

HISTORY

The Evolution of Severe Thunderstorm Criteria within the Weather Service*

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ABSTRACT

The evolution of criteria for nontornadic severe thunderstorms from undefined categories and general terms to the present day definition for this class of thunderstorm is presented. Major historical events in the development of the Severe Local Storms Unit (SELS) which directly or indirectly influenced changes in the criteria are included.

1. Precriteria events

The attempts by the early American scientists during the late eighteenth and nineteenth centuries to analyze and understand the nature of the tornado and related severe local storms has been thoroughly described by Ludlum (1970). Ludlum also wrote of the establishment of a volunteer national weather observing system by the Smithsonian Institution of Washington, D.C. in 1849. In 1862, the director of the Smithsonian issued special instructions for the observations of thunderstorms and tornadoes plus queries relative to both events. This observational network came under the administration of the U.S. Signal Corps in 1873, which had begun observations at its own stations in 1871. During this period, the characteristics of severe local storms attracted substantial attention both in this country and abroad.

In the history of severe local storms it is generally acknowledged that Lt. John P. Finley of the Signal Corps was the first meteorologist to attempt the prediction of tornadoes. Finley's experimental predictions

began in March 1884 and ended in 1886. In effect at that time were Signal Corps orders issued in 1883 that stated when weather conditions favored the occurrence of tornadoes, a special warning should be issued that violent local storms were indicated for the area of concern. The instructions also cautioned that the word "tornadoes" would not be used. The reason given for the discontinuance of tornado predictions can be found in the report of the chief signal officer for 1887 which stated, "It is believed that the harm done by such a prediction would be greater than that which results from the tornado itself" (Galway 1985). However, the collection and recoding of tornado reports continued for the purpose of research and climatology.

The ban on tornado forecasts continued as the weather service was transferred from the Signal Corps to the Department of Agriculture in 1891 and renamed the Weather Bureau. In 1905, the Weather Bureau's station regulations contained the statement, "Forecasts of tornadoes are prohibited." This statement also appeared in revised station regulations issued in 1915 and 1934. During that period forecasters were permitted to predict destructive local storms but were told not to mention the word "tornado" since it was felt that it would cause public alarm and panic. The ban on the use of the word tornado was lifted in 1938 but only occasional use was made of the possibility of tornadoes during the 1940s and then only to alert disaster officials for planning purposes (Altman 1954).

The Signal Corps authorized a detailed study of thunderstorms in 1884 under the direction of Henry Allen Hazen, a civilian employee of the corps with the title of junior professor, and a contemporary of Finley. The assistance of the Postmaster-General was solicited in this project and post offices 40 miles apart from the Atlantic Ocean to 102°W and from 35°N to the Ca-

* This account on the development of severe thunderstorm criteria is based on official Weather Bureau/National Weather Service documents, instructions, and publications. These were rather complete for the formative years of severe local storm forecasting (1952-57). However, the narrative is somewhat deficient in details for the period 1958-64 as portions of SELS correspondence were eliminated from the station files by 1967. Further, a number of weather service manual chapters on the severe local storm service, conference reports on similar documents also were available. All the above have been complemented by memory or personal involvement where documentation was scant.

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nadian border were enlisted to take thunderstorm observations for the summer of 1884 to supplement the observations of the Signal Corps stations. At this time, no attempt had been made to classify tornadoes or thunderstorms intensity. The adjectives, "severe" and "violent," which were used to describe the storms have no precise technical meaning.

Hazen (1885) summarized the first month's data and perceived the need for an intensity scale to be added to the thunderstorm observation form in use. He suggested the following:

- 1) distant lightning
- 2) distant thunder
- 3) moderate thunderstorm
- 4) heavy thunderstorm
- 5) heavy thunderstorm with very high wind, uprooting trees, blowing down buildings, etc.

