Improved Accuracy in Severe Storm Forecasting by the Severe Local Storms Unit during the Last 25 Years: Then versus Now

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ABSTRACT

The purpose of this paper is to review the large strides made in tornado and severe thunderstorm forecasting by the Severe Local Storms Unit (SELS) of the National Severe Storms Forecast Center during the last 25 years or so of its existence. The author compares and illustrates the tools available to the SELS forecasters in the early 1970s versus those of the 1990s. Also discussed is the transition over the years from a largely empirical forecast approach to an approach based strongly on physical reasoning. The evolution of the computer systems employed at SELS and their impact on the forecast operation are traced. With the advent of interactive computer processing capability, SELS forecasters were able to assess the potential for severe convection with much greater precision than ever before. Noteworthy was the improvement brought about by the automation of largely clerical tasks, allowing the forecasters more time to focus on the forecast problem at hand. In addition, the forecast staff was able to devote more time to relevant research projects and benefit from the significant advances taking place in improved understanding of mesoscale processes. Verification results are shown to validate the notion that these advances led to better predictions. For example, the watch accuracy in terms of percent of severe weather watches verified rose from 63% in 1975 to 90% in 1996. Finally, information is given showing important milestones in the history of SELS and a list of the lead forecasters whose experience, judgment, and forecast skill brought about these improvements.

1. Introduction

The Severe Local Storms (SELS) Unit, an organization dedicated to severe local storm forecasting for the 48 conterminous states was established in Kansas City, Missouri, in 1954 after a two-year maturation period at the U.S. Weather Bureau's Weather Bureau–Air Force–Navy (WBAN) Analysis Center in Washington, D.C. It became part of the Storm Prediction Center (SPC) in 1995 and remained in Kansas City until 1997 when it was moved to Norman, Oklahoma. During the 43-year tenure in Kansas City, numerous major changes took place in forecast products, computer systems, and personnel. For a chronological listing of relevant milestones during the existence of SELS see appendix A. This article focuses on the latter half of the SELS era when the most significant enhancements in procedures and computer systems took place.

The primary mission of SELS was to issue tornado or severe thunderstorm[1] watches when the forecaster felt there was a strong potential for severe convection over a specific geographical area, generally comprising approximately 65 000 km^2 (25 000 mi^2). The watches usually became valid around an hour after issuance and focused on the time interval of about 2–7 h ahead. The watch area generally took the form of a parallelogram and was defined by specifying two geographical locations as ‘‘anchor points’’ at the ends of the major axis and a half-width of the ‘‘watch box’’ (e.g., 70 mi either side of a line from city A to city B). The watch process has played an important role over the years in support of the National Weather Service's (NWS) severe weather warning program (Hales 1990).

As part of the watch process, a preliminary step in the forecasting of severe convection (then, as now) was the periodic routine issuance of convective outlooks that covered time periods of up to 24–48 h in advance. The purpose of the outlook was to delineate areas where

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[1] The SELS definition of a severe thunderstorm is one that produces hail ¾ in. in diameter or greater, or surface wind gusts of 50 kt or more, or thunderstorm winds that cause significant damage.

severe convection was likely to develop that might require the later issuance of watches (Ostby 1979). In the early days of SELS operation there were only two routine outlooks per day with an update issued at 1930 UTC between 1 February and 1 September.

The assignment of responsibilities within the unit over the years went through several changes, but an operational shift basically consisted of one lead forecaster and two assistant forecasters. The lead forecaster's primary responsibility was assessing the potential of severe convection and issuing severe weather watches as needed. The lead also was responsible for overall shift supervision. A list of SELS lead forecasters who had this important responsibility covering the period from 1972 through 1995 is given in appendix B. The assistants handled most of the convective outlooks and the various semiclerical tasks of report logging and archiving of issued watches. Even so, the assistants also provided considerable input into the forecast process, since the group operated as a team, although the lead had the ultimate responsibility for watch issuance.

Along with the increased computer capability that materialized during the 1980s and early 1990s, came the ability to increase the frequency of convective outlook issuances and add new forecast products (Ostby 1992). A mesoscale meteorologist was added in 1988 whose primary function was to bridge the gap between convective outlooks and watches by providing users with information on trends in convective activity and pointing out ‘‘hotspots’’ that might later require watches.

2. Procedures in the 1970s

a. Meteorological diagnosis

The meteorological information available to the SELS forecasters in the early 1970s seems rather primitive by today's standards. Hourly surface maps were generated on a CDC 3100 computer that ingested data from a dedicated communications line from the Federal Aviation Administration's (FAA) central computing facility. The plotted map was produced as a computer printout with a preprinted geographical background. The station model was limited to the character set that the printer in use during that era could generate (Fig. 1). Upper-air charts were produced in a similar fashion. Maps of this type were used for many years and as recently as 1990 when the use of PC technology made it possible to generate maps with the standard station model used today. Other than the basic numerical weather prediction (NWP) model output from the National Meteorological Center [NMC, now known as the National Centers for Environmental Prediction (NCEP)], derived products that are so readily obtainable now, such as convective available potential energy (CAPE), **Q** vectors and other applications of quasigeostrophic theory, and storm-relative helicity, to name a few, were virtually nonexistent or extremely difficult and time consuming to produce. By referring to a case study by Ostby (1975), one can sense the limited nature of diagnostic–prognostic guidance products accessible to the severe storms forecaster during the early 1970s. In addition to conventional data, one of the very few derived diagnostic products that the SELS forecasters could generate was hourly surface moisture convergence (Hudson 1971). Even at that, the output from the moisture convergence program was not available until 30 min after data time. For prognostic information, synoptic-scale numerical model products from the NMC were routinely received. Also as part of the operational data stream were two severe weather probability products for the short range, that is, 2–6 h (David 1973; Charba 1979), and a longer-range (12–36 h) probability product that was tailored for the convective outlook time frame (Reap and Foster 1979). Compare that, for example, with the many important parameters routinely produced currently, as depicted in the case study by Hales et al. (1997).

The primary source of radar information was from the radar summary chart (Fig. 2), which was produced manually at the National Severe Storms Forecast Center (NSSFC) by a special Radar Analysis and Development Unit (RADU) staffed by meteorological technicians plotting coded observations from individual radar sites from the operational weather radar network. Subsequent technological advances and the introduction of manually digitized radar (MDR) data at radar sites enabled the radar summary chart to be automated and centrally produced beginning in 1978 (Fig. 3).

A satellite field services station (SFSS) of the National Environmental Satellite, Data and Information Service collocated with SELS provided satellite information and interpretation. It was another data handling method to be outmoded by later technological advances. At the time, 16-mm movie loops of satellite imagery were constructed and shown to the SELS meteorologist at regular intervals. Hard copies of the satellite data were also provided and discussed periodically. Yet, the latest image available to the forecaster was seldom less than one hour old. Forecast guidance products and model data from NMC came mainly from facsimile charts. Needless to say, these various time-consuming procedures seriously limited the forecaster's ability to deal with relatively short-fused mesoscale phenomena.

b. Watch preparation and dissemination

When the SELS forecaster made the determination that a potential for severe local storms existed, the next steps included sketching the outline of the watch on a map, typing the text, and, finally, disseminating the watch. The pertinent information, extracted from the map, such as the ‘‘anchor points,’’ width of the ‘‘box’’ (the polygon-shaped area comprising the watch area), as well as the beginning and ending times, were the basic parameters manually entered on a typewriter. The

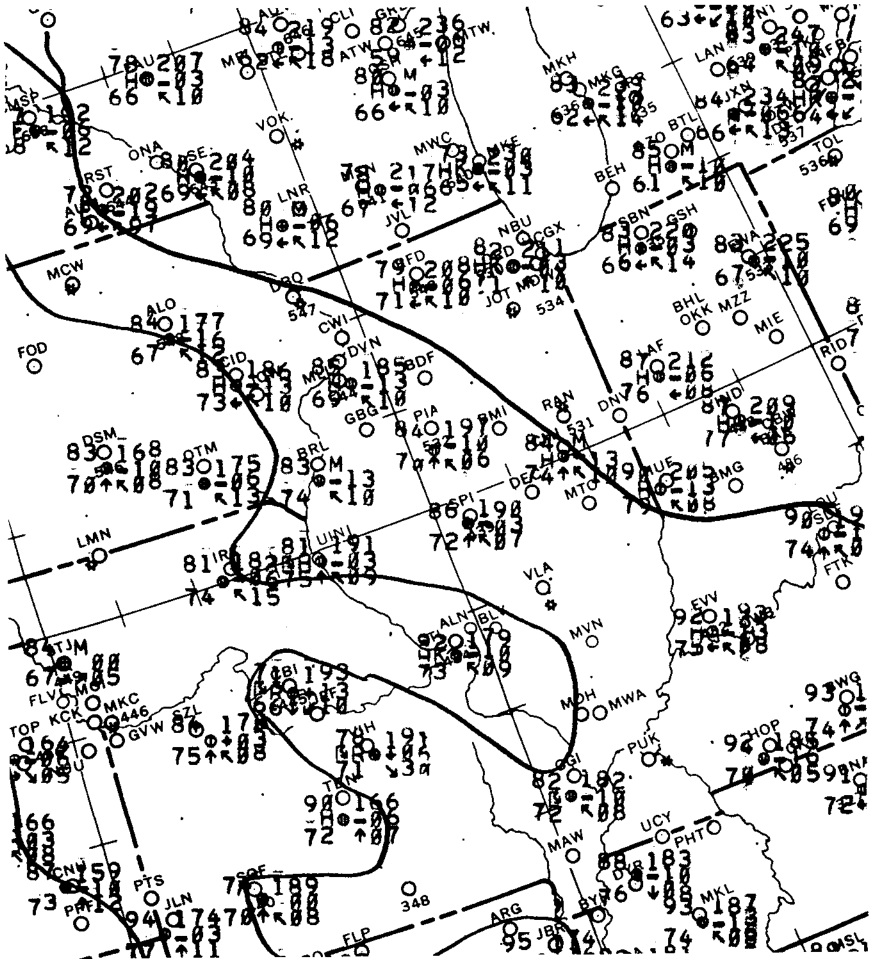


FIG. 1. Computer-generated surface chart of the 1970s. Printer paper contained a geographical background for plotting station data in the proper location. Character set of the era limited what fonts could be plotted. Note old ''airways surface observation style'' of symbols for wind direction in lieu of wind barbs.

final step was for a communications specialist to copy the same information onto punched paper tape for entry into the weather service's teletypewriter system for dissemination. It was not unusual for this process from watch conception to dissemination to consume more than 30 min. For this reason an alerting preliminary notification product, known in house as the ''quickie,'' was transmitted to field offices giving the area to be included in the upcoming watch and the time frame. This cumbersome procedure was partially streamlined in the late 1970s when the watch information was entered using a computer terminal. The terminal produced the paper tape without needing to be retyped by a communications specialist.

c. Data archiving

Both watches and severe weather events were needed to be archived to build a database for climatological studies and verification statistics. This was a sizable labor-intensive process. Each watch issued was plotted by an assistant forecaster on a separate 8.5 in. × 11 in. map section and included a tabulation of watch issue time, beginning time, duration, as well as the latitude–longitude of the two anchor points, half-width of the watch, and forecaster number (Fig. 4). The determination of this set of latitude–longitude pairs was no trivial task (see below). Computer operators keypunched the information that was subsequently batch processed on a daily basis and stored in the computer.

