several years. The years with the lowest average lead times, 1973 and 1974, also reported the highest PODs (Fig. 3). Further, a comparison of lead time with tornado index (Fig. 7) reveals the same approximate inverse relationship.

A more significant factor affecting yearly statistics may be the number of tornadoes associated with severe local storm outbreaks. Recalling that a higher degree of forecast skill is exhibited during outbreak episodes, it is logical to investigate the possible impact outbreaks have on the verification results. Figure 8 shows the total number of tornadoes reported by year, including those associated with outbreaks. Note that the number of nonoutbreak tornadoes remains relatively constant during the period, whereas the number of outbreak tornadoes

[1] A certain amount of lead time is usually required to allow for proper dissemination of the watch prior to the onset of severe local storms. However, too long a lead time may desensitize the public and reduce the effectiveness of the watch. The optimum lead time remains a matter of conjecture, but the authors believe it should be around 2 h.

fluctuates widely. It appears that the total number of tornadoes per year is highly dependent on the number of outbreak tornadoes, with the years exhibiting a great number of outbreak tornadoes also being the years with the largest tornado total. Figure 9 reveals that the years with a higher number of tornadoes, reflecting more outbreak events, also have the highest probability of detection. This is not felt to be a random occurrence, but a result of the higher forecast skill present during outbreak conditions.

5. Severe local storm outlook statistics

An objective scheme to verify the severe local storm outlooks has been devised. It is based upon a modified version of the critical success index (Donaldson *et al.*, 1975). All weather events can be divided into four groups: x—severe local storms correctly predicted, y—severe local storms not predicted, z—nonsevere weather predicted to be severe, and w—all other events which are accurately predicted.

In this notion, the probability of detection (POD) can be written as

$$\text{POD} = x/(x + y).$$

Note that the POD is identical to the "prefigurance" discussed by Panofsky and Brier (1958). A perfect forecast has a POD of one.

The false alarm ratio (FAR), written as

$$\text{FAR} = z/(x + z),$$

is the proportion of false predictions of a severe event. The FAR is also equal to (1 − "postagreement") where the postagreement is as defined by Panofsky and Brier (1958). A FAR of zero indicates a perfect forecast.

The critical success index (CSI), defined to be

$$\text{CSI} = x/(x + y + z) = [(\text{POD})^{-1} + (1 - \text{FAR})^{-1} - 1]^{-1},$$

is the ratio of successful predictions to the sum of the number of severe events and false alarms. The CSI is also known as the "threat score" (Palmer and Allen, 1949) and ranges from zero to one, with higher values indicating better forecasts. The CSI was devised to verify objectively the prediction of a severe storm event at a given point in space. However, severe local storm outlooks issued by SELS often cover several hundred thousand square miles for time periods up to 24 h.

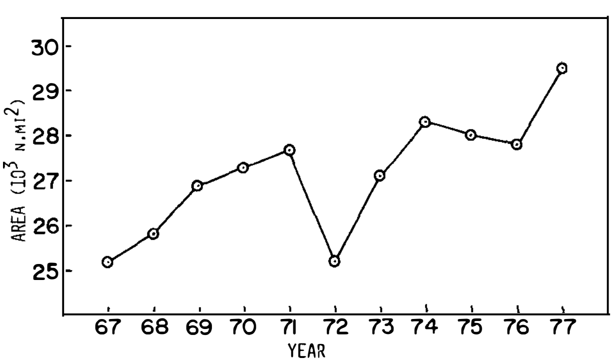

FIG. 6. Average area of tornado watches (10^3 n. mi^2).

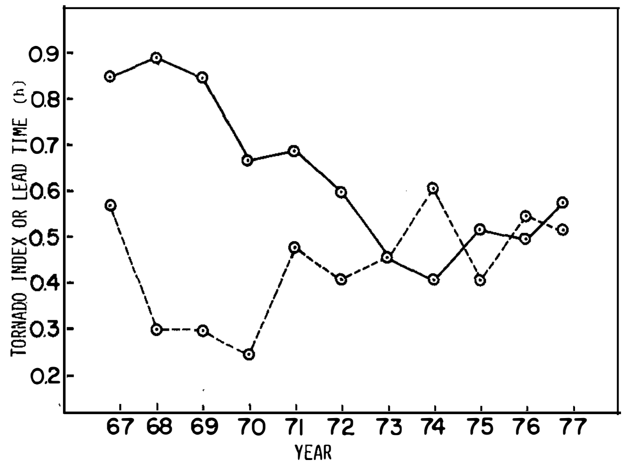

FIG. 7. Average lead time in hours (solid) and tornado index (dashed).