Two years later he revised intensity No. 5 and added a sixth category, namely,

- 5) heavy thunder (storm), with very high wind breaking small branches off trees, etc.
- 6) thunder with hurricane or tornado (U.S. Army 1886)

In 1885, the New England Meteorological Society assumed the responsibility for continuing the thunderstorm study for the Signal Corps but limited the area to New England. Little use was made of Hazen's scale as no further mention of it was found.

Hazen also proposed a scale for the intensity of a tornado based on the property loss caused by 2058 tornadoes between 1872 and 1889 (U.S. Army 1890). Property losses from about 1000 storms averaged \$3000 and he assigned this group a class 1 intensity; another 1000 or so storms averaged \$20 000 in losses and was rated a class 2 intensity; and 58 storms which averaged \$200 000 in losses was given a class 3 designation. Later in the same year, he subdivided the classes with plus and minus categories and added a zero classification. He also lowered the dollar amount in class 3 to an average of \$100 000. Hazen considered his scale reflected the violence of the storm and not the property loss but admitted that these are relatively equivalent. The plus and minus signs indicated an amount of loss above or below the average. A zero classification was given to storms with losses of less than \$100.

Hazen continued to use his intensity scale in summarizing severe and violent storm reports for the years 1890-1894. These were published in the report of the chief of the Weather Bureau for the years 1891-94. However, his data included both tornadoes and nontornadic severe thunderstorm wind reports. Henry (1896) reevaluated the data for the period 1889-96 to eliminate the nontornadic thunderstorm winds and, at the same time, Hazen's tornado intensity scale was conveniently dropped.

Although airway weather observations were initiated in 1928, the thunderstorm did not become an important weather element in the observation until 1935 when three degrees of thunderstorm intensity were defined (U.S. Weather Bureau 1958). These were (with symbols).

1) *Mild thunderstorm (T)*: lightning within the cloud; light or moderate rain; no hail; wind, if any, does not exceed 25 to 30 mph.

2) *Moderate thunderstorm (T-)*: frequent lightning cloud to ground; loud thunder; moderate to heavy rain; wind velocities to 40 mph; light to moderate hail.

3) *Severe thunderstorm (T+)*: nearly incessant thunder and lightning; heavy rain, possibly accompanied by moderate to heavy hail; wind velocities over 40 mph and continuing for as much as 15 min; rapid drop in temperature, as much as 20°F in 5 min.

In 1941, the degrees of intensity were modified to thunderstorm (T) and heavy thunderstorm (T+). Thunderstorm assumed the specifications of the former "mild" and "moderate" categories, i.e., hail, none to moderate; rain, light to possibly heavy; etc. The qualifier "severe" was replaced by "heavy" with no change in specifications. However, in 1947, determination of the thunderstorm's intensity was based upon the appearance of the storm from the point of observation. The intensities, light, moderate and heavy, were essentially assigned the same specifications as those given to mild, moderate and severe in 1935. All thunderstorms not classified as heavy were regarded as moderate when the letter symbol was used (T).

Apparently this was the only effort made to assign a scale to tornadoes or criteria to the nontornadic thunderstorm in order to define its intensity over the 50 odd years since Hazen's proposal. It was not until Fawbush et al. (1951) began experimental severe local storm forecasts in 1948 and 1949 that the evolution of severe thunderstorm criteria had its inception.

2. Initial procedures

On 17 March 1952, three years after the Air Weather Service (AWS) of the U.S. Air Force issued its first successful tornado forecast, the U.S. Weather Bureau (WB) began issuing public tornado forecasts. A select group of research forecasters and supervising analysts at the Weather Bureau-Air Force-Navy (WBAN) Analysis Center in Washington, D.C. had been developing forecast procedures and making experimental severe weather forecasts for several weeks prior to this first public release. The partial success of their tornado forecasts for 21 March 1952 prompted the Weather Bureau to continue with these releases and to establish a Severe Weather Unit (SWU) at the Analysis Center (Circular Letter [CL] No. 20-52, 19 May 1952). This unit was instructed to issue bulletins on severe local

storms which had just developed or were about to develop. These severe weather bulletins were to be issued as required and entered on the Civil Aeronautics Administration's (CAA) Service A, a teletypewriter communication network for aviation weather. While severe local storms were assumed to be associated with tornadoes, squall lines, thunderstorm gusts, hail, and/or severe turbulence, no official criteria were established at this time. However, at the operational level, "SWU Instruction No. 6," 20 May 1952 suggested the use of the descriptive but undefined categories of moderate, strong or severe when referring to thunderstorm gusts. Hail size also was to be mentioned only in general terms.