Logging of severe weather events (tornadoes, large hail, or damaging winds from thunderstorms) was another labor-intensive procedure. Every reported severe weather event that was received at SELS was manually entered onto a daily ''flysheet'' as near to real time as possible (Fig. 5). Along with the flysheet, a daily activity chart was maintained. This map showed the location of the events, any watches that were issued, and all convective outlooks pertaining to that day (Fig. 6). There were two purposes for the event logging. First, it enabled

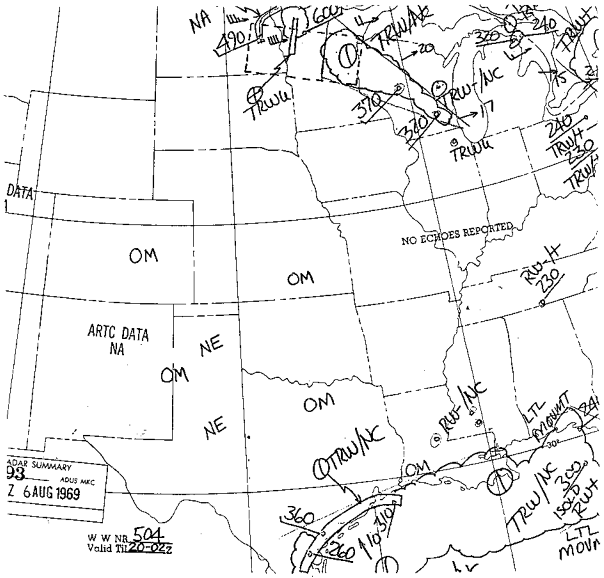


FIG. 2. Typical radar summary chart manually plotted until replaced by automated version in 1978 (see Fig. 3).

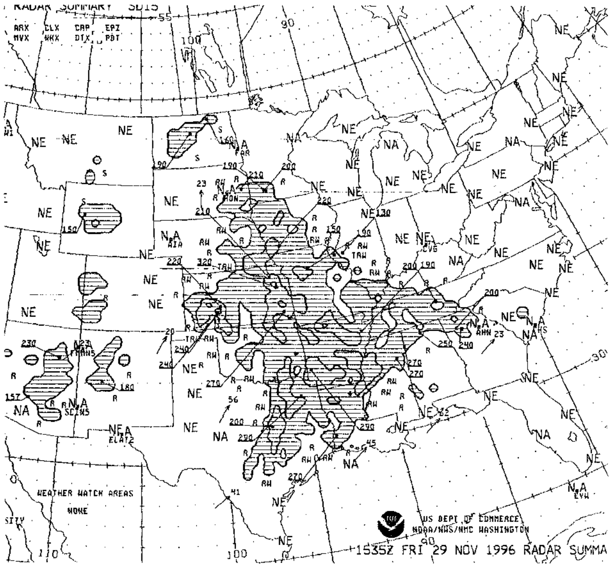


FIG. 3. Example of an automated radar summary chart generated from MDR reports.

the SELS forecaster to keep abreast of the severe weather situation as it unfolded. Second, it became the source of a preliminary database of severe weather events, known as the ‘‘rough log’’ (the ‘‘smoothed’’ or final report information would come weeks or months later via NWS field office compilations). In addition, the latitude and longitude for each report of a severe weather event was needed for the archiving process. To obtain this information, the SELS forecasters had to sift through a directory consisting of large notebooks that listed, by state, the latitude and longitude of thousands of cities and towns, big and small. It was not unusual, on an active severe weather day, that this would involve more than 100 reports (the small portion of the flysheet in Fig. 5 was part of a 200-plus report day). This directory was also used to obtain the latitude and longitude coordinates needed for archiving watches such as the one shown in Fig. 4.

It is obvious from the foregoing that there was an urgent need for streamlining these primarily clerical tasks and removing the operational meteorologist from these time-consuming procedures as much as possible. Subsequent technological advances not only made this possible, but also provided the forecaster with better tools tailored to meet the challenges of understanding and predicting severe weather phenomena.

3. Computer evolution

a. Computer systems

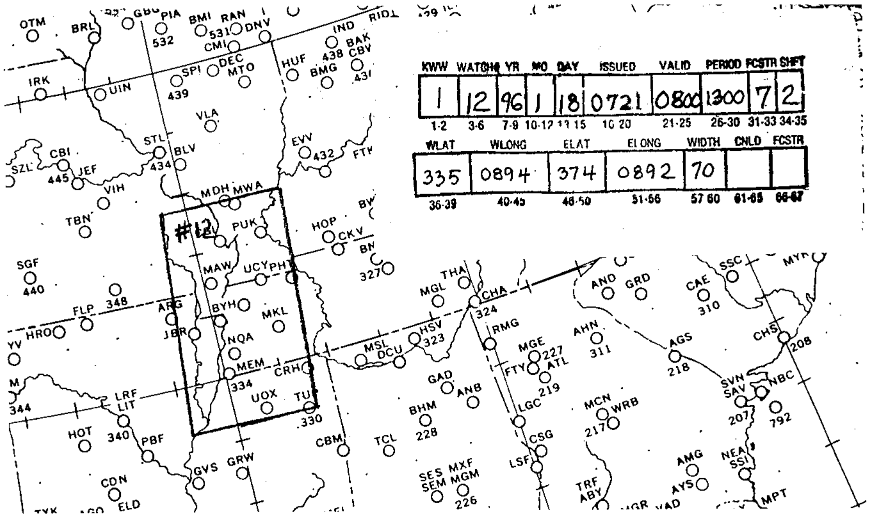
The primary computer system at NSSFC in the early 1970s was a CDC 3100. It served as the backbone of all SELS computer operations (as well as other units of NSSFC and collocated organizations).

This system was eventually replaced in 1978 by a Data General (DG) s/230 that was obtained as part of the Automation of Field Operations and Services (AFOS) procurement. CRTs became the main input–output devices, replacing card and paper tape readers. The installation of the s/230 alleviated a near-saturation situation that was occurring on the CDC 3100. It also made for some improvement in the operational arena by eliminating the need for the punched paper tape watch dissemination process. But the time-consuming procedure of logging reports manually and thumbing through huge lookup tables of geographical locations continued for some time.

The NWS-wide implementation of AFOS in the early 1980s provided the SELS forecasters with more timely and conveniently displayed meteorological data, but lacked interactive capability. Although somewhat more timely satellite, radar, and conventional data could now be put in the forecaster’s hands, there was no way to combine or superimpose data from these various sources. This problem was eventually resolved by the implementation of interactive computer technology.

b. Interactive computer technology

The first installation of interactive computer technology at the NSSFC came about in 1978 with the installation of a remote hookup to the Man–Computer Interactive Data Access System (McIDAS), a program developed at the University of Wisconsin’s Space Science and Engineering Center (SSEC; Suomi et al. 1983). This system was well suited for severe weather forecasting because of its ability to rapidly ingest satellite information and perform, in real time, analyses and intercomparisons of data. A remote terminal connected to



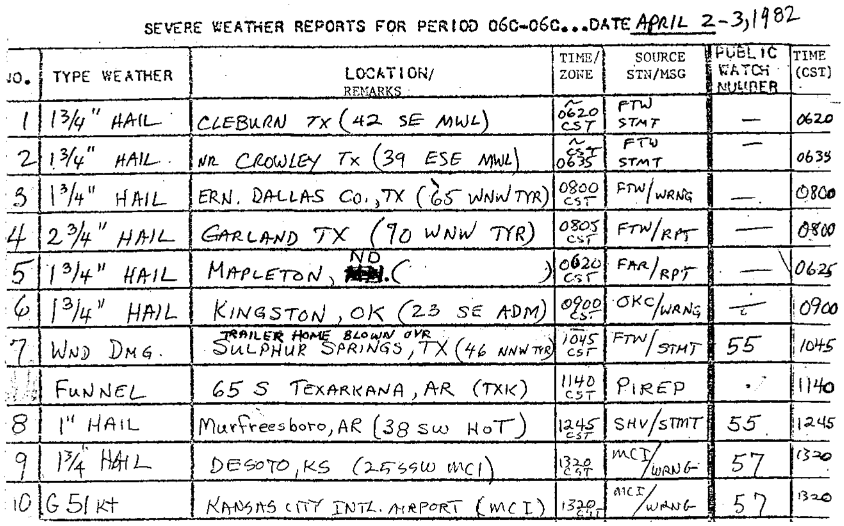
KWW	WATCH#	YR	MO	DAY	ISSUED	VALID	PERIOD	FCSTR	SHFT
1	12	96	1	18	0721	0800	1300	7	2
1-2	3-6	7-9	10-12	13 15	16 20	21-25	26-30	31-33	34-35

WLAT	WLONG	ELAT	ELONG	WIDTH	CNLD	FCSTR
335	0894	374	0892	70		
36-39	40-45	46-50	51-56	57 60	61-65	66-67

FIG. 4. Example of old style in-house severe weather watch archiving. A watch was drawn using anchor points (e.g., 50SW MEM) and half-width (e.g., 70 mi either side of a line). Data entered in stamped format include type of watch, watch number, year, month, day, issue time, start time, end time, forecaster number, shift, latitude–longitude of westernmost anchor point, latitude–longitude of easternmost anchor point, and half-width. (This system can still be used for backup if computer problems arise, as was the case in this example from 1996).

the SSEC McIDAS via a 9600-baud telephone link was placed in Kansas City during March 1980. This was followed by a stand-alone Centralized Storm Information System (CSIS) in 1982. The hardware for this consisted of a Geostationary Operational Environmental Satellite (GOES) receiving antenna system, three Harris/6 computers, three interactive terminals, an FAA ‘‘604’’ observational data input, two autodialers for accessing weather radar data, and an interface to the NSSFC MV computer system (Anthony et al. 1982; Mosher and Schaefer 1983; Ostby 1984). It represented a significant advance toward the development of a handling, analyzing, intercomparison, and display system for real-time data from all available sources. Also, proposed watch boundaries could be produced by either keystroke or mouse maneuvers and displayed on a geographical background of choice (e.g., satellite image or radar composite).

