The Birth and Early Years of the Storm Prediction Center

STEPHEN F. CORFIDI

NOAA/NWS/NCEP/Storm Prediction Center, Norman, Oklahoma

(Manuscript received 12 August 1998, in final form 15 January 1999)

ABSTRACT

An overview of the birth and development of the National Weather Service's Storm Prediction Center, formerly known as the National Severe Storms Forecast Center, is presented. While the center's immediate history dates to the middle of the twentieth century, the nation's first centralized severe weather forecast effort actually appeared much earlier with the pioneering work of Army Signal Corps officer J. P. Finley in the 1870s.

Little progress was made in the understanding or forecasting of severe convective weather after Finley until the nascent aviation industry fostered an interest in meteorology in the 1920s. Despite the increased attention, forecasts for tornadoes remained a rarity until Air Force forecasters E. J. Fawbush and R. C. Miller gained notoriety by correctly forecasting the second tornado to strike Tinker Air Force Base in one week on 25 March 1948. The success of this and later Fawbush and Miller efforts led the Weather Bureau (predecessor to the National Weather Service) to establish its own severe weather unit on a temporary basis in the Weather Bureau–Army–Navy (WBAN) Analysis Center Washington, D.C., in March 1952.

The WBAN severe weather unit became a permanent, five-man operation under the direction of K. M. Barnett on 21 May 1952. The group was responsible for the issuance of ''bulletins'' (watches) for tornadoes, high winds, and/or damaging hail; outlooks for severe convective weather were inaugurated in January 1953. An unusually large number of strong tornadoes, forecaster inexperience, and criticism regarding the unit's products culminated in staff and policy changes after it was renamed the Severe Local Storms Warning Service (SELS) in June 1953.

SELS moved from Washington to Kansas City in September 1954 in part to be closer to ''tornado alley'' and to take advantage of existing nationwide teletype communication facilities. The unit also gained a new leader when D. C. House replaced Barnett as SELS chief early that year. House instituted changes that led to more accurate watches. He also fostered the development of a separate research and development unit, an effort which had been initiated by Barnett.

SELS continued to grow as additional forecast and support staff were added through the remainder of the 1950s and 1960s. It was renamed the National Severe Storms Forecast Center (NSSFC) upon relocation to a new facility and the assumption of local and regional forecast duties in 1966. Meanwhile, the research group to which SELS had given birth in the mid-1950s left Kansas City and merged with the Weather Bureau's Weather Radar Laboratory to form the National Severe Storms Laboratory (NSSL) in Norman, Oklahoma, in 1964. SELS, renamed the Storm Prediction Center, joined NSSL in Norman in January 1997.

1. Introduction

The Storm Prediction Center (SPC) in Norman, Oklahoma, provides short-term forecasts of hazardous weather in the United States to the public and the National Weather Service's (NWS) field offices. The SPC, formerly known as the National Severe Storms Forecast Center (NSSFC), is a component of the NWS's National Centers for Environmental Prediction (NCEP; see McPherson 1994). The center continuously monitors for all types of hazardous weather and issues tornado and severe thunderstorm watches on an as-needed basis. It also issues special messages highlighting the mesoscale aspects of developing weather hazards and prepares regularly scheduled convective weather outlooks. The center is responsible for the 48 contiguous states and the adjacent coastal waters.

The SPC is an outgrowth of a series of efforts dating back to the late 1800s to better understand and predict severe convective storms. Several papers have examined some of these endeavors in recent years. Schaefer (1986) tracked the development of severe weather forecasting from the purely empirical techniques of the nineteenth century to the more physically based methods of today. Galway (1989, 1992) discussed the evolution of severe weather warning criteria in the United States and described some of the early investigations that made tornado forecasts a reality by 1950. Ostby (1992) and Doswell et al. (1993) reviewed the operational aspects of the NSSFC in the early 1990s. Lewis (1996) examined the life and work of Joseph G. Galway, who devoted nearly his entire career to the forecasting of severe local storms. Elsewhere in this issue, Bradford (1999) de-

Corresponding author address: Stephen F. Corfidi, NOAA/NWS/NCEP, 1313 Halley Circle, Norman, OK 73069.
E-mail: stephen.corfidi@noaa.gov

scribes the development of severe weather warning and preparedness activities in the United States. The present paper focuses on the birth and early years of the SPC, and on its relationship to other federal severe weather programs.

While SPC's immediate history dates to the early 1950s, its roots may be traced much further. The development of a centralized weather forecast service in the 1870s (Whitnah 1961; Hughes 1970) made apparent the need for improved documentation and increased understanding of destructive local storms. Leading this effort was Sgt. John P. Finley, of the U.S. Army Signal Corps.[1] Between 1883 and 1887, Finley organized a team of more than 2000 ''tornado reporters'' east of the Rockies to document observations of tornadoes and their associated weather conditions (Galway 1992). Using these data, a set of maps and guidelines were assembled to describe characteristic tornado-producing weather patterns based on the shape, intensity, and orientation of the observed isobaric and isothermic fields. Finley used these charts along with what limited climatological data was available to issue 57 experimental tornado ''alerts'' in 1884 and 1885. While the accuracy of these alerts remains the subject of some controversy (e.g., Murphy 1996), it must be conceded that his effort marks the first scientific attempt to anticipate severe local storm activity in the United States (Schaefer 1986).[2]

A ban on the use of the word ''tornado'' in Signal Corps forecasts kept Finley's predictions from being made public after 1886. The chief signal officer believed that public fear induced by a prediction of tornadoes ''would eventually be greater than that which results from the tornado itself'' (U.S. Army 1887).

Little progress was made in the understanding and forecasting of severe convective weather in the 1890s and early 1900s. Although researchers such as Letzmann pursued the topic in Europe (see Peterson 1992), tornadoes garnered little interest in this country. Forecasts did occasionally mention the possibility of ''destructive'' local storms, such as on the morning of 27 May 1896, prior to the touchdown of a killer tornado in St. Louis. But Weather Bureau policy continued to prohibit use of the word tornado in public forecasts (Galway 1973). Bureau officials held firm to the belief that the word tornado would provoke undue fear and alarm, and that greater knowledge of upper atmospheric conditions was needed before sufficiently accurate forecasts could be made for the small areas involved. Indeed, J. I. Widmeyer, director of the Oklahoma section of the Weather Bureau, charged that residents in his state were ''fleeing to caves and cellars whenever thunderstorms appeared'' because of earlier sensationalist reports about tornadoes (Abbe 1899). Widmeyer felt that ''exposure to the dampness of (storm) shelters resulted in more deaths than all the tornadoes that had ever occurred.''

Airplane, kite, and pilot balloon observations brought major advances to the science of meteorology in the 1920s and 1930s. Important studies such as those by Humphreys (1926) and Varney (1926) for the first time examined the unusual temperature profiles associated with many tornadic storms. The development of the radiosonde was especially significant since it made possible routine upper air observations by the late 1930s (Galway 1973).

Meteorological research accelerated following the nation's entry into World War II in December 1941. The war brought a heightened awareness of the threat posed by lightning and tornadoes on munitions plants. In response to this threat and in cooperation with the military, the Weather Bureau established a dense network of storm spotters in the vicinity of plants devoted to the manufacture or storage of ammunition during the early 1940s (Altman 1954; Galway 1992; Doswell et al. 1999). This network was soon expanded to include airfields, training camps, and other military posts. The networks were used for local warning purposes and were disbanded shortly after the war.

Concern over the vulnerability of war-related facilities to severe storms and an unusually active tornado season over the central United States prompted the War Advisory Committee on Meteorology to specifically address the problem of tornado development during the latter part of 1942 (Galway 1992). A result of this effort was publication of a significant two-part paper by Showalter and Fulks (1943) that discussed the surface and upper-level synoptic environment of tornadoes. But even though knowledge of the conditions that fostered tornado formation was on the increase, and the ban on the word tornado was lifted in 1938, very few forecasts of tornadoes were issued during the 1940s. The continuing reluctance on the part of Weather Bureau district offices to forecast tornadoes reflected the feeling that the public for the most part was uninformed as to the nature and purpose of tornado forecasts. There was, in fact, evidence to back this belief as some communities responded in near panic to rumors of impending tornadoes (Altman 1954).

2. A forecasting renaissance

It was the fortuitous occurrence of two tornadoes at the same place in less than a week that would lead to the reestablishment of a centralized severe weather forecasting program in the United States by the midpoint of the twentieth century. On the evening of 20 March 1948, a tornado struck Tinker Air Force Base, Oklahoma, without warning, causing more than $10 million in damage and several injuries. The funnel moved

[1] The Signal Corps was responsible for the collection of weather data and the dissemination of forecasts prior to the creation of the U.S. Weather Bureau in 1890.

[2] The interesting story of Finley and his work may be found in Galway (1985a,b).

diagonally across the airfield, destroying aircraft and shattering the control tower's windows. The following day, the commanding general of the Oklahoma City Air Materiel Area, Fred S. Borum, directed the base weather officers at work that evening, Major E. J. Fawbush and Captain R. C. Miller, to study the event and investigate the possibility of forecasting tornadic storms.

Fawbush and Miller immediately set out to review the work of Showalter and Fulks and others such as Lemons (1938) and Lloyd (1942). The officers did not have to wait very long to put their newfound knowledge to the test. On the afternoon of 25 March, meteorological conditions somewhat similar to those that had appeared five days earlier[3] prompted the officers to put their reputations (and jobs) on the line: they forecast that another tornado might strike the base that night. Shortly after 1800 local time, the second tornado in less than a week raked Tinker Air Force Base, causing $6 million in damage but, thanks at least in part to preparedness efforts, no injuries or deaths.