While the official records show no definition for severe thunderstorm gust criteria, an inspection of the severe weather bulletins issued between 21 May 1952 and 21 January 1953 reveals the use of "gusts 40 to 50 kts" (46 to 58 mph when miles per hour came into use in August 1952) or greater in the majority of issuances. No doubt this was influenced by the Air Force's use of 50 kt as the lower limit for severe thunderstorm wind gusts.

"Severe Weather Staff (SWS) Instruction No. 25," 21 January 1953 initiated an experimental outlook of severe weather potential for the day. This product, the forerunner of the "Convective Outlook" (AC), was called a "Severe Weather Discussion" and was sent to selected district forecast centers on a trial basis. It became a routine daily issuance in February 1953. This instruction also defined severe local weather as "tornadoes, a line or area of frequent thunderstorms producing severe turbulence and/or damaging hail and/or surface winds above 50 mph" and thus it contained the first specific mention of severe thunderstorm criteria.

Severe weather was redefined in "SWS Instruction No. 29," 26 January 1953 as "any condition in which one or more tornadoes are occurring or are expected to develop and/or any line or area of severe thunderstorms or locally destructive windstorms (50 mph or more)." Accordingly, by the end of January 1953, a nontornadic severe thunderstorm was defined as one containing "surface winds of 50 mph or more and/or damaging hail and/or severe turbulence aloft." Note that these instructions were issued by the supervisor of the SWU.

On 4 February 1953 a new Weather Bureau Manual chapter entitled "Severe Local Storm Forecasting Procedures" (WBM, Vol. III, Chapt. B-19) was issued. This chapter avoided giving criteria for severe thunderstorms and simply defined severe storm conditions as "tornadoes, severe thunderstorms, hail storms and areas of severe turbulence." This absence of criteria appears strange in view of the fact that methods for forecasting thunderstorm gusts and hail size were available (Schaefer 1986). However, the primary goal of the Weather Bureau hierarchy was the forecasting

of tornadoes, especially multiple tornado outbreaks which have historically accounted for the majority of severe thunderstorm deaths and damage. It also appears that service to the aviation industry was of concern since all official definitions of severe weather included severe turbulence.

A memorandum issued by the Chief of the Weather Bureau dated 17 June 1953 changed the name of the Severe Weather Unit to the Severe Local Storm Warning Center. The overall warning and forecasting of severe local storms was to be called the Severe Local Storm Warning Service (SELS). Further, the abbreviated title "SELS" was only used in conjunction with "Center," "Service," "Office," etc. Thus, in 1953, SWU officially became the SELS Center.

The year 1953 was an active one for tornadoes. The mean number of tornadoes for the period 1916-52 (156) was exceeded by 170%. The death count totaled 516 (a number exceeded only three times since the systematic tabulation of tornado data began in 1916). Two-thirds of the deaths occurred on 3 days: 11 May at Waco, Texas, 8 June at Flint, Michigan, and 9 June at Worcester, Massachusetts. However, by mid-June the SELS Center was under heavy criticism for both the quality and the size of its forecast areas. Taunts from those who prophesied that severe weather could not be predicted, and spotty (but consistent) uncooperativeness from the Weather Bureau field stations weighed heavily on the staff. One SELS forecaster requested a transfer after the Worcester tornado.