Facilitating the implementation and application of interactive computer processing was NSSFC’s Techniques Development Unit (TDU). This unit was formed in 1976 to evaluate new methods and to improve the forecasting ability of the NSSFC operational meteorologists. The unit’s activities included scientific studies on weather



SEVERE WEATHER REPORTS FOR PERIOD 06C–06C...DATE APRIL 2-3, 1982

NO.	TYPE WEATHER	LOCATION/ REMARKS	TIME/ ZONE	SOURCE STN/MSG	PUBLIC WATCH NUMBER	TIME (CST)
1	1 3/4" HAIL	CLEBURN TX (42 SE MWL)	0620 CST	FTW STMT	—	0620
2	1 3/4" HAIL	NR CROWLEY TX (39 ESE MWL)	CST 0635	FTW STMT	—	0635
3	1 3/4" HAIL	ERN. DALLAS CO., TX (65 WNW TYR)	0800 CST	FTW/WRNG	—	0800
4	2 3/4" HAIL	GARLAND TX (70 WNW TYR)	0805 CST	FTW/RPT	—	0800
5	1 3/4" HAIL	MAPLETON, ND. ( )	0620 CST	FAR/RPT	—	0625
6	1 3/4" HAIL	KINGSTON, OK (23 SE ADM)	0900 CST	OKC/WRNG	—	0900
7	WND DMG.	TRAILER HOME BLOWN OVR SULPHUR SPRINGS, TX (46 NNW TYR)	1045 CST	FTW/STMT	55	1045
	FUNNEL	65 S TEXARKANA, AR (TXK)	1140 CST	PIREP		1140
8	1" HAIL	Murfreesboro, AR (38 SW HOT)	1245 CST	SHV/STMT	55	1245
9	1 3/4" HAIL	DESOTO, KS (25 SSW MCI)	1320 CST	MCI/WRNG	57	1320
10	G 51 KT	KANSAS CITY INTL. AIRPORT (MCI)	1320 CST	MCI/WRNG	57	1320

FIG. 5. Portion of flysheet from 2 Apr 1982. Severe events logged in order of receipt in real time.

FIG. 6. Portion of manually prepared activity chart covering a 24-h period ending at 1200 UTC. Also plotted were all convective outlooks and watches issued during the period. Numbered reports are keyed to the corresponding flysheet and entered in their approximate geographical locations. Legibility of the reports is not important. Rather, the intent here is to simply illustrate the magnitude of the manual entry system.

conditions leading to severe storms, and the development and implementation of modern interactive computer technology in the forecast environment. The TDU staff made several significant contributions to the understanding of mesoscale phenomena (e.g., Lemon and Doswell 1979; Doswell 1982; Schaeffer and Livingston 1982). During the 1980s the focus of TDU gradually shifted to become more involved with computer technology and applications (Mosher 1991). TDU found that forecasting skill could be improved greatly if the forecasters had quick, easy access to data, and the ability to easily manipulate the data using known physical processes into severe weather potential information.

The next enhancement to NSSFC's interactive computer processing capability was the Visible and Infrared Spin Scan Radiometer (VISSR) Atmospheric Sounder (VAS) Data Utilization Center (VDUC), implemented in 1991. Using an IBM mainframe-based computer system, it replaced many of the functions previously performed on CSIS (Browning 1991). The SELS forecaster now had the capability to combine and display satellite, radar, and conventional observations in near–real time on one computer screen (Ostby 1993). Also, because of its greater processing power, VDUC provided the capability to generate fields and parameters of greater number (Browning 1992) with more emphasis on the mesoscale. This also permitted the implementation of forecast tools that represented a more scientific approach rather than the largely empirical methods of the previous era. Although there had been earlier significant theoretical work in understanding the physical processes involved in severe convection (Schaeffer 1986; Galway 1992), the lack of interactive computer processing was an inhibiting factor. Computing **Q** vectors or storm relative helicity, for example, would have been a daunting task without the needed processing power and software. With the advent of VDUC other important parameters such as CAPE and other wind shear–buoyant energy relationships (Johns et al. 1990), interactive Skew T–log$p$ analyses (Bothwell 1992), as well as improved visualization techniques (Cope 1992), could be examined. Also, newer datasets were being ingested including profiler (Leftwich and Beckman 1991) and lightning networks (Lewis 1989) as well as composited radar data for operational use. In addition, the forecaster could modify sounding data to attempt to account for anticipated spatial and temporal variations in the storm environment. Not only are these various parameters easily computed for initial analyses, they can also be calculated using prognostic model data for various forecast time projections, making it an even more powerful tool. Quicker access and response time as well as better visualization and diagnostic procedures provided the SELS forecaster the wherewithal and the opportunity to produce more timely and accurate severe weather watches.

The next computer system to be implemented at NSSFC came about in early 1995 with the installation of the NCEP (McPherson 1994) Advanced Weather Interactive Processing System (N-AWIPS; desJardin et al. 1997) that featured some of the capabilities of VDUC with the added ingredient of timely model data. However, at that time the system was more applicable to synoptic-scale forecasting (Rothfusz et al. 1998). Plans call for future upgrades to include greater applicability to mesoscale forecasting.

4. Meteorological advances

While the technological advances over the years were important to forecast improvement at SELS, scientific advances going on at the same time were equally significant. This included two major refinements in the approach to forecasting severe convection that evolved over a period of time. One was a shift from employing largely empirical procedures to placing greater emphasis on physical processes. Second was the realization that improvements in forecasting required greater emphasis on understanding the role of mesoscale processes and how to apply that knowledge. These early empirical methods or ‘‘rules of thumb’’ (Fawbush et al. 1951; Galway 1992) did have their roots in sound physical reasoning, that is, identification of regions that have the greatest instability, moisture, and favorable vertical wind configuration. The danger, however, is that it is easy for a forecaster to fall into the trap of employing so-called checklists and ignore the underlying physical principles and thereby risk overlooking important aspects of the meteorological situation, as pointed out by Doswell et al. (1993) as well as Moller et al. (1994). Furthermore, these rules of thumb are mostly related to large-scale processes and, therefore, are more applicable to forecasting for time and space scales generally reserved for convective outlooks as opposed to the mesoscale-oriented severe weather watch consideration. For example, as noted by Doswell (1987), while the forecasting of large-scale processes can lead one to the conclusion of favorable conditions over a region for deep, moist convection (i.e., moisture, instability, and a lifting mechanism), the lift necessary to start deep convection is generally a product of mesoscale processes. This initiation of convection due to mesoscale processes is reiterated by Rockwood and Maddox (1988).

Another significant area of progress that has evolved over the years concerns the role of jet streams in the development of severe convection. Beebe and Bates (1955) hypothesized that the divergence field accompanying superposition of intersecting jets could be associated with the upward motion necessary to release potential instability. Uccellini and Johnson (1979) studied additional aspects bringing in the magnitude of the horizontal ageostrophic components to estimate vertical motion as they pertain to jet streaks. Quasigeostrophic **Q** vector analyses (Hoskins et al. 1978) have been applied to initial and forecast model data to better understand and visualize these effects (see, e.g., Durran and Snellman 1987). Hales et al. (1997) computed quasigeostrophic **Q** vectors and transverse jet circulations (Uccellini and Johnson 1979) to assess the contribution of upper-level dynamics to the tornado outbreak of 27 March 1994.

With the advanced computer processing capability, it was now possible to test various mesoscale research findings and conceptual models dealing with severe convection as a way to improve the watch–warning process. An area of great attention in recent years has been on the recognition of the importance of supercells (Browning 1964), which are characterized by long-lived mesoscyclones. The relevance to the forecasting of severe convection stems from the fact that a significant number of supercell events have included violent tornadoes that frequently result in fatalities (Moller et al. 1994). Data compiled at NSSFC show that for the period 1980–91, of 614 tornado-related fatalities, 93% occurred in F2–F5 tornadoes (Ostby 1992). Hales (1998) showed that for the period 1952–95, while F3–F5 tornadoes, which he termed as ‘‘intense,’’ accounted for only 7% of all tornadoes reported in the United States, they resulted in nearly 90% of all tornado-related fatalities and injuries.

One of the more promising avenues for forecasting severe convection in recent years emerged from the work of Weisman and Klemp (1982) who showed that much of the relationship between storm type, wind shear, and buoyancy could be represented in the form of a bulk Richardson number (BRN) using various combinations of parameters that relate instability and vertical wind shear to mesoscyclogenesis and tornadogenesis. Their modeling results and calculation of BRN for a series of storms suggested that multicellular growth occurs most readily for BRN > 30 and the supercellular growth is confined to magnitudes of BRN between 10 and 40.

The hodograph is an important diagnostic tool in wind shear evaluation and it has been noted that strong vertical shear is often observed in supercell development (Doswell 1991). Numerous other studies have been performed using various combinations of vertical shear and instability, such as storm-relative environmental helicity

(SREH), CAPE, BRN, and energy-helicity index to name some of the more common parameters (Davies-Jones et al. 1990; Johns et al. 1990; Brooks et al. 1993; Davies 1993; Davies and Johns 1993; Brooks and Doswell 1994; Mead 1997). Variations of these parameters were introduced into the forecasting operations at SELS in recent years and have been used successfully (Leftwich 1990). However, the discrimination between tornadic and nontornadic supercells is far from straightforward (Brooks and Doswell 1994; Mead 1997) since tornadic environments have been noted to range from high CAPE–low shear to low shear–high CAPE (Johns et al. 1993; Korotky et al. 1993).