The accuracy of Fawbush and Miller's forecast drew attention throughout the meteorological community, and the officers were soon responsible for the prediction of tornadoes across much of the central United States (see Miller 1972; Miller and Crisp 1999). A formal Air Weather Service unit, the Severe Weather Warning Center (SWWC), was established at Tinker under the direction of Fawbush and Miller in February 1951. The unit was responsible for the preparation of advisories for tornadoes, damaging winds, and extreme turbulence at all air force sites on the U.S. mainland.

Early on, many of SWWC's forecasts were routinely released to the Weather Bureau and the public, especially in Oklahoma and across the South (Popkin 1967). This ended on 5 March 1952, following an outbreak of tornadoes in Alabama, Arkansas, and Georgia. Word had leaked out that military bases in the region had been warned of possible tornadoes to, as Lynch (1970) puts it, ''the exclusion of the public.'' In response to the ensuing controversy, air force personnel were soon prohibited from releasing SWWC forecasts to the public (Altman 1954).

Limiting access to its forecasts drew only more attention to the air force's successful tornado program. The prohibition also increased pressure on Weather Bureau officials to either relay SWWC forecasts to the public or issue their own. In July 1950, such pressure prompted Bureau Chief Francis W. Reichelderfer to issue a memorandum advising field office employees to avoid phrases such as ''The Weather Bureau does not make tornado forecasts'' or ''We are not permitted to issue tornado forecasts'' when conducting poststorm media interviews (U.S. Weather Bureau 1950). Such statements, Reichelderfer said, incorrectly implied that the bureau was unwilling or unable to make tornado forecasts. The note also warned, however, that because tornado forecasting was one of the bureau's ''most difficult tasks,'' that a ''good probability of verification'' should exist when such forecasts are made.

3. The Weather Bureau responds

Another season of mounting public and congressional (Congressional Record 1952) debate finally persuaded Reichelderfer to establish the bureau's own severe weather unit in March 1952. The unit was set up in Washington, D.C., at the WBAN Center, a joint weather analysis and forecasting operation of the Weather Bureau, army, and navy.[4] Fifteen forecasters from the WBAN analysis section, the bureau's central research office, and its field stations were chosen to staff the unit on an interim basis. Some of these individuals had participated in a ''visiting forecaster'' program started by Reicheldefer in 1950 that brought selected field personnel to the bureau's Central Office to help develop severe weather forecast techniques (Galway 1992). In addition, during the winter of 1951/52, L. Carstensen and Frederick Shuman[5] of the bureau's Scientific Services Division had been tasked with studying the large-scale synoptic features associated with tornadoes in the Midwest (Altman 1954). The efforts of these and other pilot programs were now about to pay off.

The new WBAN group was prepared to issue public forecasts on Sunday, 9 March, but another week would pass before conditions were deemed favorable for tornadic storms. On the morning of Monday, 17 March, the 1500 UTC 500-kPa analysis revealed a small but rather intense short-wave trough over the Four Corners region (Fig. 1). The disturbance was expected to move rapidly east around the periphery of an upper low over Colorado. Forecasters reasoned that this motion would cause the low to redevelop and strengthen over the southern plains, creating an environment favorable for tornadoes. At 2300 EST on Monday, 17 March, the WBAN unit issued its first public tornado ''bulletin'' (Altman 1954; Galway 1989). This forecast, shown in Fig. 2, mentioned the ''possibility of tornadoes in east-

[3] See Maddox and Crisp (1999 in this issue) for a comparison of the synoptic environments of 20 and 25 March 1948.

[4] The WBAN Center was located at 24th and M Streets in northwest Washington. It was created by the executive order of F. D. Roosevelt in 1942 to consolidate civilian (Weather Bureau) and military (army and navy) meteorological efforts during World War II. Centralization proved so advantageous that the office remained in operation after the war. To better exploit the emerging power of computers, the center moved to Suitland, Maryland, to join the bureau's Extended Forecast Section and the Joint Numerical Weather Prediction Unit as the National Weather Analysis Center (NAWAC) in 1955. These three groups were later combined to form the National Meteorological Center (NMC) in January 1958. More recently, NMC was reorganized as NCEP in October 1995.

[5] Shuman was later director of the NMC (1963–81).

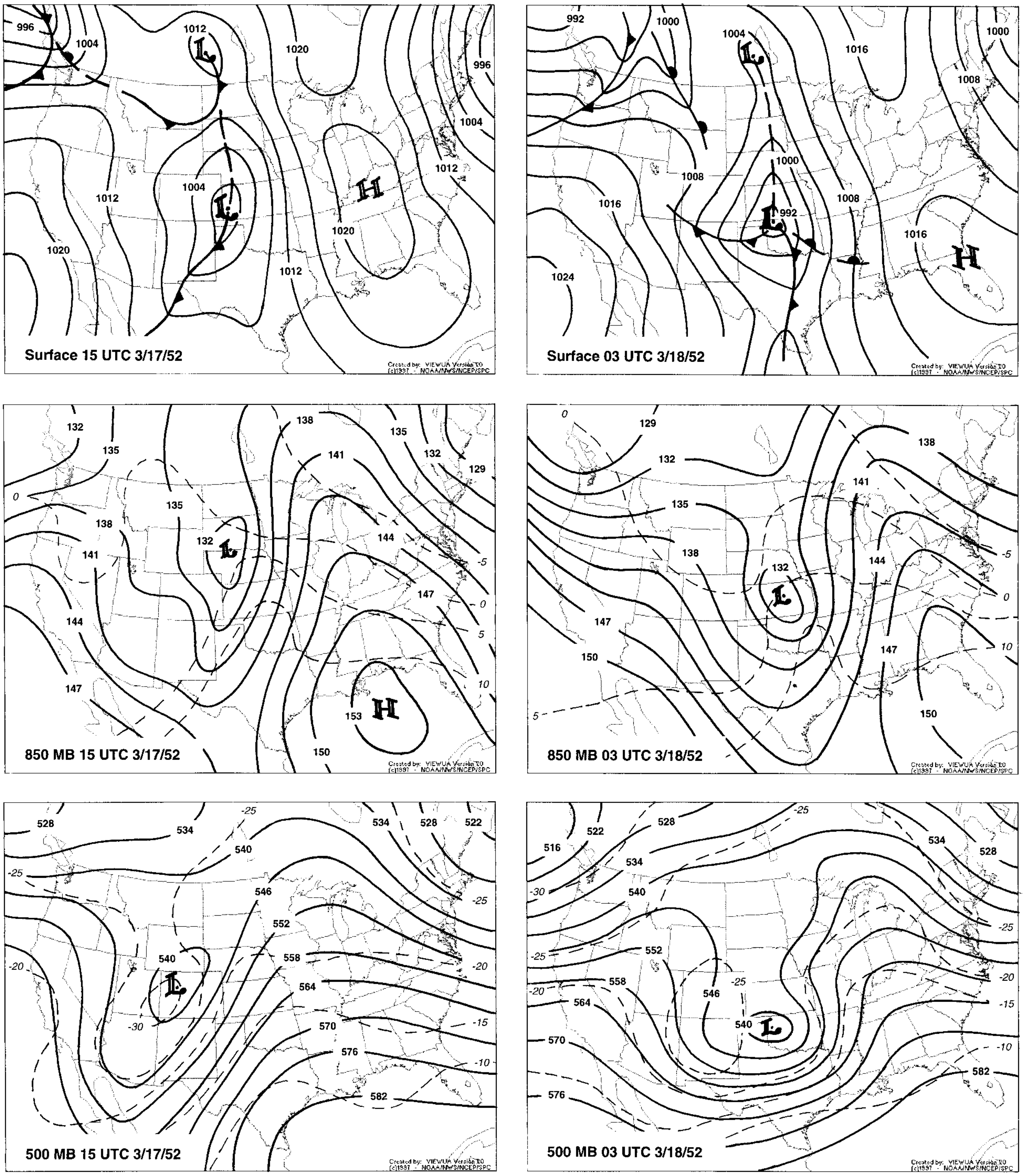

FIG. 1. Conventional surface, 850-, and 500-kPa analyses valid at 1500 UTC 17 Mar 1952 (left) and 0300 UTC 18 Mar 1952 (right). Surface pressure in mb, heights in mb heights in dam (bold), and temperatures in °C (italics).

ern Texas and extreme southeastern Oklahoma tonight, spreading into southern Arkansas and Louisiana before daybreak'' on 18 March.

Although the low did indeed deepen over Oklahoma (Fig. 1) and two tornadoes occurred in north Texas, none were reported in the area outlooked (Fig. 2). In retrospect, it appears that the persistence of an anticyclone of continental origin over the forecast region

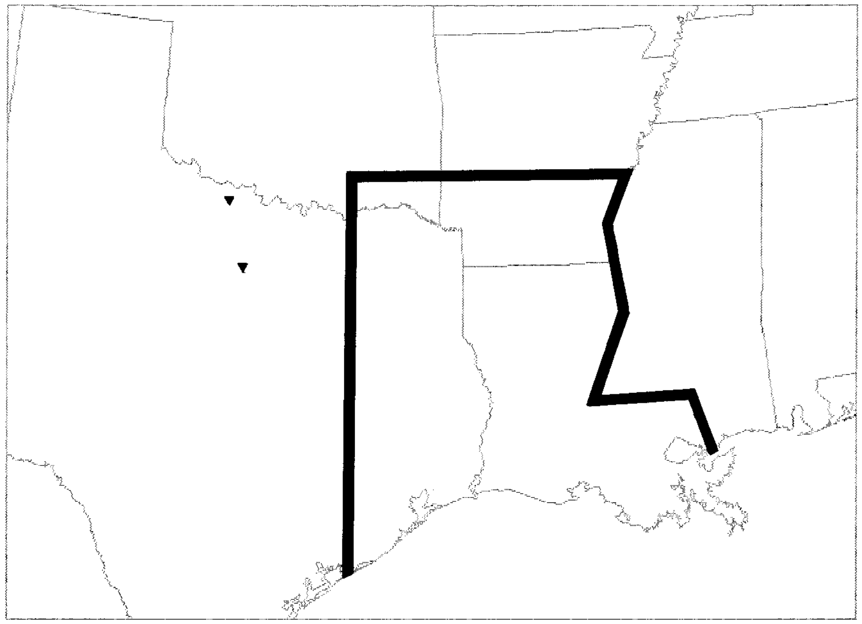

FIG. 2. Areal extent of WBAN tornado bulletin issued at 2300 EST (0400 UTC) 17 Mar 1952. Triangles denote tornadoes reported during the valid time period of the watch.

prior to 17 March inhibited boundary layer moisture return and destabilization despite the presence of considerable kinematic support for severe convective storms.