It has been found that a modification of the CSI is necessary to provide a meaningful measure of skill in severe local storm outlooks. Briefly, the modified form of the CSI incorporates both the percent of severe local storms that occurred within the outlook area (POD) and a measure of the postagreement. The postagreement is empirically modified to produce a meaningful false alarm ratio that considers the effect of over- and underforecasting. For details, see Weiss (1977).

Figure 10 presents yearly verification results for the 0830 GMT severe local storm outlook. A general increase in the level of skill in predicting severe events has occurred since 1973. The POD rises 12% during the 5-year period, with a corresponding decrease in the number of false alarms. With the exception of 1976, a steady increase in the CSI is apparent. The higher FAR in 1976 is responsible for the drop in overall skill that year.

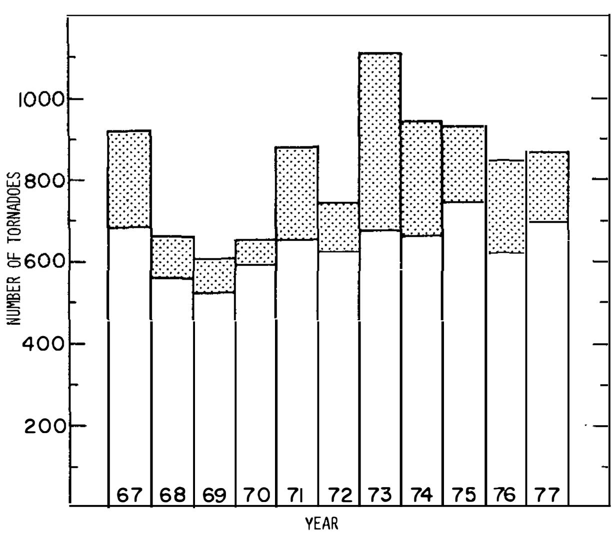

FIG. 8. Total tornadoes, including those during major tornado outbreaks (stippled).

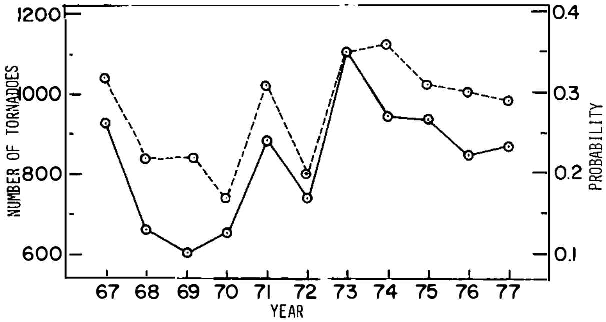

FIG. 9. Yearly tornado totals (solid) and probability of detection for tornadoes (dashed). Left scale refers to number of tornadoes and right scale to probability of detection.

During the period 1973–77, over 82% (490 out of 595) of all tornado deaths occurred on days with 10 or more tornadoes. Therefore, statistics have been compiled for situations when 10 or more tornadoes occurred during the severe local storm outlook period (Fig. 11). According to Galway (1977), these days cannot be strictly classified as outbreak days since the classification is by number of tornadoes only. (Spatial and temporal considerations have been ignored). Nearly 60% of the days in this section meet the Galway outbreak criteria, with all true outbreaks (total of 67) included in the data.

The severe local storm outlooks for days with 10 or more tornadoes showed a POD of greater than 0.45, with a sharp increase over the last two years. The FAR of around 0.23 is significantly better than it is on the average tornado day. The resulting CSI is generally above 0.40, with an impressive increase in the skill level during 1976 and 1977. Comparing these statistics to those for all days, it is seen that considerably greater skill exists in forecasting days with considerable tornadic activity.