The criticism came down hardest on the SELS supervisor, Kenneth M. Barnett, a quiet, soft spoken person who attempted to be chief forecaster, chief researcher and chief placater to the mounting tide of complaints. Perhaps the most annoying, and certainly the most distracting problem was the constant flow of high echelon Weather Bureau Central Office personnel through the SELS working area. Since the central office was a short walk from SELS, the duty forecaster was often required to cease work and brief the visitor(s) on the current weather. Most of the time, Barnett would rush to the aid of the forecaster and by midsummer 1953, it was evident that Barnett had no desire to spend another tornado season as SELS supervisor.

Barnett knew there was a need to reduce both the size of forecast areas and the frequency of the Severe Weather bulletins. As a result, the average size of the tornado areas issued by SELS dropped from 37 802 miles² in 1952 to 26 944 miles² during the first 6 months of 1953. Complaints about size of SELS areas were usually accompanied with a comparison to the size of Air Force areas which averaged 12 000-15 000 miles². This argument ignored the fact that SELS might issue an area 75 miles either side of a line 200 miles long, whereas the Air Force would typically cover the same situation with three areas 30 miles either side of a line 200 miles long with 10-20 mile-wide "safe" corridors between areas. Since these were counted as three

different areas, the Air Force's average was 12 000 instead of 30 000 miles².

The only study on SELS nontornadic severe thunderstorm areas appeared in a memorandum from Barnett to the Chief of the Weather Bureau, dated 1 October 1953. It examined thunderstorm bulletins issued for July, August, and September 1953. The average areas were 70 000, 43 000 and 16 500 miles² respectively. However, areas of nonsevere thunderstorms [known today as "Other (General) Thunderstorms"] were included in the averages.

An in-house instruction to the forecast staff (No. 68, 8 June 1953) by Barnett stated that bulletins would be issued only when lines and areas of thunderstorms had coverage of 50% or more and be limited in size $\leq 10\,000$ square miles². This was ludicrous considering the sparse radar network in existence, and the fact that radar reports were transmitted via Service A on a time-available basis. The effect of this instruction was hardly noticeable in the operation of SELS since none of the 37 tornado areas issued for the remainder of 1953 were less than the 10 000 mile² requirement and only three of them were less than 20 000 miles².

3. Development of criteria

Barnett attempted to get an official definition of a severe thunderstorm. In a 30 July 1953 memorandum to the assistant Chief of the Bureau, Barnett proposed defining a "severe thunderstorm" as one which includes any or all combinations of

- surface wind gusts from 50 to 75 mph
- severe turbulence aloft
- hail aloft and/or at the surface up to 1 in. diameter.

Reference to gusts and hail would be made only when gusts above 75 mph or hail greater than 1 in. were expected. Severe turbulence would be implied in all bulletins.

Barnett's proposal included other suggestions for streamlining the contents of the bulletins. The chief of the Synoptic Reports and Forecasts Division requested comments and suggestions on the proposal from the district forecast offices and selected first order stations on 11 September 1953. Suggestions from the field plus central office input resulted in "SELS Center Instruction No. 85" dated 2 October 1953 which listed "semiofficial" criteria for a severe thunderstorm as

- 1) average wind speed of ≥ 50 mph and/or gusts to ≥ 75 mph
- 2) and/or hail approximately ≥ 1 in. in diameter
- 3) severe turbulence aloft

These became effective immediately.

In early winter, 1953, Barnett announced he was leaving the Weather Bureau for the U.S. Army Signal Corps. Donald C. House, a district forecaster at the Kansas City, Missouri forecast office, was named the

new supervisor of the SELS Center. He arrived for duty in March 1954.

Meanwhile, "Multiple Address Letter (MAL) No. 6-54" (14 January 1954) outlined the severe local storm and forecasting procedures to be used in 1954. No official criteria for severe thunderstorms were mentioned in the MAL. "SELS Center Instruction No. 3-54" (1 February 1954) noted that "a new and more rigid definition of severe thunderstorms will be adopted soon." This instruction also stated that severe weather areas be limited to $\leq 10\,000$ miles². It conceded that in intense situations "40 000 miles² might be considered an absolute maximum total size for severe weather forecast areas current at any one time."