The active weather pattern that prompted the first WBAN tornado forecast on 17 March continued through the remainder of the week. On Friday, 21 March, a deep trough that had brought a late winter storm to the Great Basin on 19 and 20 March was poised to move east across the central United States. Given the intensity of this system and the presence of a strong baroclinic zone over the southern plains to focus development, significant surface cyclogenesis was expected to occur over Oklahoma and Arkansas (Fig. 3). Midtropospheric winds were already in excess of 40 m s^{-1} over the southern plains on the morning of 21 March and were expected to increase as a 50 m s^{-1} speed maxima over southern New Mexico continued eastward during the day. Near the surface, ample boundary layer moisture was present to support deep convection over the lower Mississippi Valley. The 15°C isodrosotherm extended from southeast Oklahoma to west Tennessee. Thus, it appeared that there would be at least some threat for tornadoes as the Oklahoma low deepened and moved northeastward later in the day.

Forecasters issued WBAN Tornado Bulletin Number Two at 1300 EST on Friday, 21 March. The bulletin alerted the public to the possibility of tornadoes in ''the northern half of eastern Texas, southern Arkansas, extreme southeastern Oklahoma and northern Louisiana late this afternoon and extending into this evening.'' An update at 2230 EST expanded the forecast to include parts of Kentucky, west Tennessee, and southern Indiana through daybreak (Fig. 4).

At 1530 EST, a tornado touched down in Diercks, Arkansas, the first in a series of more than two dozen tornadoes that continued through the next morning across parts of Arkansas, Kentucky, Mississippi, Missouri, and Tennessee. The storms claimed 204 lives and injured more than 1000 (Carr 1952; Galway 1981). Most of the activity occurred along the warm front associated with the southern plains low. Total damage was estimated at more than $15 million. As Fig. 4 shows, although forecasters failed to anticipate the significance of the event in northeast Arkansas, the storms elsewhere in that state and those in Tennessee and Kentucky were well forecast. The high death toll appears to at least some extent reflect the comparatively poor communication and disaster preparedness plans that were in place at the time.

The earliest tornado bulletins such as those for the 21 March event were transmitted directly from WBAN to the district forecast offices via the Service A[6] teletype network. Dissemination would continue as the district centers alerted local Weather Bureau and media offices by phone. The district centers also included the bulletins in their appropriate state forecasts. In addition, the WBAN unit prepared a separate release for the Wash-

[6] The Service A teletype communication network was operated by the Civil Aeronautics Administration (CAA) for aviation weather messages.

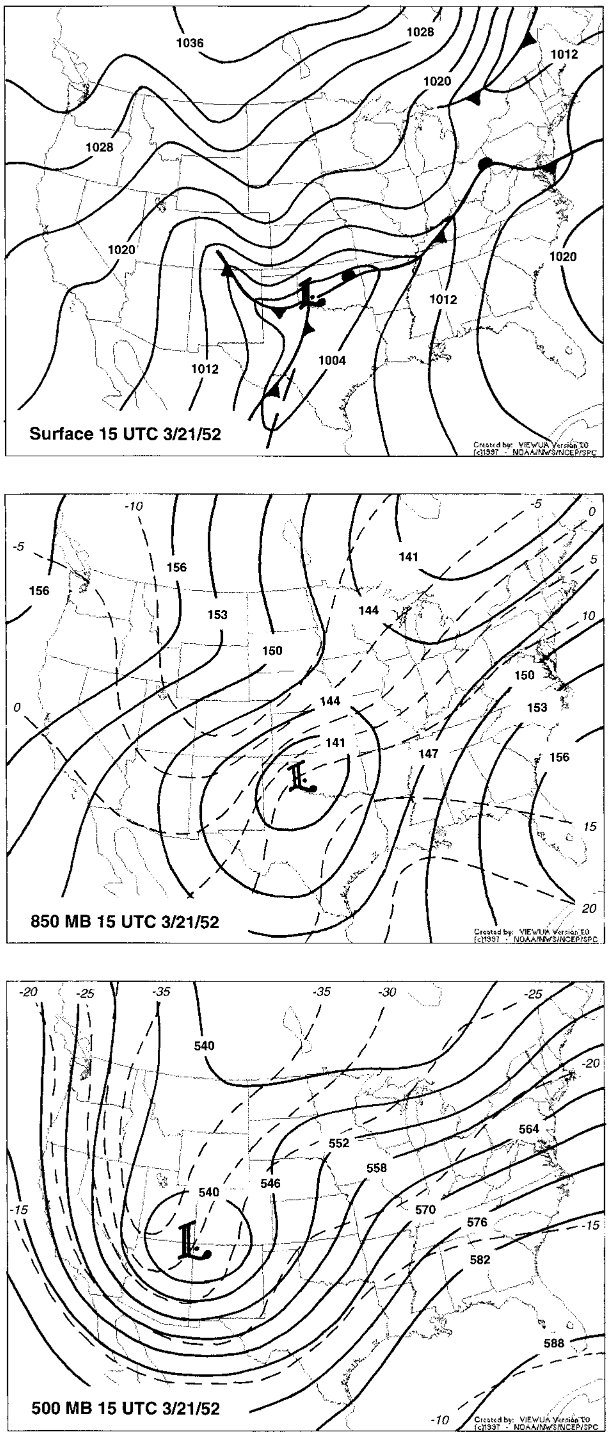

FIG. 3. As for Fig. 1 but for 1500 UTC 21 Mar 1952 (left) and 0300 UTC 22 Mar 1952 (right).

ington offices of the major press associations each time a tornado forecast was made (Altman 1954). This method of dissemination was, however, short lived. Beginning later that spring and continuing through the mid-1950s, tornado forecasts were released to the public by the bureau's district and local forecast offices, nearly always after consultation with the WBAN severe weather staff (see section 8).

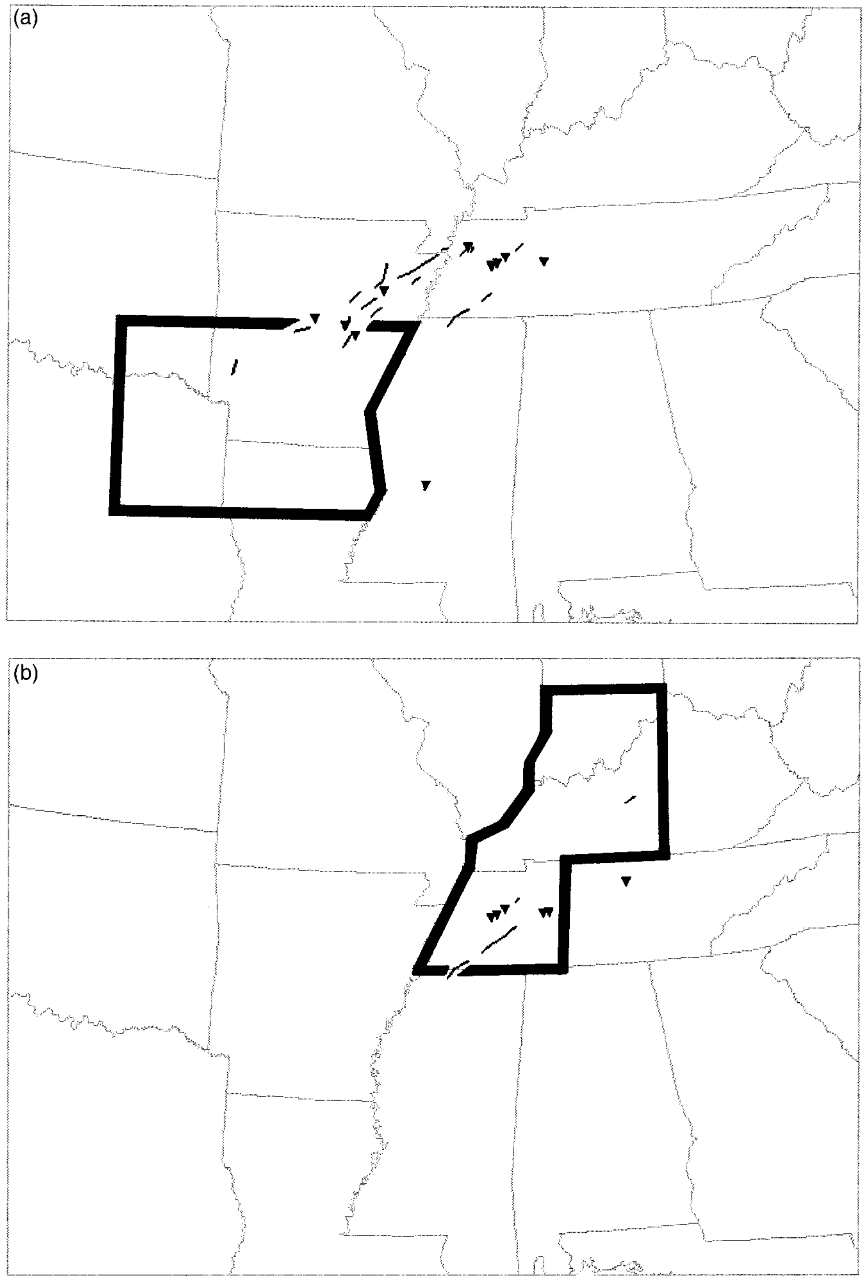

FIG. 4. Areal extent of WBAN tornado bulletins issued at (a) 1300 (1800 UTC) EST 21 Mar 1952 and (b) 2230 EST (0330 UTC) 21 Mar 1952. Triangles and lines denote reported tornadoes and tornado paths, respectively, during the valid time period of each watch.