A major emphasis in recent years has been the development of conceptual models and simulations to overcome these uncertainties in discriminating between tornadic and nontornadic thunderstorm environments (e.g., Doswell et al. 1990; Brooks and Doswell 1994; Stensrud et al. 1997). Detailed case studies have been made applying these conceptual models to notable severe weather outbreaks. Some examples of these include the Plainfield tornado of 28 August 1990 (Korotky et al. 1993), the outbreak of 21–23 November 1992 (Cortinas and Stensrud 1995), and the 27 March 1994 tornado outbreak (Hales et al. 1997).

Johns and Hart (1993) noted the forecast problems in distinguishing between supercell thunderstorms that produce tornadoes and those that produce severe thunderstorms (e.g., bow echoes, derechoes). This is operationally important because it involves the decision making process of whether to issue a tornado or severe thunderstorm watch. As noted by Johns (1993), bow-echo-induced downbursts account for a large majority of casualties and damage resulting from convectively induced nontornadic winds in the United States. These bow-echo events are frequently associated with widespread damaging winds. Stensrud et al. (1997) applied a mesoscale model to nine severe weather events to evaluate the model's ability to discriminate between tornadic and nontornadic (bow echo or damaging straight-line winds) events using CAPE, SREH, and BRN and obtained encouraging results. Brooks and Doswell (1994) used proximity soundings to investigate the environments of tornadic and nontornadic mesocyclones as they pertain to supercells.

Thompson (1998) focused on a conceptual model for sustained low-level mesoscyclones with tornadic supercells along the lines of Davies-Jones and Brooks (1993) and applied it to operationally available Eta Model data. The results were encouraging even though being limited by the model's 80-km horizontal resolution (Rogers et al. 1995) and the use of constant pressure level data to estimate storm-relative winds. Thompson (1998) also showed how this technique could be used in an operational setting.

This impressive array of mesoscale knowledge developed over time provided the SELS forecasters a much sounder physical basis for understanding and forecasting severe convection and brought about a significantly improved approach to the forecast process.

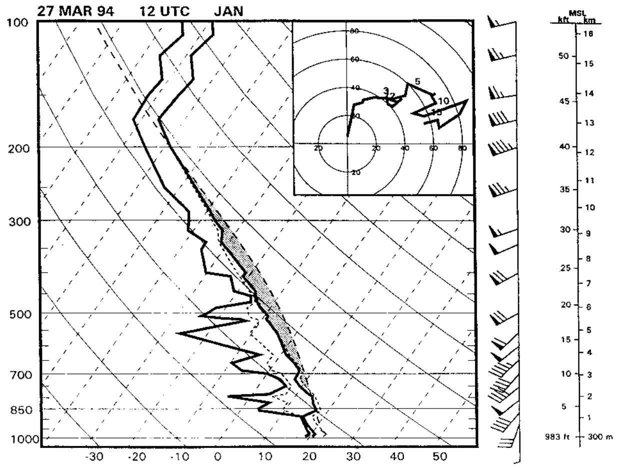


FIG. 7. Skew *T*–log*p* (including most unstable lifted parcel) and hodograph (insert at upper right) at Jackson, MS (JAN), for 1200 UTC 27 Mar 1994. Shaded region denotes CAPE. Wind barbs at the right are 2.5 (short barb), 5 (long barb), and 25 m s^{-1} (flag). Thin solid lines sloping up to the left are dry adiabats, whereas dashed lines sloping up to the right are isotherms in increments of 10°C (from Hales et al. 1997).

5. Procedures in the 1990s

a. Meteorological diagnosis

With interactive computer processing firmly in place, the severe weather meteorologist now had a myriad array of products from which to choose. Rapid access to satellite imagery and composite radar displays that could be superimposed and intercompared had become routine. In addition, physical processes important to the development of severe convection described in section 4 could be quickly visualized and understood from computer screen displays of products such as lifted index, moisture convergence, numerical model output, and a variety of wind shear/instability estimates. Computer-generated analyses of thermodynamic diagrams, such as the Skew *T*–log*p*, yielded rich information such as CAPE and storm-relative helicity (Fig. 7). Examples of how the application of these products can be used to enhance the forecast process are found in Johns and Doswell (1992), Hales et al. (1997), and Thompson (1998).

The advent of Weather Surveillance Radar-1988 Doppler (WSR-88D) data has proved tremendously valuable in diagnosing the evolution of severe convection. An example of this kind of application is shown in Hilgendorf and Johnson (1998). Data from all WSR-88D locations in the United States were available to the SELS forecaster by direct dial using a principal user processor. Another powerful tool from the WSR-88D is the production of velocity–azimuth display algorithm (VAD) wind profiles (Crum and Alberty 1993). For ex-

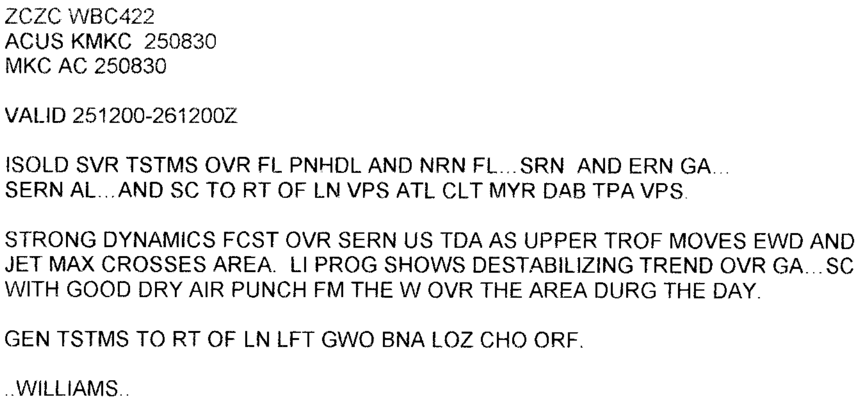


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FIG. 8. Example of a 1970s era convective outlook. Note the brevity in describing the reasoning behind the forecast.

ample, using the latest VAD profile, the forecaster can readily update estimates of SREH in near–real time to aid in the assessment of supercell potential.

As stated previously, technological advances and the automation of many clerical tasks provided the SELS staff the ability to concentrate its efforts on the forecast process and also gave the opportunity to add more forecast products as well as include more detailed guidance information for NWS field offices and other users. The number of convective outlooks was increased from 2 day^{-1} in the 1970s to 4 day^{-1} in the 1990s with amendments as needed. In addition, a second-day outlook and a mesoscale discussion product were added in 1986. Also, it is interesting to note how the meteorological content of convective outlooks changed over that period by comparing a convective outlook from the 1970s (Fig. 8) with one from the 1990s, which conveyed much more useful information on both the synoptic scale and mesoscale to the user (Fig. 9). Thus, a huge benefit was realized by being able to provide a suite of forecast products that kept users better informed of severe weather potential and the reasoning behind the forecasts. This process also facilitated the forecast coordination process among NWS field offices.

b. *Watch preparation and dissemination*

Watches are now constructed interactively on a computer screen through simple mouse manipulations. Each manipulation refines and redraws the watch boundaries and yields a new set of descriptive parameters (i.e., watch endpoint locations in terms of city names and latitude–longitude pairs). When the forecaster is satisfied with the watch location, the parameters are automatically transferred to the forecaster's PC to supply the necessary information through a menu-driven PC program that generates the watch text for transmission.

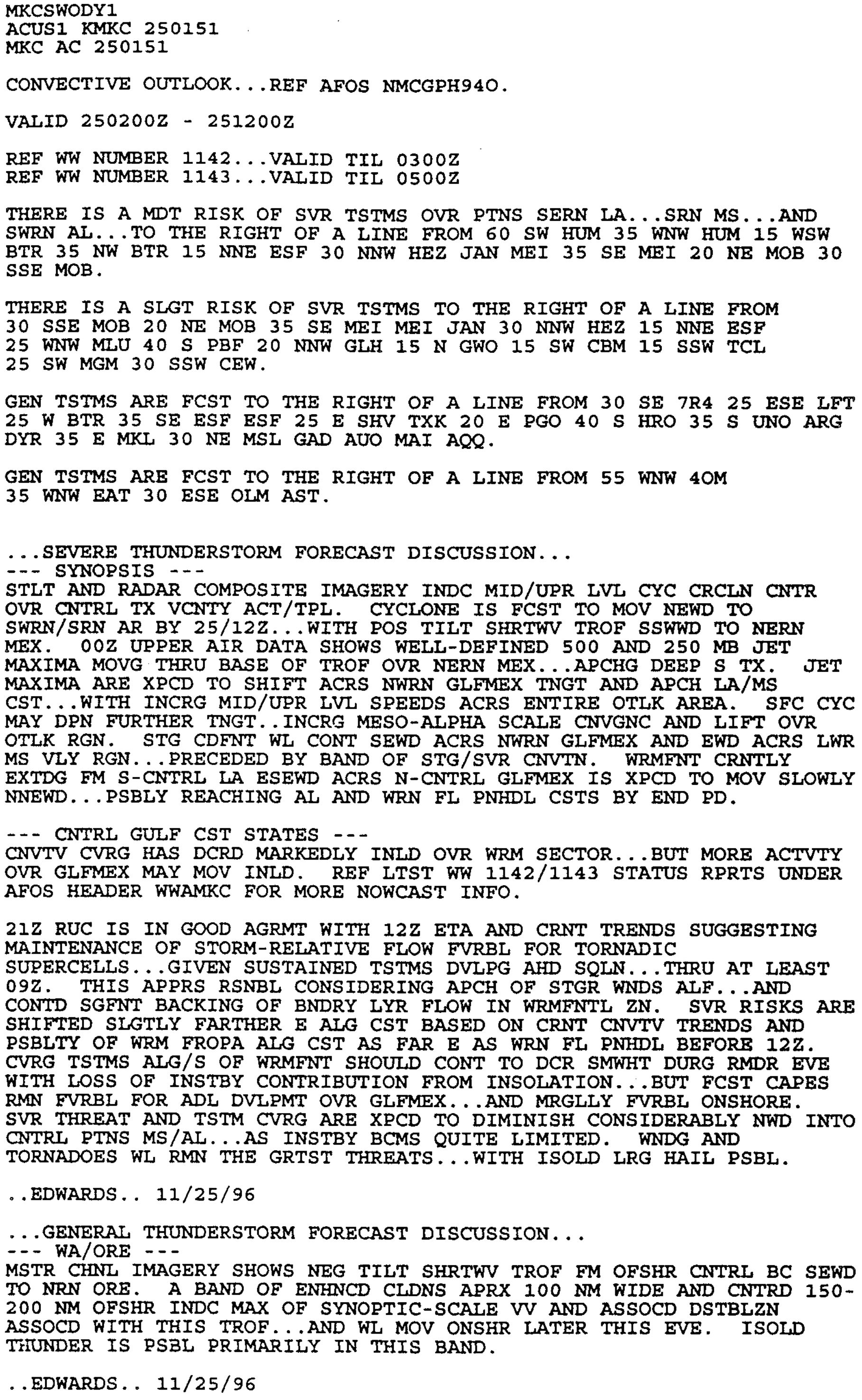
c. *Data archiving*

The two main components for archiving remain the same as back in the 1970s: 1) the information that describes the watch and 2) a database of severe weather events. The former is entirely automated and a hard copy containing all the particulars is also generated (Fig. 10). The logging of severe weather events is semiautomated. NWS local storm reports (LSRs) are produced by a local office when severe weather is reported in the office's county warning area. These LSRs are formatted to be read by the SELS (now SPC) computer and automatically archived. Formats that cannot be machine read or reports that come from other sources are logged manually on a PC. The former manually produced flysheet is now computer generated (Fig. 11), as is the previous manual activity chart.