6. Discussion and evaluation of the outlooks

From Fig. 10, it is seen that the average POD for the 0830 GMT outlook is just under 40% during the 5-year period. However, it exhibits wide fluctuations during the year. Greatest skill occurs during the spring months when over 50% of all severe events are correctly forecast. Similarly, CSI indicates the greatest skill in prediction from March into June. During this time of year, the climatological probability of having 40 or more severe reports on a given day is at a maximum (Wilson, 1977).

Thus, our forecasting ability is best when tornado risk is highest. This is most likely the result of favorable thermodynamic and hydrodynamic conditions on the synoptic scale, which can often be correctly anticipated by the experienced severe local storm forecaster. On the other hand, the problems of forecasting severe local storms in the summer months are well known (Miller, 1972). Major weather systems are generally weak during this time of the year, and with moist unstable air widespread over much of the nation, confinement of potential severe local storm areas is extremely difficult. Summer forecasting must also deal more frequently with the occurrence of severe storm events under northwest flow aloft, an atypical and often subtle severe local storm pattern that can produce widespread reports (Johns, 1977).

Other statistics indicate increasing skill on updated outlooks, i.e., subsequent outlooks, on the same day (Weiss, 1977). During most of the year, the increase in skill is most noticeable in the afternoon (1930 GMT) outlook.

In general, an increase in the level of skill for the medium range prediction of severe events has occurred since 1973. This can be attributed to an increase in the experience level of the SELS forecasters issuing the outlook as well as the improved numerical models generated by NMC. A major problem in anticipating severe local storm situations involves correctly forecasting synoptic patterns known to produce severe events. The improved accuracy of the numerical output, especially the LFM model, has made it less difficult for the SELS forecasters to assess the severe local storm threat properly.

A semiobjective technique to evaluate LFM output in relation to severe local storm potential (David, 1976) has been developed. Using this as guidance, there is less variation in the forecast method and consequently a more consistent outlook.

7. Summary and conclusions

Verification statistics have been examined to determine the trends in forecast skill at the National Severe Storms Forecast Center. The forecasts studied included the short range tornado watches and the medium range severe local storm outlooks.

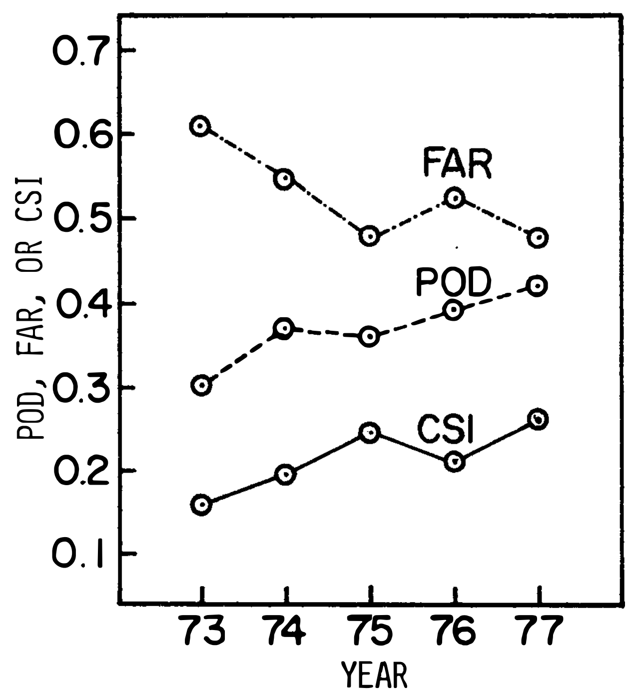

FIG. 10. Average probability of detection (dashed), false alarm ratio (dot-dashed), and critical success index (solid) for the 0830 GMT severe weather outlook.

The verification data indicate that since 1973 the skill level of the severe local storm outlook has been generally increasing. The greatest skill is apparent during the spring and early summer. It is during this time that the most significant severe local storm episodes generally occur. On days when 10 or more tornadoes occur, a much higher degree of skill is present.

Much of this increase in skill can be attributed to the improved numerical models at NMC, especially the LFM (van Haaren, 1978). Since medium range severe local storms forecasting is partially a problem in synoptic pattern recognition, the use of the LFM output enables the forecaster to accept the overall pattern and concentrate on the smaller scale details crucial to the forecast (i.e., speed of movement of mid tropospheric short wave troughs, low level moisture advection, airmass destabilization, etc.).