4. A permanent severe weather unit

The WBAN severe weather group became a permanent operation on 21 May when it was formally recognized as the Severe Weather Unit (SWU) by Weather Bureau Circular Letter 20-52. Although the unit continued to use the center's facilities, it was still not considered a part of the joint Weather Bureau, army, and navy operation (U.S. Weather Bureau 1952). Forecast responsibility that had been limited to tornadoes expanded at this time to include damaging hail, high winds (greater than or equal to 50 mph), and extreme turbulence.

Five permanent forecasters were selected to provide around-the-clock coverage of the SWU in the summer of 1952 (Table 1). Members of the temporary staff that had been at work since March continued to cover shifts

TABLE 1. The first permanent SWU forecasters, their enter-on-duty dates (1952), and previous Weather Bureau assignments (WB = Weather Bureau; WBAS = Weather Bureau airport station).

Forecasters	Entered on duty	Previous assignments
Brunstein, Alan I.	1 Oct	WBAN Center
Carr, James A.	1 Sep	WBAN Center
Galway, Joseph G.	25 Jul	WBAS, Jacksonville, FL
Martin, Robert H.	15 Aug	WB Central Office
Stowell, David J.	2 Oct	WBAS, Fairbanks, AK

as necessary until the transition to permanent staffing was completed in September (Table 2).[7] The new forecasters were comparatively young and shared similar backgrounds. Most had been with the Weather Bureau less than 10 years and had attended meteorology school with the military during World War II. According to Galway (1992), relatively inexperienced forecasters were intentionally chosen as it was thought that they would be less likely to harbor preconceived notions about severe storm prediction. Three of the original five permanent SWU forecasters left the group within two years of their selection. Only Joseph Galway, the first forecaster to join the unit, remained with the SWU after 1955 (Lewis 1996).

A special "Instructions and Information" notice dated 20 May 1952 standardized the issuance of severe weather bulletins (U.S. Weather Bureau 1952). The notice stated that bulletins were to be released on an as-needed basis "to provide in a single message a description and short period forecast of severe weather conditions over the whole country in a concise, unified form." These forecasts thus differed from conventional forecasts that covered all the types of weather that might affect a specific locality. The period covered by each message was to be approximately 6 h. Updates were to be prepared as necessary, whether or not a previous forecast had expired, and each issuance was to be complete within itself. While their purpose was to highlight the potential for severe convective weather much as a watch does today, in terms of their geographical scope and format, bulletins were in fact more like present-day convective outlooks (Fig. 5). Use of standard aviation contractions minimized teletype transmission time.

To minimize false alarms and provide the necessary lead time to ensure adequate public response, bulletin areas were to be kept as small as possible. No restrictions, however, were placed on the geometric shape of the forecast areas. Forecasts were typically not parallelograms, but rather irregularly shaped regions that included parts of one or more states. Some were even circles (see, e.g.,

TABLE 2. Known temporary SWU forecasters (Jun–Sep 1952), and their permanent Weather Bureau assignments.

Forecasters	Assignment
Bristor, Charles L.	Central Office, Scientific Services Division
Croom, Herman L.	Unknown
Harris, Dale R.	Central Office, Scientific Services Division
Hughes, Grover D.	WBAN Center
James, Ralph P.	WBAN Center
Opplinger, Fred K.	WBAS, Baltimore, MD
Smith, Clarence S.	WBAN Center
Younkin, Russell J.	WBAS, Knoxville, TN

[7] Until 12 June 1952, SWU bulletins carried no record of the issuing forecaster. Beginning on that date, the forecaster's initials and those of the WBAN supervising analyst were included at the bottom of the message. At the present time, the names of only 8 of the original 15 temporary forecasters are known.

```
SEVERE WEATHER BULLETIN 211900Z
WEATHER BUREAU CENTRAL BULLETIN NUMBER 1

N/S SQUALL LINE LIKELY TO FORM THROUGH CENTRAL OR W CENTRAL
PORTIONS OF SOUTH DAKOTA, NEBRASKA, KANSAS AND WESTERN OKLAHOMA
BY ABOUT 2200Z.  SQUALL LINE WILL BE ACCOMPANIED BY THUNDERSTORMS
AND LOCAL SURFACE GUSTS TO OCCASIONALLY 50 KTS, AS WELL AS HEAVY
HAIL REACHING THE GROUND.  SQUALL LINE WILL MOVE EASTWARD AT
ABOUT 25 KTS.  MOST INTENSE ACTIVITY EXPECTED IN CENTRAL AND
EASTERN KANSAS.  IN ADDITION TO SQUALL LINE THUNDERSTORMS,
SCATTERED THUNDERSTORMS WILL FORM IN THE EASTERN DAKOTAS,
SOUTHERN AND WESTERN MINNESOTA, IOWA, NEBRASKA, KANSAS, MISSOURI,
OKLAHOMA, THE TEXAS PANHANDLE AND EASTERN NEW MEXICO.  SCATTERED
THUNDERSTORMS WILL PERSIST THROUGHOUT THE AFTERNOON IN FLORIDA.

(Message sent via Circuit 7072 to LaGuardia (New York) and Miami,
and via teletype to Kansas City and Salt Lake City)
```

FIG. 5. The first SWU Severe Weather Bulletin, issued 21 May 1952 (transcribed from original aviation contraction format).

Lewis 1996, p. 265). The areas were determined by the severe weather forecaster in collaboration with the WBAN supervising analyst and the District Forecast Center(s) involved. Assistance was also occasionally provided by Carstensen, Shuman, and WBAN supervisor Joseph R. Fulks. The products were consecutively numbered on a monthly basis until February 1954, when annual numbering began.

The SWU gained approval for a separate supervisory position during the summer of 1952, and Kenneth M. Barnett was selected as unit supervisor the following December. Barnett brought a varied operational background to the SWU. He had served as a navy aerologist during World War II, an aviation forecaster in Kansas City from 1946 to 1948, and, most recently, as an advisor to the Irish Meteorological Service (Galway 1992, 1994). Prior to Barnett's arrival, SWU administrative duties had been handled by WBAN chief Fulks. Even after Barnett's selection, however, overall responsibility for SWU products remained with Fulks.

During his time with the SWU, Barnett emphasized the thermodynamic parameters involved in the preparation of tornado forecasts (Barnett 1953). His work focused on identifying regions where steep 850–700-mb lapse rates were present above areas of high boundary layer moisture content. Barnett's objective technique, plotted daily on the ''potential instability'' chart (later known as the ''raob'' chart; Galway 1992), was the forerunner of the two-part ''thermodynamic analysis'' produced today at SPC.

Barnett also endeavored to develop an official definition of a severe thunderstorm. As strange as it might seem, the Weather Bureau had embarked on a program for forecasting severe storms without bothering to define just what was meant by ''severe.'' Even the 50 mph wind threshold mentioned earlier was a loose figure, as early bulletins reveal frequent use of ''gusts 40 to 50 kts'' (46–58 mph). In fall 1953, in consultation with field and central office staff, Barnett issued ''SELS Criteria for Severe Thunderstorms'' (U.S. Weather Bureau 1953c), which finally quantified the hail size (greater than or equal to 1 in.) and wind speeds (average speed of at least 50 mph, and/or gusts to 75 mph or more) officially recognized as severe (Galway 1989).

Albert K. Showalter succeeded Fulks as WBAN supervisor in January 1953. Showalter was no stranger to the field of severe weather forecasting: nine years earlier, he had coauthored the two-paper report with Fulks already mentioned (Showalter and Fulks 1943) that discussed the synoptic conditions associated with tornado development. This report helped lay the foundation for Fawbush and Miller's work in the late 1940s. Showalter was also known for the index of thermodynamic instability that bears his name (Showalter 1953). His work was subsequently used in the development of Galway's ''lifted index'' in the mid-1950s (Galway 1956). Both indices remain valuable diagnostic tools today.

5. The birth of SELS

The Severe Weather Unit evolved rapidly in 1953—a year that produced an unusually large number of significant tornadoes. In January, the unit initiated an experimental program to issue daily outlooks of the severe weather potential for the upcoming day. These trial ''Severe Weather Discussions'' were issued around 0500 CST and were intended as guidance for selected Weather Bureau district offices for the noon to midnight (CST) time period. Both existing convective weather and the prospects for additional development were discussed. The product became operational in February and was renamed the ''Convective Outlook'' when regular transmission on Service A began in April 1955.

The SWU was renamed the Severe Local Storm Warning Service (SELS) on 17 June 1953, shortly after death-dealing tornadoes struck the major population centers of Waco, Texas; Flint, Michigan; and Worcester, Massachusetts. Devastating storms from Nebraska to New England on 7–9 June alone claimed more than 200 lives, and the Waco storm was the worst ever in Texas (Lynch 1970). These events severely tested the endurance of the unit's young and relatively inexperienced staff. Although the tornadoes on 7 and 8 June were well forecast, those that occurred in New England on 9 June caught forecasters by surprise. One forecaster requested, and was granted, a transfer following the Worcester storm (Lewis 1996).

The Worcester event, taunts from those who continued to believe that severe storms were unpredictable, and complaints that the unit's forecast areas were too large all made SELS the focus of mounting criticism during the summer of 1953 (Galway 1989). In addition, district forecasters were sometimes less than enthusiastic about accepting forecast products from a centralized forecast center.