6. Forecast improvement

a. *Research studies*

The SELS unit made great progress over the years because of the improved technology mentioned previously, increased understanding of the atmosphere on both synoptic and mesoscales as described in section 4, and the invaluable experience acquired by skilled severe storm forecasters (Ostby 1993). Also, in addition to the increase in productivity, more time became available to conduct forecast studies that were applicable to the severe local storm problem. While the research was diversified, it followed two main paths. One was to improve the understanding of mesoscale processes related to severe weather forecasting, and the other was to place emphasis on improving forecasts for geographical areas other than the southern plains where most of the longstanding severe weather techniques had their roots (Miller 1972). Examples of the former include case studies of various tornado outbreaks or significant severe storm events (Browning et al. 1989; Hales 1984; Johns and Leftwich 1988; July 1990; Hales et al. 1997). Among challenging problem areas investigated were tornadoes associated with tropical cyclones (Weiss 1985; Ostby and Weiss 1993; Vescio et al. 1996), northwest flow and derechos (Johns 1982, 1984; Johns and

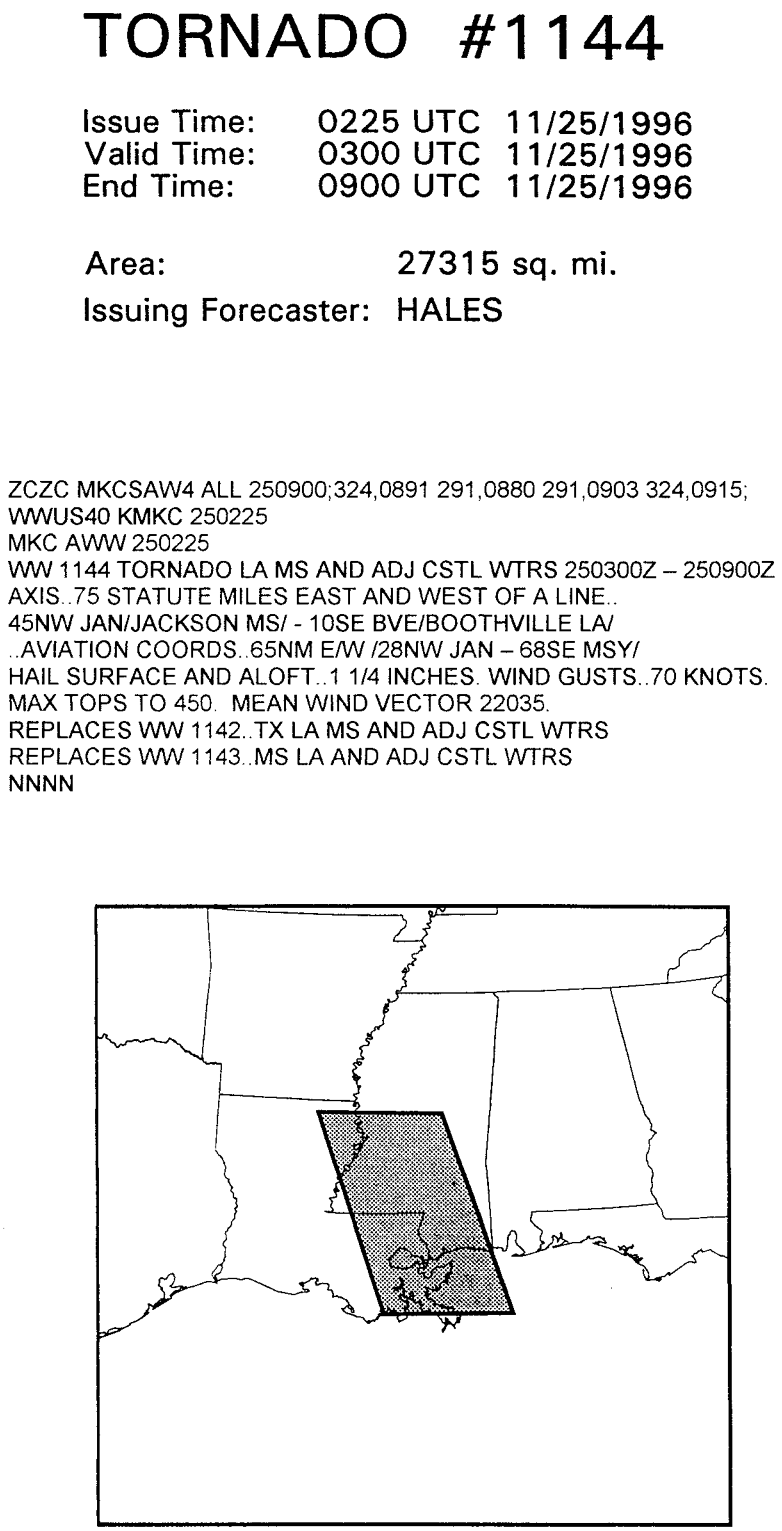


```
MKCSWODY1
ACUS1 KMKC 250151
MKC AC 250151

CONVECTIVE OUTLOOK...REF AFOS NMCGPH94O.

VALID 250200Z - 251200Z

REF WW NUMBER 1142...VALID TIL 0300Z
REF WW NUMBER 1143...VALID TIL 0500Z

THERE IS A MDT RISK OF SVR TSTMS OVR PTNS SERN LA...SRN MS...AND
SWRN AL...TO THE RIGHT OF A LINE FROM 60 SW HUM 35 WNW HUM 15 WSW
BTR 35 NW BTR 15 NNE ESF 30 NNW HEZ JAN MEI 35 SE MEI 20 NE MOB 30
SSE MOB.

THERE IS A SLGT RISK OF SVR TSTMS TO THE RIGHT OF A LINE FROM
30 SSE MOB 20 NE MOB 35 SE MEI MEI JAN 30 NNW HEZ 15 NNE ESF
25 WNW MLU 40 S PBF 20 NNW GLH 15 N GWO 15 SW CBM 15 SSW TCL
25 SW MGM 30 SSW CEW.

GEN TSTMS ARE FCST TO THE RIGHT OF A LINE FROM 30 SE 7R4 25 ESE LFT
25 W BTR 35 SE ESF ESF 25 E SHV TXK 20 E PGO 40 S HRO 35 S UNO ARG
DYR 35 E MKL 30 NE MSL GAD AUO MAI AQQ.

GEN TSTMS ARE FCST TO THE RIGHT OF A LINE FROM 55 WNW 4OM
35 WNW EAT 30 ESE OLM AST.


...SEVERE THUNDERSTORM FORECAST DISCUSSION...
--- SYNOPSIS ---
STLT AND RADAR COMPOSITE IMAGERY INDC MID/UPR LVL CYC CRCLN CNTR
OVR CNTRL TX VCNTY ACT/TPL.  CYCLONE IS FCST TO MOV NEWD TO
SWRN/SRN AR BY 25/12Z...WITH POS TILT SHRTWV TROF SSWWD TO NERN
MEX.  00Z UPPER AIR DATA SHOWS WELL-DEFINED 500 AND 250 MB JET
MAXIMA MOVG THRU BASE OF TROF OVR NERN MEX...APCHG DEEP S TX.  JET
MAXIMA ARE XPCD TO SHIFT ACRS NWRN GLFMEX TNGT AND APCH LA/MS
CST...WITH INCRG MID/UPR LVL SPEEDS ACRS ENTIRE OTLK AREA.  SFC CYC
MAY DPN FURTHER TNGT..INCRG MESO-ALPHA SCALE CNVGNC AND LIFT OVR
OTLK RGN.  STG CDFNT WL CONT SEWD ACRS NWRN GLFMEX AND EWD ACRS LWR
MS VLY RGN...PRECEDED BY BAND OF STG/SVR CNVTN.  WRMFNT CRNTLY
EXTDG FM S-CNTRL LA ESEWD ACRS N-CNTRL GLFMEX IS XPCD TO MOV SLOWLY
NNEWD...PSBLY REACHING AL AND WRN FL PNHDL CSTS BY END PD.

--- CNTRL GULF CST STATES ---
CNVTV CVRG HAS DCRD MARKEDLY INLD OVR WRM SECTOR...BUT MORE ACTVTY
OVR GLFMEX MAY MOV INLD.  REF LTST WW 1142/1143 STATUS RPRTS UNDER
AFOS HEADER WWAMKC FOR MORE NOWCAST INFO.

21Z RUC IS IN GOOD AGRMT WITH 12Z ETA AND CRNT TRENDS SUGGESTING
MAINTENANCE OF STORM-RELATIVE FLOW FVRBL FOR TORNADIC
SUPERCELLS...GIVEN SUSTAINED TSTMS DVLPG AHD SQLN...THRU AT LEAST
09Z.  THIS APPRS RSNBL CONSIDERING APCH OF STGR WNDS ALF...AND
CONTD SGFNT BACKING OF BNDRY LYR FLOW IN WRMFNTL ZN.  SVR RISKS ARE
SHIFTED SLGTLY FARTHER E ALG CST BASED ON CRNT CNVTV TRENDS AND
PSBLTY OF WRM FROPA ALG CST AS FAR E AS WRN FL PNHDL BEFORE 12Z.
CVRG TSTMS ALG/S OF WRMFNT SHOULD CONT TO DCR SMWHT DURG RMDR EVE
WITH LOSS OF INSTBY CONTRIBUTION FROM INSOLATION...BUT FCST CAPES
RMN FVRBL FOR ADL DVLPMT OVR GLFMEX...AND MRGLLY FVRBL ONSHORE.
SVR THREAT AND TSTM CVRG ARE XPCD TO DIMINISH CONSIDERABLY NWD INTO
CNTRL PTNS MS/AL...AS INSTBY BCMS QUITE LIMITED.  WNDG AND
TORNADOES WL RMN THE GRTST THREATS...WITH ISOLD LRG HAIL PSBL.

..EDWARDS.. 11/25/96

...GENERAL THUNDERSTORM FORECAST DISCUSSION...
--- WA/ORE ---
MSTR CHNL IMAGERY SHOWS NEG TILT SHRTWV TROF FM OFSHR CNTRL BC SEWD
TO NRN ORE.  A BAND OF ENHNCD CLDNS APRX 100 NM WIDE AND CNTRD 150-
200 NM OFSHR INDC MAX OF SYNOPTIC-SCALE VV AND ASSOCD DSTBLZN
ASSOCD WITH THIS TROF...AND WL MOV ONSHR LATER THIS EVE.  ISOLD
THUNDER IS PSBL PRIMARILY IN THIS BAND.

..EDWARDS.. 11/25/96
```