Tornado watch statistics reveal that the percentage of watches verifying has been gradually increasing since 1970. The probability of detection (POD) for tornadoes has shown a small decrease since 1974; however, this appears to be highly correlated with the number of outbreak tornadoes reported in a given year. A much higher degree of skill is illustrated during tornado outbreaks, when two-thirds of all watches verify. The POD during outbreaks is more than twice the POD on less significant tornado days. Nearly 70% of all tornado deaths occurred during outbreaks in the 11-year period.

While a slight improvement trend is suggested by the verification, it has not kept pace with the major advances in large-scale numerical weather prediction and remote sensing of the atmosphere during the last decade. This is because short range tornado forecasting, by either subjective or objective methods, requires the inference of small-scale atmospheric processes from synoptic scale data.

Operational numerical weather prediction models continue to be restricted to synoptic scale forecasts. Some attempt has been made to forecast severe local storm occurrence by statistical methods using diagnostic analysis and large scale model output (Charba, 1979; Reap and Foster, 1977; David, 1974). While this objective guidance is helpful, the relationship between the synoptic scale and smaller scale features remains uncertain (Anthes, 1976). Further, the potential of these statistical methods is inherently limited by the lack of resolution of the parent numerical models and the predictive value of aviation surface and radar observations. The standard upper air observational network cannot meet the requirements to detect mesoscale systems (House, 1960, 1964; Pearson, 1976; American Meteorological Society, 1976; Pielke, 1977). Further, the available data have decreased by 10–15% over the last two decades, as evidenced by cutbacks in the rawinsonde, pibal, and hourly aviation observational programs. While satellite data have often proved invaluable in locating low level boundaries conducive to convective development as well as the actual convection itself, the imagery mainly supports the forecaster's *diagnostic* effort.

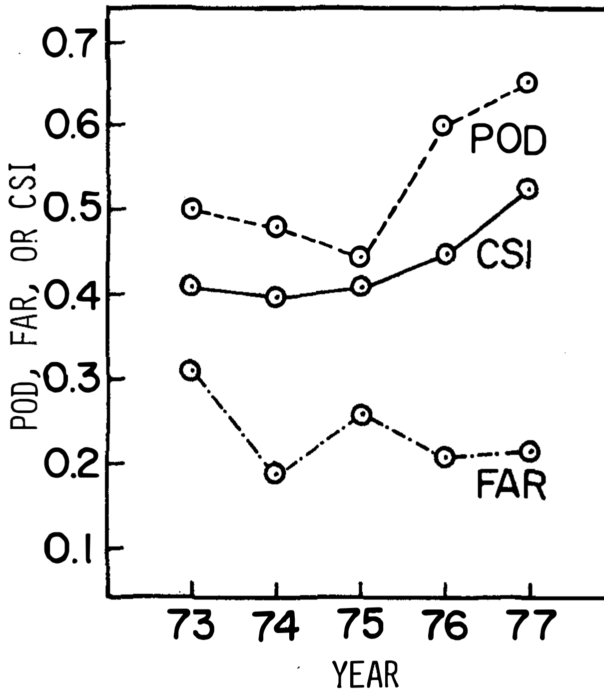

FIG. 11. Same as Fig. 10, except on days with 10 or more tornadoes.

It appears that significant improvements in severe local storm forecasting must be based upon a rigorous, objective approach to the understanding of subsynoptic circulations and their physical relationship to large-scale flow patterns (i.e., Doswell, 1976; Schaefer, 1977; Fritsch and Chappell, 1978; Schaefer *et al.*, 1979). Dynamical relationships between mesoscale systems must be inferred from both satellite imagery (Lemon, 1978) and synoptic scale development as depicted by large-scale numerical models (McNulty, 1978b). To accomplish this, further advances in computer power are necessary (Kreitzberg, 1976a). Major improvements in the mesoscale prediction process are then likely to be realized by combing data from new satellite systems with nested mesoscale models (Kreitzberg, 1976b). Owing to the computational limits, future operational numerical models will be restricted to the "regional" scale. Specific mesoscale forecasts will still require a man-machine mix (Fritsch and Kreitzberg, 1978). When this type of system becomes operational, the need for experienced forecasters with an aptitude for subsynoptic scale analyses will continue (Ramage, 1976).

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