Criticism regarding watch size was largely unwarranted as the size of tornado forecast areas was in fact already on the decrease in 1953. Average forecast area size decreased from nearly 38 000 mi^2 in 1952 to 27 000 mi^2 during the first half of 1953 (Galway 1989).[8] SELS supervisor Barnett, however, did not think that this was enough. Bowing to pressure from the Air Transport Association, a June 1953 memo was issued limiting the suggested size of an ''ideal'' forecast area to just 10 000 mi^2 (U.S. Weather Bureau 1953b). That such a size criteria would be nearly impossible to attain is illustrated by the fact that none of the watches issued during the remainder of the year covered less than 10 000 mi^2, and only three were for less than 20 000 (Galway 1989).

By midsummer, it was clear that the mounting pressure was taking its toll on Barnett and that he did not want to spend another season with SELS. The search to find

[8] By comparison, the average area covered by SPC tornado and severe thunderstorm watches today is about 25 000 mi^2 (about half the state of Iowa).

FIG. 6. SELS chief D. C. House in 1961.

a new supervisor began in the late fall of 1953, after Barnett accepted an assignment with the Army Signal Corps. Barnett did not, however, leave SELS until the following spring.

Kansas City Assistant Regional Director Donald C. House was selected as Barnett's replacement in March 1954 (Fig. 6). In the regional office House had had frequent contact with Scientific Service Division personnel and was familiar with the various tornado research efforts under way at the time in the central states (Galway 1989). He had also done some applied work with the Showalter index (House 1952) and investigated the significance of the 700-mb ''no advection'' line (U.S. Weather Bureau 1954). House's mission, as stated by Bureau Chief Reichelderfer, was two part: to improve severe weather forecast techniques and to reduce the size of forecast areas (Galway 1989). House accomplished his second task during his first year: The average size of SELS tornado ''bulletins'' decreased from more than 20 000 mi^2 in late 1953 to less than 15 000 mi^2 in 1954 (Galway 1989).[9]

House's enthusiasm for severe weather forecasting was immediately apparent. He manned the forecast desk several days a week during severe weather season (Fig. 7) and strived to enhance the scientific basis of the unit by furthering staff research efforts begun under Barnett. Under House's direction, SELS meteorologists made numerous lasting contributions to severe weather forecasting in the mid- to late 1950s.[10] House also encouraged forecasters to apply the vorticity advection concepts described by Riehl et al. (1952). The goal was to place more emphasis on the role high-altitude conditions play in the development of severe convective storms. As Galway (1989) states, House's leadership was to a large extent responsible for establishing SELS ''as a viable and respected forecast unit of the Weather Bureau.'' House remained with SELS until August 1965, when he assumed a post with the newly formed Environmental Science Services Administration (ESSA) in Washington.

6. The move to Kansas City

In anticipation of a convective season perhaps as active as the previous one, SELS staffing increased to include a sixth forecaster and an additional researcher in April 1954. The researcher, Ferdinand C. Bates, joined Robert G. Beebe and assistant Georgina Neubrand, both of whom had come to SELS in 1953 (see section 10). Including House and the 6-member charting staff, SELS staffing now totaled 16.

Perhaps the most noteworthy highlight of 1954 was the unit's relocation from Washington to Kansas City. While the selection of House, with his Kansas City base, as SELS supervisor may not have been totally incidental to the late summer move, officially the relocation was

[9] The reduction in watch size was, unfortunately, accompanied by a comparative decrease in forecast accuracy. As a result, average watch size soon returned to about 27 000 mi^2 (Schaefer 1998, personal communication).

[10] These papers include those by F. C. Bates (1955), R. G. Beebe (1995), Beebe and Bates (1955), J. A. Carr (1955), D. S. Foster (1958), Foster and Bates (1956), J. G. Galway (1956), J. T. Lee (1955), and B. W. Magor (1958); others may be found in Galway (1992).

FIG. 7. View of the SELS plotting board, showing D. C. House (center) with forecasters H. Swenson (left) and J. Galway (right), Apr 1956.

made to satisfy two main goals. The first was to silence plains and Midwestern critics who believed that the office should be located in an area more prone to severe weather. The second objective was to provide increased contact and more rapid communication with those district offices typically affected by severe weather (Chicago, Kansas City, and New Orleans). Since Kansas City was already an aviation message switching center, it was strategically located for nationwide dissemination of teletype weather messages. The move was also the first step in a planned consolidation of the nation's severe weather forecasting efforts. This plan would see the SWWC join SELS in Kansas City in 1956 (see section 7).

FIG. 8. Federal building at 911 Walnut Street, Kansas City, MO, c. 1958.

The Kansas City relocation was made in two phases. House and three forecasters arrived in August. They joined a fourth forecaster who was already in Kansas City and had just been assigned to SELS. On 1 September 1954, Kansas City became responsible for that portion of the country west of 90° longitude, while Washington continued to handle activity to the east. Two weeks later, Kansas City assumed responsibility for the entire nation, and the WBAN group ceased operation (Galway 1989). Of the four remaining forecasters in Washington, two left for Kansas City that week, while the other two accepted assignments elsewhere in the analysis center.

The first tornado bulletin transmitted from Kansas City was issued by D. C. House at 1410 CST on 8 September 1954. The forecast covered parts of northern Nebraska and southeast South Dakota and was valid from 1700 to 2300 CST. It did not verify (Galway 1973).

SELS shared its first home in Kansas City with the district forecast office at Municipal Airport (now known as the ''Downtown Airport''). After about a year at the airport, SELS joined the district office in moving to the seventh floor of the nearby federal office building at 911 Walnut Street in November 1955 (Fig. 8). Three years later, the office moved to more spacious quarters on the

FIG. 9. J. R. Lloyd, meteorologist-in-charge of the Kansas City forecast office, 1948–52.

ninth floor. SELS remained at that location until June 1966, when it relocated to the 17th floor of the new federal building at 601 East 12th Street.

Although SELS remained in Kansas City for more than 40 years and became closely identified with the town, it was not, in fact, that city's first severe weather connection. In January 1952, at the request of Meteorologist-In-Charge (MIC) Joseph R. Lloyd (Fig. 9), the Kansas City district office had been granted permission to establish a small research group to apply and further develop the severe weather forecasting techniques pioneered by Lloyd (1942), Showalter and Fulks (1943), and the SWWC. The group was authorized to request special radiosonde ascents at Weather Bureau sites as deemed necessary. It was Lloyd's intention to use the research work to help establish a tornado and severe weather forecasting program at Kansas City in 1953 or 1954.

Lloyd was a strong-willed individual and knew that his research proposal would not endear him to Weather Bureau management. He was instead motivated by pressure from outside sources to have Kansas City relay SWWC tornado forecasts to the public and/or issue similar advisories of its own (Galway 1992). Instigation in this regard was especially strong in Oklahoma as the SWWC routinely notified public safety and Red Cross officials in that state whenever a tornado forecast was issued.[11] As a result, many SWWC forecasts were finding their way to the public. It should be remembered that at this time ultimate forecast responsibility for tornadoes within a given district still resided with the district office (Foster 1953). Lloyd reasoned that if the district centers were to reliably forecast tornadoes, it would be wise to establish some degree of forecast expertise at the district level.

Lloyd had invited Fawbush and Miller to present their tornado prediction technique to the Kansas City forecast staff in February 1950, just weeks after the two had made a presentation at the annual meeting of the American Meteorological Society in St. Louis. Shortly thereafter he set up a liaison with the Tinker staff, to ensure that all SWWC forecasts were sent to his office via teletype (McDermott 1951; U.S. Air Force 1951). By 1952, Lloyd himself was regularly issuing reworded air force forecasts to the press (Lynch 1970).

After the formation of the WBAN SWU in May 1952, Lloyd's group was restricted to forecasting tornadoes only within the Kansas City district office's forecast area, and only after consultation with the SWWC and SWU. Kansas City remained, however, a liaison point between the SWU and SWWC, and all SWU coordination calls with SWWC were to be made through Kansas City (U.S. Weather Bureau 1953a).

Lloyd died in August 1952. His research program was reduced to a one-man operation run by D. S. Foster for its second and final season in 1953. The results of Foster's work (Foster 1953) clearly show the value of having an individual dedicated to a specific forecast task. For example, the percentage of days when severe weather occurred but no severe weather forecast was issued rose from 23% to 82% on Foster's days off (i.e., when the task was left to the regular district staff). Similarly, the percentage of tornadoes that occurred in forecast areas increased from 13% to 39% when Foster manned the separate severe weather desk.

In the fall of 1953, acting MIC Henry L. Jacobson petitioned the Weather Bureau central office to maintain an independent severe weather operation in Kansas City to complement the SWU in Washington. Not too surprisingly, Bureau Chief Reichelderfer, a champion of fiscal responsibility, rejected Jacobson's idea, citing duplication of effort. Nevertheless, although Lloyd's operation lasted barely two seasons, his pioneering efforts were instrumental in hastening Washington's decision to begin issuing routine severe weather forecasts in 1952. His work also, of course, helped pave the way for SELS' move to Kansas City in September 1954.

[11] Oklahoma was at the time part of the Kansas City district office's area of responsibility, which also included Kansas, Missouri, and Nebraska.

7. The operation grows

SELS of the mid-1950s was a small operation compared with the Storm Prediction Center of today. Typically, each shift was covered by a single forecaster and an accompanying chartist (data plotter). SELS did not work in isolation, however, as the unit shared space with the district office. The forecast desk was manned on a 24-hour basis only from March through June. Through the remainder of the year, the forecaster scheduled to cover the midnight shift (0000–0830 LT) worked a day ''research'' shift (0700–1530 LT) unless severe weather was expected during the overnight hours. The midnight person was, however, on call if unexpected severe activity did develop.