FIG. 9. A convective outlook from 1996. Contrast the detailed reasoning contained herein with that of Fig. 8.

Hirt 1987), bow echoes (Johns 1993), winter tornadoes (Galway and Pearson 1981), cold-sector severe thunderstorms (Grant 1995), storm-relative winds and helicity (Kerr and Darkow 1996; Thompson 1998), and tornadoes associated with boundaries (Rogash 1995). Regional studies to improve understanding and prediction of severe weather in various geographical areas included the following: Los Angeles Basin (Hales

(a)



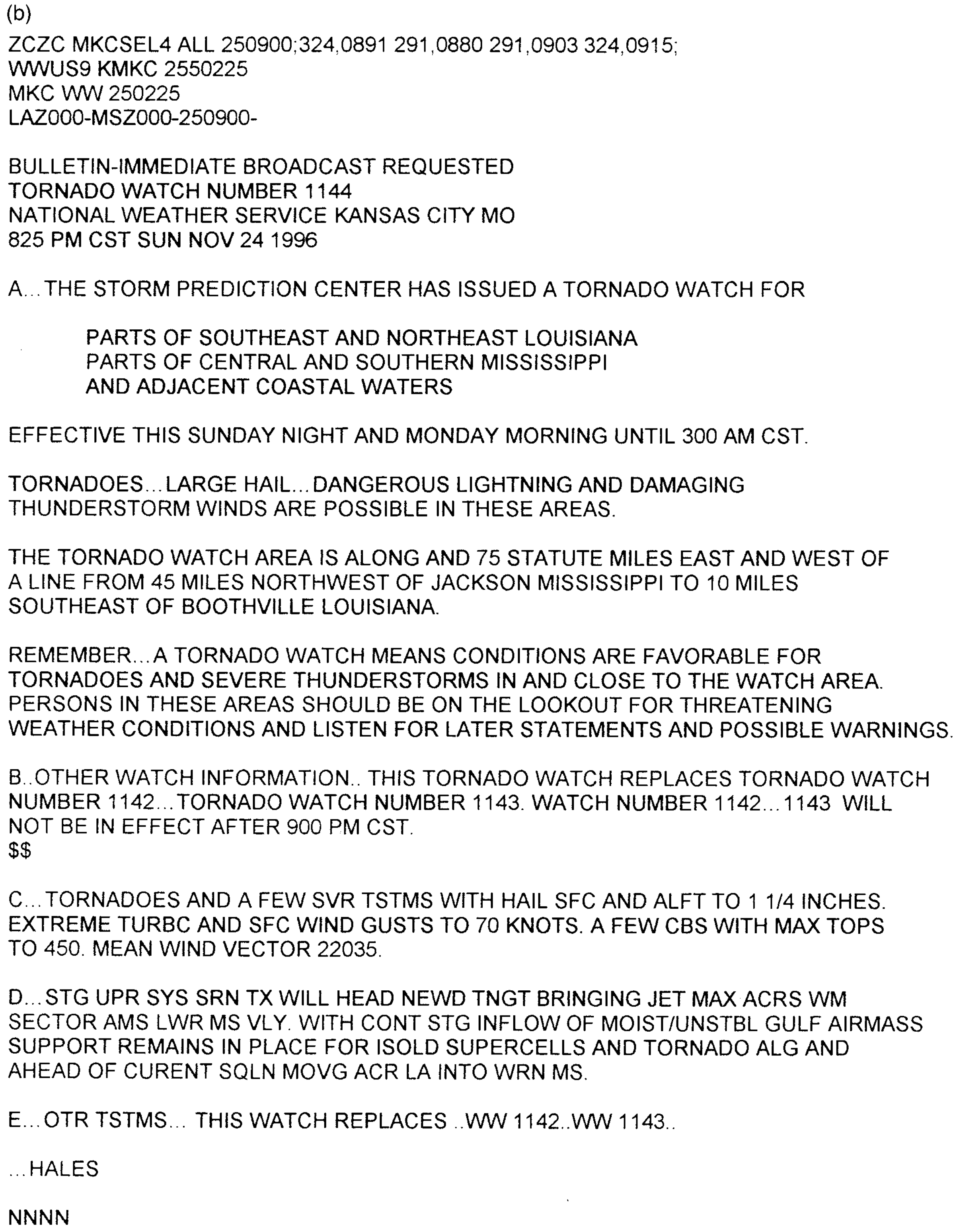
TORNADO #1144

Issue Time: 0225 UTC 11/25/1996
Valid Time: 0300 UTC 11/25/1996
End Time: 0900 UTC 11/25/1996

Area: 27315 sq. mi.
Issuing Forecaster: HALES

```
ZCZC MKCSAW4 ALL 250900;324,0891 291,0880 291,0903 324,0915;
WWUS40 KMKC 250225
MKC AWW 250225
WW 1144 TORNADO LA MS AND ADJ CSTL WTRS 250300Z - 250900Z
AXIS..75 STATUTE MILES EAST AND WEST OF A LINE..
45NW JAN/JACKSON MS/ - 10SE BVE/BOOTHVILLE LA/
..AVIATION COORDS..65NM E/W /28NW JAN - 68SE MSY/
HAIL SURFACE AND ALOFT..1 1/4 INCHES. WIND GUSTS..70 KNOTS.
MAX TOPS TO 450.  MEAN WIND VECTOR 22035.
REPLACES WW 1142..TX LA MS AND ADJ CSTL WTRS
REPLACES WW 1143..MS LA AND ADJ CSTL WTRS
NNNN
```

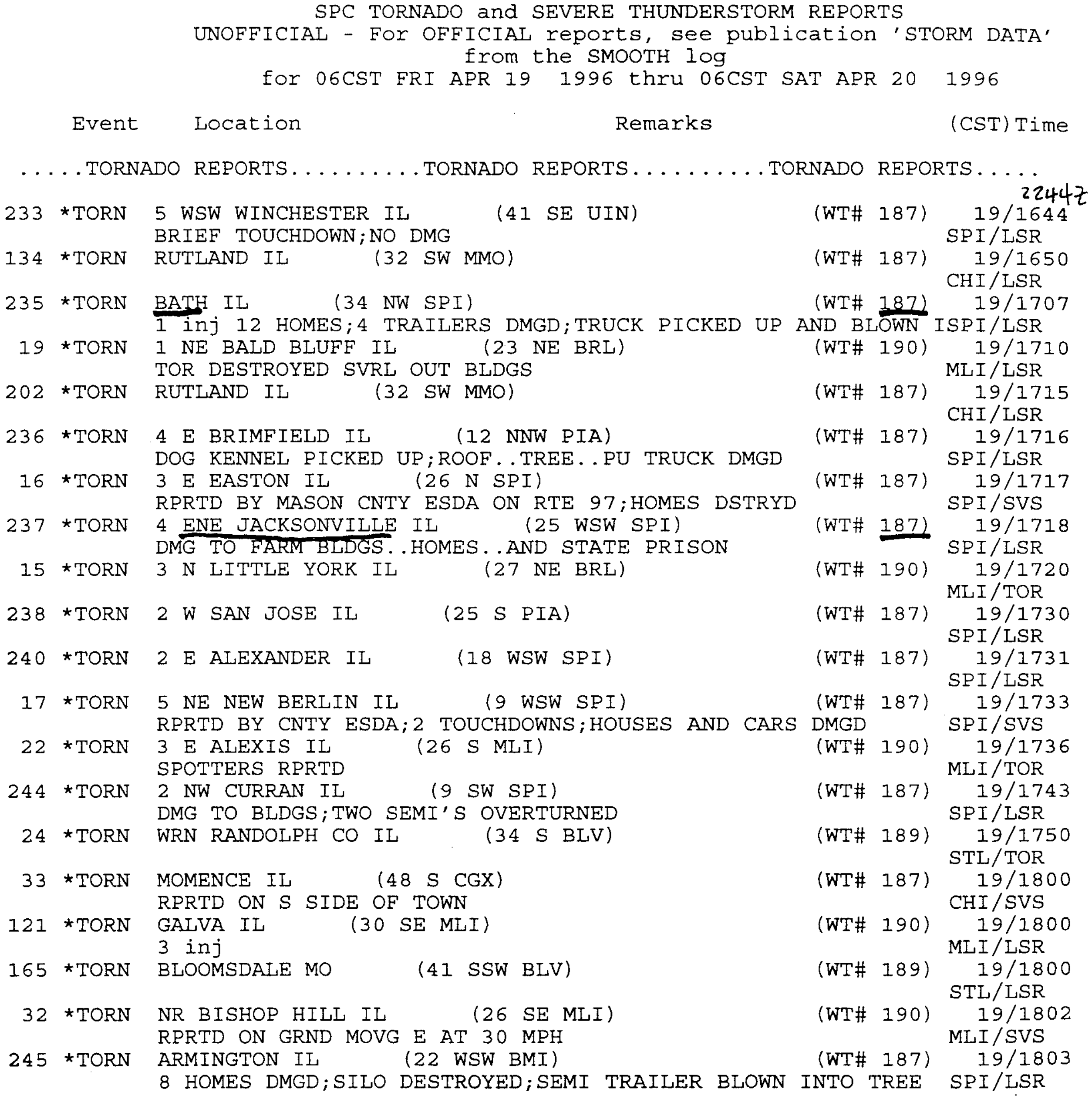
FIG. 10. Details of an issued watch of 25 Nov 1996. This automated version replaced the labor-intensive process shown in Fig. 4. (a) The graphic portion showing the geographical location of the watch including the quickie as well as the latitude–longitude coordinates of the four corner points and the pertinent times involved. (b) The text portion of the watch.