The receipt of data from Weather Bureau and military weather surveillance radars on a timely basis via the Service A teletype network was a problem that had plagued SELS since its earliest days. Creation of the dedicated Radar Report and Warning Coordination (RAWARC) teletype circuit in September 1955 solved this problem. With RAWARC, radar observations could now be received directly from each radar site, rather than on a time-available basis as was the case with Service A (Galway 1992). In addition, because the circuit's switching and control operation was collocated with SELS and the Kansas City district office, RAWARC could also be used for the rapid dissemination of SELS forecast products. A staff of 11 ''COMMS'' (communication) technicians provided continuous monitoring and control of the circuit. COMMS remained an integral part of SELS until automated switching and relay equipment arrived in 1985.

A separate Radar Analysis and Development Unit (RADU) was created in January 1956 to better utilize the data provided by the RAWARC circuit. RADU collected and analyzed civilian and military radar observations from around the country and transmitted hourly national summaries of the data on RAWARC. Duplicate reports of the same echo were eliminated, and echoes were assigned a relative strength depending upon the characteristics of the particular radar used to observe them. RADU's summaries proved very valuable to SELS. Forecasters could now not only examine the data in a more timely fashion but were also relieved from having to plot reports by hand. RADU was also responsible for the quality control of network radar observations and for the development of techniques to enhance the use of radar data in forecasting and warning (Ostby et al. 1989). The unit began facsimile transmission of a graphical national radar summary in 1960.

RADU's responsibilities changed considerably as network equipment and operational procedures evolved over the years. RADU's original staffing of 11 was reduced to 5 when it was reorganized as the ''SIGRAD'' Unit in April 1978.[12] SIGRAD provided plotting and analysis support to SELS and convective SIGMET forecasters.[13] The development of automated digitized radar plotting software at NSSFC allowed for the decommissioning of SIGRAD in October 1987.

Another group that joined SELS in the Kansas City forecast complex in January 1956 was the Air Force's SWWC. Relocation of the 40-man operation from Tinker Air Base was part of a larger Eisenhower administration effort to eliminate duplication of weather-related activities in the federal government. Negotiations for a joint severe weather center had actually been under way since before SELS left Washington in 1954. The Weather Bureau originally wanted the joint relocation to be in Chicago, while the Air Force favored Kansas City.

SWWC's advisories alerted military commanders and personnel to the possibility of severe weather at specific sites. The format and intent of SWWC forecast products thus differed considerably from those of SELS. SWWC influence fostered major content and format changes in SELS products in 1957 and 1961 (see section 8) and hastened the bureau-wide adoption of revised severe weather criteria during the same period (see Galway 1989, 590–592).

Pressure continued to eliminate duplication in the federal government's weather-related programs in the late 1950s. This eventually led to a proposal not overwhelmingly supported by air force personnel that SELS assume responsibility for all convective weather forecasts, both civilian and military. SELS assumed this role in February 1961, and the SWWC was disbanded. For the following three years (through March 1964), SELS was the sole source of severe convective weather forecasts in the United States.

The air force's severe weather forecast requirements expanded to include coverage of nonconvective wind storms, blowing dust, dense fog, heavy rainfall, and winter storms in addition to severe local storms in 1964. As a result, the SWWC was resurrected as the Military Weather Warning Center (MWWC) in March of that year. Collocated with SELS, the unit remained in Kansas City until January 1970, when it moved to Offutt Air Force Base as part of a reorganization of the Air Force's Global Weather Central.

8. Maturation: The late 1950s through the mid-1960s

As previously noted, fear of public unrest was the primary reason cited by the Weather Bureau for its reluctance to issue tornado forecasts during the first half of this century. As late as 1952, Ivan R. Tannehill, chief of the bureau's forecast division, defended the bureau's ''no tell'' policy by stating that because such storms affect

[12] Digitized radar summary charts permanently replaced hourly manual facsimile analyses at this time.

[13] The Convective SIGMET Unit was established in April 1978 to provide hourly significant meteorological information advisories to in-flight aircraft regarding hazardous convective weather.

such a small area, more people were likely to lose their lives as a result of forecast-generated hysteria than from tornadoes themselves (Lynch 1970). As word of successful forecasts began to spread, however, the bureau's justification changed. Emphasis shifted to the risk of public indifference (the ''cry wolf syndrome'') if tornadoes failed to occur in a forecast area (Whitnah 1961). Chief Reicheldefer summarized the bureau's lack of confidence in tornado forecasting with a comment made on 18 March 1952, the day after the issuance of SWU's first tornado bulletin. Reichelderfer said that ''in the long run, we think that this type of forecast will not be very acceptable to the public'' (Lynch 1970).

Of course, Reichelderfer was wrong. By the latter half of the 1950s, success of the air force and Weather Bureau severe weather programs had just about eliminated public doubt regarding the value of tornado forecasts. Alarm over such forecasts was also lessened by intensive educational efforts promoting tornado awareness and safety. Tornado forecasts were in fact often cited as a means of saving lives (U.S. Weather Bureau 1955). The only criticism of note was voiced in Oklahoma, where a writer in Tulsa noted that the state's reputation might suffer as a result of the numerous severe weather advisories being issued for the region (Altman 1954).

During this period, a typical SELS tornado forecast would read as follows: ''possibility of an isolated tornado along and thirty miles either side of a line from Amarillo, Texas, to 20 miles north of Gage, Oklahoma, from 5:15 to 9:00 PM. . . .'' Such a forecast would have first been discussed via telephone with the district offices(s) involved. If it was agreed that a public forecast of tornadoes was indeed prudent, the district forecaster would notify the local Weather Bureau offices in that area, in addition to the media. If the proposed forecast affected only one district office, that office had final say as to whether or not tornadoes would be mentioned in the public forecast. If, on the other hand, a proposed tornado forecast involved more than one district office, SELS made the final decision. It was not until 1958 that SELS assumed total authority for public tornado and severe thunderstorm forecasts (Galway 1989). The forecast text was prepared by SELS and transmitted on the Service A and RAWARC teletype circuits.

As is the case today, local offices were responsible for issuing messages that canceled all or portions of severe weather forecasts in their areas of responsibility. Normally these messages were sent only after consultation with SELS. This was, however, not always the case. D. C. House liked to relate an anecdote that occurred before coordination become commonplace. An office had taken the liberty of issuing an ''all clear'' message without calling SELS. Just as the message was being broadcast on a local radio station, storm winds toppled the station's transmitting tower, knocking it off the air in the middle of the all clear announcement (Knox 1958).

Prior to 1957, SELS bulletins and outlooks were written in a technical format using standard aviation weather contractions. District offices were responsible for rewriting the forecasts for public dissemination. With the establishment of RAWARC, however, SELS could issue its own plain language products directly to the public. Thus, beginning in February 1957, SELS forecasts were issued in two parts: one for aviation (using the same format as in past years), and another in plain language form for unedited use by the public. Additional format changes were implemented in 1961, when SELS assumed responsibility for military severe weather forecast products (see Galway 1989).

A new product, the daily Severe Local Storms Synopsis, was initiated in February 1958. This was essentially a preliminary convective outlook, describing the threat for severe and general thunderstorm development the upcoming day. It was issued at 0240 CST during the severe weather season (1 February–31 August) and was updated by the regular convective outlook issued about three hours later (Galway 1973).

From the beginning, the SELS ''operational philosophy'' emphasized the analysis of real-time meteorological data. This philosophy did not change even after the arrival of centralized numerical model forecasts in the late 1950s. The surface pressure field was routinely analyzed each hour in 1-mb increments (Fig. 10). Since the observations were plotted by hand, the entire country was generally not analyzed. Instead, forecasters indicated on a blank map those regions where observations were to be plotted by the chartist (Knox 1958). To maintain a broader perspective, SELS also received copies of the North American surface analyses completed every six hours by the district office staff.

Upper air sounding data were also routinely plotted, and prognostic soundings were constructed to assess the impact of diurnal and/or advective temperature changes. Reflecting House's interest in the role of upper-level features in modulating convective development, streamlines of high-level flow were drawn by plotting the maximum winds observed at each radiosonde site on the so-called jet chart (Lee and Galway 1958).

The installation of an IBM 1620 computer in April 1963 was a major milestone that greatly enhanced SELS' diagnostic capabilities. Forecasters could now obtain real-time objective analyses of parameters such as upper-level divergence and vorticity advection. A second-generation mainframe system using a CDC 3100 enabled data plotting routines to be automated in the latter part of 1965.

Allen D. Pearson, head of the Weather Bureau's Emergency Warning Branch in Washington, became the third SELS supervisor upon the departure of House for ESSA in the summer of 1965. Pearson came to SELS intent on increasing public awareness of the hazards posed by severe thunderstorms and tornadoes. He was especially anxious to implement the preparedness programs recommended by the review committee on the Palm Sunday 1965 tornado outbreak. Pearson oversaw relocation of the Kansas City forecast complex, renamed as the Na-

FIG. 10. SELS analysis area with (left to right) A. M. James Jr., D. C. House, and C. F. Chappell, Apr 1961 (courtesy Curtis Publishing Co.).

tional Severe Storms Forecast Center, to the new federal building on East 12th Street in June 1966.[14] Earlier that same year, the word ''forecast'' was replaced by ''watch'' in SELS' public tornado and severe thunderstorm products. This was done to more closely parallel the ''watch/warning'' terminology that had been in use for hurricane products since the mid-1950s (Galway 1989).

9. Research and development

In October 1952, the Weather Bureau instituted a two-week course on severe local storms that was conducted by the Scientific Services Division at the WBAN center in Washington. All 5 permanent SWU forecasters attended the course, in addition to 10 forecasters from the field. The course emphasized the need for operational-based research, and by early 1953 each SWU forecaster had an assigned area of study that was to be conducted during periods of quiet weather (Galway 1992).