(b)

```
ZCZC MKCSEL4 ALL 250900;324,0891 291,0880 291,0903 324,0915;
WWUS9 KMKC 2550225
MKC WW 250225
LAZ000-MSZ000-250900-

BULLETIN-IMMEDIATE BROADCAST REQUESTED
TORNADO WATCH NUMBER 1144
NATIONAL WEATHER SERVICE KANSAS CITY MO
825 PM CST SUN NOV 24 1996

A...THE STORM PREDICTION CENTER HAS ISSUED A TORNADO WATCH FOR

        PARTS OF SOUTHEAST AND NORTHEAST LOUISIANA
        PARTS OF CENTRAL AND SOUTHERN MISSISSIPPI
        AND ADJACENT COASTAL WATERS

EFFECTIVE THIS SUNDAY NIGHT AND MONDAY MORNING UNTIL 300 AM CST.

TORNADOES...LARGE HAIL...DANGEROUS LIGHTNING AND DAMAGING
THUNDERSTORM WINDS ARE POSSIBLE IN THESE AREAS.

THE TORNADO WATCH AREA IS ALONG AND 75 STATUTE MILES EAST AND WEST OF
A LINE FROM 45 MILES NORTHWEST OF JACKSON MISSISSIPPI TO 10 MILES
SOUTHEAST OF BOOTHVILLE LOUISIANA.

REMEMBER...A TORNADO WATCH MEANS CONDITIONS ARE FAVORABLE FOR
TORNADOES AND SEVERE THUNDERSTORMS IN AND CLOSE TO THE WATCH AREA.
PERSONS IN THESE AREAS SHOULD BE ON THE LOOKOUT FOR THREATENING
WEATHER CONDITIONS AND LISTEN FOR LATER STATEMENTS AND POSSIBLE WARNINGS.

B..OTHER WATCH INFORMATION.. THIS TORNADO WATCH REPLACES TORNADO WATCH
NUMBER 1142...TORNADO WATCH NUMBER 1143. WATCH NUMBER 1142...1143  WILL
NOT BE IN EFFECT AFTER 900 PM CST.
$$

C...TORNADOES AND A FEW SVR TSTMS WITH HAIL SFC AND ALFT TO 1 1/4 INCHES.
EXTREME TURBC AND SFC WIND GUSTS TO 70 KNOTS. A FEW CBS WITH MAX TOPS
TO 450. MEAN WIND VECTOR 22035.

D...STG UPR SYS SRN TX WILL HEAD NEWD TNGT BRINGING JET MAX ACRS WM
SECTOR AMS LWR MS VLY. WITH CONT STG INFLOW OF MOIST/UNSTBL GULF AIRMASS
SUPPORT REMAINS IN PLACE FOR ISOLD SUPERCELLS AND TORNADO ALG AND
AHEAD OF CURENT SQLN MOVG ACR LA INTO WRN MS.

E...OTR TSTMS... THIS WATCH REPLACES ..WW 1142..WW 1143..

...HALES

NNNN
```

FIG. 10. (*Continued*)



```
                 SPC TORNADO and SEVERE THUNDERSTORM REPORTS
          UNOFFICIAL - For OFFICIAL reports, see publication 'STORM DATA'
                            from the SMOOTH log
             for 06CST FRI APR 19  1996 thru 06CST SAT APR 20  1996

     Event    Location                            Remarks               (CST)Time

  .....TORNADO REPORTS..........TORNADO REPORTS..........TORNADO REPORTS.....
                                                                            22447
233 *TORN  5 WSW WINCHESTER IL      (41 SE UIN)              (WT# 187)   19/1644
           BRIEF TOUCHDOWN;NO DMG                                        SPI/LSR
134 *TORN  RUTLAND IL      (32 SW MMO)                       (WT# 187)   19/1650
                                                                         CHI/LSR
235 *TORN  BATH IL      (34 NW SPI)                          (WT# 187)   19/1707
           1 inj 12 HOMES;4 TRAILERS DMGD;TRUCK PICKED UP AND BLOWN ISPI/LSR
 19 *TORN  1 NE BALD BLUFF IL      (23 NE BRL)               (WT# 190)   19/1710
           TOR DESTROYED SVRL OUT BLDGS                                  MLI/LSR
202 *TORN  RUTLAND IL      (32 SW MMO)                       (WT# 187)   19/1715
                                                                         CHI/LSR
236 *TORN  4 E BRIMFIELD IL      (12 NNW PIA)                (WT# 187)   19/1716
           DOG KENNEL PICKED UP;ROOF..TREE..PU TRUCK DMGD                SPI/LSR
 16 *TORN  3 E EASTON IL      (26 N SPI)                     (WT# 187)   19/1717
           RPRTD BY MASON CNTY ESDA ON RTE 97;HOMES DSTRYD               SPI/SVS
237 *TORN  4 ENE JACKSONVILLE IL      (25 WSW SPI)           (WT# 187)   19/1718
           DMG TO FARM BLDGS..HOMES..AND STATE PRISON                    SPI/LSR
 15 *TORN  3 N LITTLE YORK IL      (27 NE BRL)               (WT# 190)   19/1720
                                                                         MLI/TOR
238 *TORN  2 W SAN JOSE IL      (25 S PIA)                   (WT# 187)   19/1730
                                                                         SPI/LSR
240 *TORN  2 E ALEXANDER IL      (18 WSW SPI)                (WT# 187)   19/1731
                                                                         SPI/LSR
 17 *TORN  5 NE NEW BERLIN IL      (9 WSW SPI)               (WT# 187)   19/1733
           RPRTD BY CNTY ESDA;2 TOUCHDOWNS;HOUSES AND CARS DMGD          SPI/SVS
 22 *TORN  3 E ALEXIS IL      (26 S MLI)                     (WT# 190)   19/1736
           SPOTTERS RPRTD                                                MLI/TOR
244 *TORN  2 NW CURRAN IL      (9 SW SPI)                    (WT# 187)   19/1743
           DMG TO BLDGS;TWO SEMI'S OVERTURNED                            SPI/LSR
 24 *TORN  WRN RANDOLPH CO IL      (34 S BLV)                (WT# 189)   19/1750
                                                                         STL/TOR
 33 *TORN  MOMENCE IL      (48 S CGX)                        (WT# 187)   19/1800
           RPRTD ON S SIDE OF TOWN                                       CHI/SVS
121 *TORN  GALVA IL      (30 SE MLI)                         (WT# 190)   19/1800
           3 inj                                                         MLI/LSR
165 *TORN  BLOOMSDALE MO      (41 SSW BLV)                   (WT# 189)   19/1800
                                                                         STL/LSR
 32 *TORN  NR BISHOP HILL IL      (26 SE MLI)                (WT# 190)   19/1802
           RPRTD ON GRND MOVG E AT 30 MPH                                MLI/SVS
245 *TORN  ARMINGTON IL      (22 WSW BMI)                    (WT# 187)   19/1803
           8 HOMES DMGD;SILO DESTROYED;SEMI TRAILER BLOWN INTO TREE  SPI/LSR
```

FIG. 11. A portion of the computer generated flysheet covering the 24-h period ending at 1200 UTC 6 Apr 1996.

1985), North Dakota (Hirt 1985), the Northwest (Evenson and Johns 1995), the Southeast (Anthony 1988), and the Northeast (Johns and Dorr 1996). While these examples cited only include studies by SELS personnel, research outside of SELS/NSSFC was of great value as discussed in section 4 and relevant findings were incorporated, providing additional important contributions to the overall forecast improvement.

b. Verification

Verification statistics used to verify the severe weather watches issued by SELS show that there has been a large improvement in forecaster accuracy from 1973 to 1996. Figure 12 shows the percent correct (COR) and the probability of detection (POD) for the period from 1973 to 1996. A severe weather watch is considered to have verified if one or more tornadoes or severe thunderstorm events occur within the watch and during its valid time. As shown in Fig. 12, the percentage of watches that verified increased from 63% in 1973 to 90% in 1996. The POD determines what percentage of individual severe weather events occurred within valid watches. Figure 12 shows that in 1973, only about 30% of all severe weather events occurred within valid

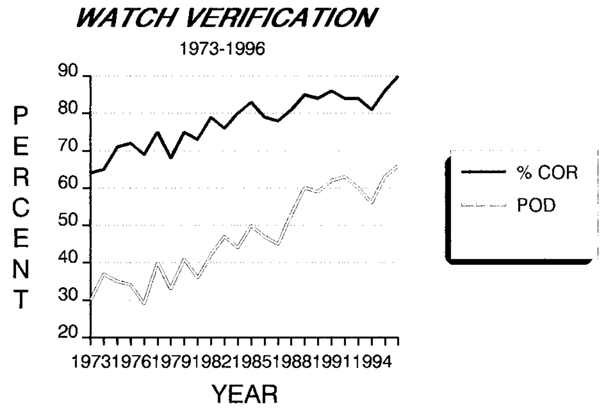


FIG. 12. SELS severe weather watch verification, 1973–96. Upper curve represents percent correct (% COR); lower curve, probability of detection (POD).

watches. By 1996, the POD had more than doubled, with 66% of severe weather events occurring within valid watches.