Building on this foundation, SELS supervisor Barnett planted the seed for what would in large part become the National Severe Storms Laboratory when he requested a research forecaster and assistant to support staff research projects in the summer of 1953.[15] As already noted, House continued in this direction, bringing a second research forecaster on board in the spring of 1954. Field station workshop visits by SELS forecasters (begun in 1956), as well as presentations at American Meteorological Society meetings (Galway 1994) furthered these efforts and brought increased exposure to the fledgling unit. Research staffing also continued to grow through the mid- to late 1950s, including such names as Charles F. Chappell (Fig. 10), Howard H. Hanks Jr., and Dansy T. Williams in addition to Beebe and Bates.

SELS-related research intensified with the formation of the Tornado Research Airplane Project (TRAP) in 1956. The goal of this program was to use aircraft to probe the temperature and humidity structure of air masses in tornado forecast areas. Extra research assistants were hired to process the data collected by TRAP flights. SELS forecasters provided weather briefings to the TRAP pilots. In return, forecasters received pilot reports on the location of significant weather features such as cold fronts and dry lines, as well as information regarding the degree of convective development (Galway 1992). Although TRAP collected several years' worth of valuable data, aircraft mechanical difficulties and personnel problems plagued the program from the start. As a result, TRAP

[14] In addition to SELS and its supporting staff, the NSSFC included the Kansas City Weather Bureau office (formerly known as the district office) and the local radar warning group (the ''public service unit''). The severe storm ''core'' of the NSSFC was renamed the Storm Prediction Center in October 1995.

[15] It should be noted that the roots of NSSL also trace back to the mesoscale networks set up by the Weather Bureau's director of meteorological research, Harry Wexler, in the early 1950s. These networks were originally established to test the ''pressure jump'' theory of Morris Tepper (Tepper 1950), but later expanded in scope and supported the pioneering mesoanalysis work of Fujita et al. (1956).

FIG. 11. Cockpit view of a B26 NSSP weather research flight, Apr 1961. (courtesy Curtis Publishing Co.)

management was transferred to the Kansas City district meteorological office headed by Clayton F. Van Thullenar in December 1957 (Goddard 1962). This administrative move marked the beginning of what would be a nearly two-decade absence of formal research and development in SELS. It should be noted, however, that while TRAP management was removed from SELS, some TRAP personnel continued to work as SELS forecasters on an occasional basis for several years after the managerial change (C. A. Doswell III 1998, personal communication).

TRAP assumed a new name, the National Severe Local Storms Research Project, when joint collaboration with the air force, the Federal Aviation Administration, and the National Aeronautics and Space Administration began in 1960. The name was shortened to National Severe Storms Project (NSSP) the following year, with Van Thullenar assuming the title of project director and Chester W. Newton named as chief scientist. NSSP's official mission was to investigate the formation and behavior of squall lines and to obtain knowledge that might be used to mitigate their damaging effects. Data collection was enhanced by access to more than a dozen aircraft (Fig. 11) and by the establishment of two surface observation networks over parts of Kansas, Oklahoma, and Texas in 1961. The results of NSSP's investigations are detailed in a series of 22 technical reports published in the early to mid-1960s.

Airborne thunderstorm investigations had been conducted over Oklahoma since the late 1940s in part because of the state's high incidence of severe convection. Equally important, however, was the relative accessibility of Tinker Air Force Base and Will Rogers Field compared with the busy downtown airport in Kansas City. As a result, Oklahoma became the focus of TRAP–NSSP field operations to an increasing degree during the late 1950s and early 1960s. Citing these advantages and the proximity of the new Department of Meteorology at the nearby University of Oklahoma, the Weather Bureau established its Weather Radar Laboratory (WRL) on the grounds of the former North Base Naval Air Station in Norman in 1963.

To eliminate duplication and foster more focused field research, NSSP and WRL were consolidated as the National Severe Storms Laboratory (NSSL) in Norman in March 1964. The lab was placed under the direction of Edwin Kessler, formerly of The Travelers Research Center in Connecticut. Van Thullenar, who remained in Kansas City to close NSSP's offices, retired shortly after the Norman merger. Newton, meanwhile, left to become a senior scientist at the National Center for Atmospheric Research. Galway (1992) provides a more detailed discussion of SELS research efforts in the 1950s and 1960s.

After a nearly two-decade hiatus, a formal research and development program returned to SELS with the establishment of the Techniques Development Unit (TDU) under the direction of Joseph T. Schaefer in March 1976. This unit was created to develop computer-based techniques aimed at improving severe weather forecasts and to conduct applied severe weather research. The TDU was instrumental in procuring and evaluating the Man–Computer Interactive Data Access System (McIDAS), which later evolved into the Centralized Storm Information System (CSIS). CSIS revolutionized real-time meteorological data analysis at SELS in the early to mid-1980s (Anthony et al. 1982; Ostby 1984).

The severe weather function of NSSFC (i.e., the SELS unit in Kansas City) was renamed the Storm Prediction

Center on 1 October 1995 as part of an NWS modernization plan that saw its parent organization, the National Meteorological Center, reorganized as the National Centers for Environmental Prediction. In an effort to hasten the application of theoretical advances by encouraging interaction between research and operational personnel, SPC joined NSSL at the lab's Norman facility upon completion of a move from Kansas City in January 1997.

10. Postscript

The preceding pages have presented an overview of the development of SELS, the immediate predecessor of today's Storm Prediction Center. The narrative has necessarily focused on policy changes and administrative events that are documented in Weather Bureau literature. The real history of any organization, however, is that of its people: the myriad interpersonal exchanges and individual decisions that are made on a day-to-day basis. Details of this nature are, of course, not readily preserved. Whatever respect the SPC commands today is due in large measure to SELS' ability to attract dedicated and motivated individuals during its formative years. These people were committed to obtaining a better understanding of severe storm behavior—and to applying that knowledge to better serve the public.

Acknowledgments. The author would like to thank Chuck Doswell, Joseph Schaefer, Steven Weiss, and an anonymous reviewer for their helpful comments and suggestions. Edwin Kessler provided insight on NSSP's move to Norman, and Carolyn Kloth and Richard Williams helped gather photographs and internal manuscripts. Sincere thanks are extended to Marlene Bradford, who recently completed a doctoral dissertation at Texas A&M University on the history of severe weather forecasting, for her encouragement and assistance in locating unpublished material. Finally, the author would like to dedicate this paper to Joseph G. Galway as a tribute to his pioneering work in documenting the evolution of severe weather forecasting in the United States.

APPENDIX

List of Acronyms with Selected Locations/Dates of Operation/Notes

CAA	Civil Aeronautics Administration
CDC	Control Data Corporation
COMMS	SELS Communications Unit (1956–85; monitored RAWARC)
CSIS	Centralized Storm Information System
ESSA	Environmental Science Services Administration (1965–70)
IBM	International Business Machines Corporation
McIDAS	Man–Computer Interactive Data Access System
MIC	Meteorologist-in-charge
MWWC	Military Weather Warning Center (Kansas City, Missouri, 1964–70)
NAWAC	National Weather Analysis Center (Washington, D.C., 1955–57)
NCEP	National Centers for Environmental Prediction (1995–present)
NMC	National Meteorological Center (1958–95)
NOAA	National Oceanic and Atmospheric Administration (1970–present, formerly ESSA)
NSSFC	National Severe Storms Forecast Center (Kansas City, Missouri, 1966–95; USWB and NWS)
NSSL	National Severe Storms Laboratory (Norman, Oklahoma, 1964–present)
NSSP	National Severe Storms Project (Kansas City, Missouri, and Norman, Oklahoma, 1961–64)
NWS	National Weather Service (1970–present, formerly USWB)
RADU	SELS Radar Analysis and Development Unit
RAWARC	Radar Report and Warning Coordination (teletype circuit)
SELS	Severe Local Storms Warning Service (Washington, D.C., and Kansas City, Missouri, 1953–95)
SIGRAD	SELS Convective SIGMET/Radar Unit (SELS, 1978–87)
SIGMET	Significant Meteorological Information Advisories
SPC	Storm Prediction Center (Kansas City, Missouri, and Norman, Oklahoma, 1995–present; NWS)
SWU	Severe Weather Unit (Washington, D.C., 1952–53; USWB)
SWWC	Severe Weather Warning Center (Tinker Air Force Base, Oklahoma, and Kansas City, Missouri, 1951–61; USAF)
TDU	SELS Techniques Development Unit (1976–present)
TRAP	Tornado Research Airplane Project (Kansas City, Missouri, 1955–59; USWB)
USAF	United States Air Force
USWB	United States Weather Bureau (1870–1970)
WBAN	Weather Bureau–Army–Navy Analysis Center (Washington, D.C., 1942–55)
WRL	Weather Radar Laboratory (Norman, Oklahoma, 1963–64)

REFERENCES

Abbe, C., 1899: Unnecessary tornado alarms. *Mon. Wea. Rev.,* **27,** 255.

Altman, H. E., 1954: Notes about the history of tornado forecasts and warnings. NOAA/NWS/NCEP Storm Prediction Center, 26 pp. [Available from NOAA/NWS/NCEP Storm Prediction Center, Norman, OK 73069.]

Anthony, R., W. Carle, J. T. Schaefer, R. Livingston, A. Siebers, F.