While all severe local storms pose a threat to life and property, as noted previously, tornadoes that are considered "significant" [classified on the Fujita scale as F2 to F5; Fujita (1973)] cause much of the damage and most of the deaths attributed to tornadoes each year. Therefore, it is of considerable importance that these "significant" tornadoes be included in timely watches. Figure 13 shows the percentage of F2–F5 tornadoes that occurred within tornado watches, severe thunderstorm watches, and all watches combined, respectively, for the period 1978–96. Figure 13 reveals that in 1978, only 42% of the F2–F5 tornadoes occurred within valid watches. By 1995, that percentage had risen to 95%. Figure 13 also shows considerable forecaster ability to discriminate between tornadic and severe thunderstorm situations. For example, in 1996, 72% of the significant tornadoes occurred within tornado watches while only 13% of the F2–F5 tornadoes occurred when severe thunderstorm watches were in effect.

7. Concluding remarks

During the last 25 years of the existence of SELS, rapid progress was made in forecast performance. The advent of improved computer technology and its application to severe storms forecasting have been of paramount importance to this progress, beginning with the installation of a McIDAS terminal followed by the full-scale CSIS system and its successor, VDUC.

The research advances in mesoscale and storm-scale meteorology described in section 4 had a profound effect on SELS operations and contributed significantly to forecast improvement. These included more lucid ways to diagnosis, depict, and/or infer critical relevant processes such as forcing for synoptic-scale vertical motion (**Q** vectors), buoyant energy (CAPE), and vertical shear (SREH).

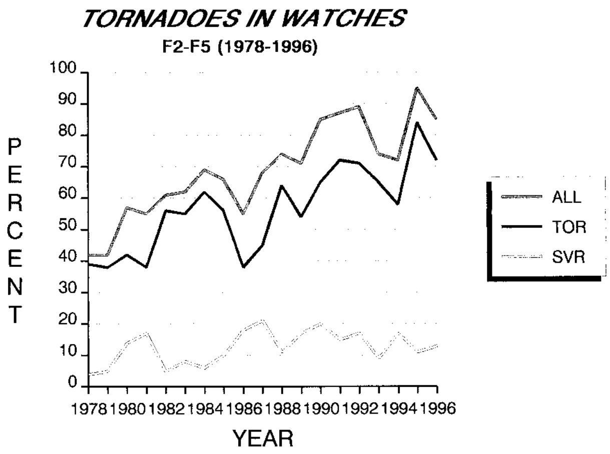


FIG. 13. Percent of F2–F5 tornadoes in SELS severe weather watches, 1978–96. Bottom curve shows percent in severe thunderstorm watches (SVR); and the middle curve, tornado watches (TOR). The upper curve (ALL) is the sum of the lower two, that is, the percent of F2–F5 tornadoes in either tornado or severe thunderstorm watches.

Another key factor in this progress was the ability to automate numerous clerical tasks and allow forecasters to focus more of their attention on the critical issue of predicting the development of severe convection. This was especially important because the staffing levels within SELS did not include clerical positions that would deal with some of the time-consuming duties of event logging and data archiving. Moving these clerical tasks to the computer also allowed the SELS staff to greatly increase its productivity. This resulted in the development of new forecast products and more frequent issuances. In addition to enhancing the forecast operation, the technological advances meant that the forecast staff could devote time to research studies to improve the understanding of mesoscale processes and conduct a variety of regional and case studies.

While the verification statistics presented herein are impressive, the "bottom line" is in terms of saving lives. In that regard, it is worthy to note that the death toll from tornadoes across the United States, which stood at 972 for the 10-year period ending in 1970, fell to 590 for a similar interval ending in 1980, and dropped further to 430 for the 10 years ending in 1996. The reason for this success is certainly due in large part to the performance of SELS, but other important groups were involved as well. Significant improvements in the NWS warning program and preparedness efforts at the local weather service office, as well as safety and preparedness programs carried out by emergency managers, volunteer spotters, ham radio operators, and the media, resulted in a more enlightened public. All these groups contributed to this positive trend (Ostby 1992).

Ongoing research and higher-resolution computer models give encouragement for further improvements in our ability to anticipate severe convection and provide more accurate forecasts. For example, additional research using observations from field experiments such as the Verification of the Origins of Rotation in Tornadoes Experiment (VORTEX; Rasmussen et al. 1994) is leading to the development of new conceptual models, such as that of supercell tornadogenesis (Rasmussen and Straka 1999, manuscript submitted to *Mon. Wea. Rev.*). Other new findings and refinements are sure to arise from this wealth of data.

Increasing computational capability at the NCEP has aided in the severe storm forecast process with higher-resolution models, such as the 29-km mesoscale version of the Eta Model, known as the Meso Eta (Black 1994). Application of these higher-resolution models should improve results of some of the previously cited studies. For example, it is reasonable to expect better forecasts using the technique of Thompson (1998), which relied on the 80-km Eta Model.

What began as a one time ‘‘miracle forecast’’ by Fawbush and Miller on 25 March 1948 (Maddox and Crisp 1999), gradually evolved into a highly specialized organization (SELS/SPC) within the NWS dedicated to the difficult task of forecasting conditions favorable for the development of severe local storms anywhere in the 48 conterminous states. The watch process has contributed to the saving of many lives over the years and its terminology has found a place in our everyday vocabulary. For instance, one prestigious greeting card company has as one of its get-well cards, ‘‘Into each life some rain must fall’’ on the cover, and ‘‘followed by large hail and damaging winds’’ on the inside. In any event, forecasting severe weather still presents enormous challenges in the United States where there are more tornadoes than any place on Earth. For example, Cortinas and Stensrud (1995) while applying a mesoscale model to the severe weather outbreak of 21–23 November 1992 noted how assimilation and interpretation of mesoscale model output ‘‘will present both a tremendous opportunity and a tremendous challenge for operational forecasters.’’ Doswell et al. (1990) pointed out that the requirement for large values of CAPE and strong vertical shear for supercells is a common misconception and noted examples of supercells that occurred in only weakly unstable environments—again, a challenge to forecasters. However, the skills of meteorologists who pursue this endeavor coupled with continuing technological and scientific advances bode well for this important function.

Acknowledgments. The author is thankful to the two anonymous reviewers for providing many useful comments that improved the manuscript.

APPENDIX A

SELS Milestones

A historical outline of SELS (Severe Local Storms Unit, National Severe Storms Forecast Center).

1948	25 Mar: First tornado forecast (Fawbush and Miller) at Tinker AFB
1951	Fawbush and Miller established Severe Storms Forecast Center for Air Force facilities in 48 states
1952	March: WBAN Analysis Center Severe Storms Forecast Unit
1952	17 March: First tornado watch
1952	21 March: First successful tornado watch
1953	Renamed ‘‘SELS’’—Around the clock coverage
1954	Seven forecasters, six chartists, two research forecasters
1954	August: SELS transferred to Kansas City (911 Walnut St.)
1955	First convective outlook
1955	National Severe Storms Project (NSSP) established
1956	First SELS workshop held
1956	Air Force unit moved to Kansas City
1956	Radar Analysis and Development Unit (RADU) established
1957	Two types of forecasts: Aviation and public
1960	Donald House named meteorologist-in-charge (MIC)
1960	RADU began transmitting 3-hourly radar summary charts via fax
1961	Convective outlook transmitted by fax
1963	IBM 1620 computer installation
1964	NSSP Renamed National Severe Storms Laboratory (NSSL), moved to Norman, Oklahoma
1965	Allen Pearson named MIC
1965	IBM 1620 computer replaced by CDC 3100
1966	Renamed NSSFC and moved to 601 E. 12th Street
1968	Status reports for watches
1970	Satellite meteorologists assigned to NSSFC
1970	USAF unit moved to Offutt AFB (Nebraska)
1970	1500 UTC Day-1 outlook
1971	KCRT—First computerized data transmission, tested and installed
1972	National Public Service Unit (NPSU) established
1972	Satellite Field Services Station (SFSS) established and collocated with NSSFC
1973	Aviation and public watches combined
1973	Regional Weather Coordination Center (RWCC) established
1975	RWCC ceased operations
1976	Techniques Development Unit (TDU) established
1978	RADU ceased operations
1978	Convective SIGMET unit established
1978	AFOS installed
1978	Convective outlook update at 1930 UTC (1 Feb–1 Sep) and when severe forecast otherwise
1980	Frederick Ostby named director
1982	1930 UTC convective outlook issued year round—Fax product year round

1982	2 Apr: First particularly dangerous situation (PDS) watch
1982	National Aviation Weather Advisory Unit (NAWAU) established
1982	CSIS, First operational McIDAS workstation, installed
1983	NSSFC transferred organizationally to NMC
1983	SFSS became part of NSSFC
1984	NSSFC computer upgraded—DG MV/4000
1986	First day-2 outlook
1986	First mesoscale discussion
1987	NSSFC computer upgraded—DG MV/7800
1988	Converted SFSS positions to mesoscale meteorologists
1988	Lightning data available on test basis
1988	PC technology introduced
1991	VDUC (enhanced McIDAS workstation) installed to replace CSIS
1994	NPSU ceased operations
1994	First NSSFC internet access
1995	First 0200 UTC day-1 outlook
1995	NSSFC World Wide Web site established
1995	SELS became SPC, NAWAU became Aviation Weather Center (AWC)
1995	Joseph Schaefer named SPC director
1997	SPC completed move to Norman

APPENDIX B

SELS Lead Forecasters in Place in 1972 and Beyond

Forecasters are listed in the chronological order that they became leads. At any one time there were five of these forecasters fulfilling this role in the unit; for example, in 1973, the five leads were Galway, Magor, Crumrine, David, and McGuire. At the time of the transfer of the SPC to Norman, Oklahoma, the five were Hales, Weiss, Rogash, Vescio, and Corfidi.

Joseph G. Galway (1952–65, 1972–84)
Bernard W. Magor (1953–77)
Hilmer A. Crumrine (1962–74)
Clarence L. David (1965–79)
Edward L. McGuire (1971–75)
Larry F. Wilson (1975–93)
John E. Hales (1975–present)
James H. Henderson (1977–84)
Robert H. Johns (1979–94)
Steven J. Weiss (1984–present)
Richard W. Anthony (1985–94)
Donald Baker (1994–95)
Joseph A. Rogash (1994–present)
Michael D. Vescio (1994–present)
Steven F. Corfidi (1994–present)

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