Mosher, J. Young, and T. Wittaker, 1982: The Centralized Storm Information System at the NOAA Kansas City complex. Preprints, *Ninth Conf. on Weather Forecasting and Analysis,* Seattle, WA, Amer. Meteor. Soc., 40–43.
Barnett, K. M., 1953: Semi-objective procedure to indicate when tornado forecasts should be issued. NOAA/NWS/NCEP Storm Prediction Center, 5 pp. [Available from NOAA/NWS/NCEP Storm Prediction Center, Norman, OK 73069.]
Bates, F. C., 1955: A technique for predicting extreme turbulence related to thunderstorms. *Bull. Amer. Meteor. Soc.,* **36,** 379–383.
Beebe, R. G., 1955: Types of air masses in which tornadoes occur. *Bull. Amer. Meteor. Soc.,* **36,** 349–350.
—— and F. C. Bates, 1955: A mechanism for assisting in the release of convective instability. *Mon. Wea. Rev.,* **83,** 1–10.
Bradford, M., 1999: Historical roots of modern tornado forecasts and warnings. *Wea. Forecasting,* **14,**
Carr, J. A., 1952: A preliminary report on the tornadoes of 21–22 March 1952. *Mon. Wea. Rev.,* **80,** 50–58.
——, 1955: The delta-t method for determining low-level warm air advection. NOAA/NWS/NCEP Storm Prediction Center, 12 pp. [Available from NOAA/NWS/NCEP Storm Prediction Center, Norman, OK 73069.]
Congressional Record, 1952: 82d Cong., 2d sess., pt. 2:2757 and pt. 3:3558–3559.
Doswell, C. A. III, S. J. Weiss, and R. H. Johns, 1993: Tornado forecasting: A review. *The Tornado: Its Structure, Dynamics, Prediction, and Hazards. Geophys. Monogr.,* No. 79, Amer. Geophys. Union, 557–571.
——, A. R. Moller, and H. E. Brooks, 1999: Storm spotting and public awareness since the first tornado forecasts of 1948. *Wea. Forecasting,* **14,** 544–557.
Foster, D. S., 1953: The severe weather forecasting program at Kansas City - March 1 to August 31, 1953. NOAA/NWS/NCEP Storm Prediction Center, 16 pp. [Available from NOAA/NWS/NCEP Storm Prediction Center, Norman, OK 73069.]
——, 1958: Thunderstorm gusts compared with computed downdraft speeds. *Mon. Wea. Rev.,* **86,** 91–94.
——, and F. C. Bates, 1956: A hail size forecasting technique. *Bull. Amer. Meteor. Soc.,* **37,** 135–141.
Fujita, T., H. Newstein, and M. Tepper, 1956: Mesoanalysis, an important scale in the analysis of weather data. USWB Research Paper 39, 83 pp.
Galway, J. G., 1956: The lifted index as a predictor of latent instability. *Bull. Amer. Meteor. Soc.,* **37,** 528–529.
——, 1973: Severe local storm forecasting in the United States. SELS Workshop Notes, National Severe Storms Forecast Center, Kansas City, MO, 13 pp.
——, 1981: Ten famous tornado outbreaks. *Weatherwise,* **34,** 100–109.
——, 1985a: J. P. Finley: The first severe storms forecaster (Part 1). *Bull. Amer. Meteor. Soc.,* **66,** 1389–1395.
——, 1985b: J. P. Finley: The first severe storms forecaster (Part 2). *Bull. Amer. Meteor. Soc.,* **66,** 1506–1510.
——, 1989: The evolution of severe thunderstorm criteria within the Weather Service. *Wea. Forecasting,* **4,** 585–592.
——, 1992: Early severe thunderstorm forecasting and research by the United States Weather Bureau. *Wea. Forecasting,* **7,** 564–587.
——, 1994: The Kansas City Chapter of the American Meteorological Society: A History 1934–1994. 73 pp. [Available from NOAA/NCEP/NWS Aviation Weather Center, Kansas City, MO 64106.]
Goddard, B. B., 1962: The development of aircraft investigations of squall lines from 1956–1960. NSSP Rep. 2, Washington, DC, 28 pp. [Available from National Information Service, Operations Division, Springfield, VA 22161.]
House, D. C., 1952: Use of Showalter's index. *Forecaster's Forum,* **4,** 7–9.
Hughes, P., 1970: *A Century of Weather Service.* Gordon and Breach, 212 pp.
Humphreys, W. J., 1926: The tornado. *Mon. Wea. Rev.,* **54,** 501–503.
Knox, J. L., 1958: The severe local storm centre at Kansas City. *Royal Meteor. Soc., Canadian Branch,* **8,** 35–51.
Lee, J. T., 1955: Thunderstorms and tornadoes of February 1, 1955. *Mon. Wea. Rev.,* **83,** 45–51.
——, and J. G. Galway, 1958: The jet chart. *Bull. Amer. Meteor. Soc.,* **39,** 217–223.
Lemons, H., 1938: Some meteorological aspects of Nebraska tornadoes. *Mon. Wea. Rev.,* **66,** 205–208.
Lewis, J. M., 1996: Joseph G. Galway. *Wea. Forecasting,* **11,** 263–268.
Lloyd, J. R., 1942: The development and trajectories of tornadoes. *Mon. Wea. Rev.,* **70,** 65–75.
Lynch, D., 1970: *Tornado . . . Texas Demon in the wind.* Texian Press, 163 p.
Maddox, R. A., and C. A. Crisp, 1999: The Tinker AFB tornadoes of March 1948. *Wea. Forecasting,* **14,** 492–499.
Magor, B. W., 1958: A meso-low associated with a severe storm. *Mon. Wea. Rev.,* **86,** 81–90.
McDermott, P., 1951: Flash—Tornado warning! *The Saturday Evening Post,* 28 July, 17–19, 53–57.
McPherson, R. M., 1994: The National Centers for Environmental Prediction: Operational climate, ocean, and weather prediction for the 21st century. *Bull. Amer. Meteor. Soc.,* **75,** 363–373.
Miller, R. C., 1972: Notes on the analysis and severe storm forecasting procedures of the Air Force Global Weather Central. AWS Tech. Rep. 200 (rev.), Air Weather Service, Scott Air Base, IL, 190 pp. [Available from the National Techncal Information Service, 5285 Port Royal Rd, Springfield, VA 22151.]
——, and C. A. Crisp, 1999: Events leading to establishment of the United States Air Force Severe Weather Warning Center in February 1951. *Wea. Forecasting,* **14,** 500–506.
Murphy, A. H., 1996: The Finley affair: A signal event in the history of forecast verification. *Wea. Forecasting,* **11,** 3–20.
Ostby, F. P., 1992: Operations of the National Severe Storms Forecast Center. *Wea. Forecasting,* **7,** 546–563.
——, 1984: Use of CSIS in severe weather prediction. *Recent Advances in Civil Space Remote Sensing,* H. W. Yates, Ed., *Proc. SPIE,* Vol. 481, Arlington, VA, 78–83. [Available from Society of Photo-Optical Instrumentation Engineers, Box 10, Bellingham, WA 98227.]
——, E. J. Parvin, and J. G. Galway, 1989: NSSFC special report: Kansas City Forecast Office, 1950–1989. NOAA/NWS/NCEP Storm Prediction Center, 147 pp. [Available from NOAA/NWS/NCEP Storm Prediction Center, Norman, OK 73069.]
Peterson, R. E., 1992: Johannes Letzmann: A pioneer in the study of tornadoes. *Wea. Forecasting,* **7,** 166–184.
Popkin, R., 1967: *The Environmental Science Services Administration.* Praeger, 278 pp.
Riehl, H., and Coauthors, 1952: *Forecasting in Middle Latitudes. Meteor. Monogr.,* No. 5, Amer. Meteor. Soc., 80 pp.
Schaefer, J. T., 1986: Severe thunderstorm forecasting: A historical perspective. *Wea. Forecasting,* **1,** 164–189.
Showalter, A. K., 1953: A stability index for thunderstorm forecasting. *Bull. Amer. Meteor. Soc.,* **34,** 250–252.
——, and J. R. Fulks, 1943: Preliminary report on tornadoes. U.S. Weather Bureau, Washington, DC, 162 pp.
Tepper, M., 1950: A proposed mechanism of squall lines. *J. Meteor.,* **7,** 21–29.
U.S. Air Force, 1951: When to duck. *Takeoff,* 22 July, 5.
U.S. Army, 1887: Report of the Chief Signal Officer of the U.S. Army, Washington, D.C., 21–22.
U.S. Weather Bureau, 1950: Statements concerning tornado forecasting. Circular Letter No. 52–20. 12 July, 1 p. [Available from NOAA/NWS/NCEP Storm Prediction Center, Norman, OK 73069.]
——, 1952: Severe weather bulletins. Instructions and information for severe weather unit. No. 6, 20 May, 5 pp. [Available from NOAA/NWS/NCEP Storm Prediction Center, Norman, OK 73069.]
——, 1953a: Relations with Air Weather Service. Instructions and information for severe weather staff. No. 32, 30 January, 1 p.

[Available from NOAA/NWS/NCEP Storm Prediction Center, Norman, OK 73069.]

——, 1953b: Over-forecasting. Instructions and information for severe weather staff. No. 68, 8 June, 2 pp. [Available from NOAA/NWS/NCEP Storm Prediction Center, Norman, OK 73069.]

——, 1953c: Criteria for severe thunderstorms. SELS Center instructions. No. 85, 2 October, 1 p. [Available from NOAA/NWS/NCEP Storm Prediction Center, Norman, OK 73069.]

——, 1954: 700mb ''no advection'' lines. SELS Center Note to Forecasters, 3 March, 1 p. [Available from NOAA/NWS/NCEP Storm Prediction Center, Norman, OK 73069.]

——, 1955: Memorandum. 7 June 1955. [Available from NOAA/NWS/NCEP Storm Prediction Center, Norman, OK 73069.]

Varney, B. M., 1926: Aerological evidence as to the cause of tornadoes. *Mon. Wea. Rev.,* **54,** 163–165.

Whitnah, D. R., 1961: *A History of the United States Weather Bureau.* University of Illinois Press, 267 pp.