One change of note appeared in "MAL No. 6-54." Issuances from the SELS Center would cease to be called Severe Weather bulletins and would be Severe Weather forecasts. This change was intended to make a careful distinction between forecasts and warnings. However, district forecast offices interpreted this as an erosion of their authority. At that time, Weather Bureau regulations stated that the final decision for all forecasts issued within a district office's forecast area was the responsibility of the district forecaster. This included SELS severe weather bulletins whether or not tornadoes were included. However, when two or more districts were included within the same severe weather forecast area, the final decision for the issuance reverted to the SELS forecaster. "MAL No. 25-54" (17 March 1954) clarified and continued this arrangement. It was not until 1958 that SELS assumed the sole authority for the issuances of severe weather forecasts.

Finally, on 10 March 1954, the Weather Bureau officially defined a severe thunderstorm in "MAL No. 21-54." It stated that a severe thunderstorm was one that produced frequent lightning and one or more of the following:

- 1) Instantaneous surface wind gusts of ≥ 75 mph and/or winds averaged over 1 min of ≥ 50 mph
- 2) hail, surface or aloft, of ≥ 0.75 in. diameter
- 3) severe turbulence (then the highest category of turbulence)

The hail limit was adopted from Souter and Emerson (1952) as "the smallest size of hailstones that cause significant damage at airplane speeds between 200 and 300 mph." A revised chapter in the *Weather Bureau Manual* was issued 2 July 1954 with the above criteria.

When D.C. House became the SELS Supervisor, his commission was stated briefly by the Chief of the Bureau: improve severe local storm forecasting techniques, and reduce forecast area size. House brought to SELS a personal enthusiasm and drive that soon infected the forecast staff. He accomplished one of the Chief's mandates the first year. The SELS Center issued 237 tornado forecasts in 1954 with an average area size of 14 884 miles². In the fall of 1954, an ambitious development program to improve forecasting tech-

niques began taking into account meteorological processes through the whole atmosphere rather than concentrating from the surface to 500 mb as had been the practice up to that time. The eventual results established the SELS Center as a viable and respected forecast unit of the Weather Bureau by the late 1950s. The intensity of House's interest in severe local storms can be measured by the practice he made of scheduling himself on the SELS forecast desk three days a week during the prime severe storm season (February–August), a routine that continued until his transfer to Environmental Scientific Services Administration (ESSA) Headquarters, Washington, D.C. in August 1965.

During the late spring and early summer of 1954, it was rumored at the Analysis Center that SELS would be transferred to Kansas City. Although the decision to do so was made on 11 July 1954, it did not become general knowledge until the release of "MAL No. 72-54" on 23 August 1954. (A week prior to the MAL, all SELS transferees had received departure and arrival dates.) The transfer of SELS was one small part of a revamping of Weather Bureau operations that was initiated by the Department of Commerce "to see if it [Weather Bureau] was engaged in activities which could be done better by private industry, or conversely, if it should be doing some things it was not doing" (Stone 1954).

In the spring of 1953, a committee headed by J. J. George, then in charge of the Meteorological Department at Eastern Airlines, was commissioned by the Commerce Department to investigate Weather Bureau operations and to make recommendations in regard to the various weather related activities of the Weather Bureau. One recommendation of the George Report (as it was called by the meteorological community) was the "transfer of functions being performed by other agencies that were within the scope of the Weather Bureau functions established by law and policy." The forecasting of severe local storms fell within these functions. Other notable changes in the operation and structure of the Weather Bureau were influenced by, if not the result of, the George Report recommendations. These included the establishment of a national weather radar network, automatic weather stations, a weather research laboratory, and the contracting of specific Weather Bureau functions to private agencies.

The SELS move to Kansas City was made in two phases. The supervisor and three forecasters departed during the third week of August 1954. A fourth forecaster, already in Kansas City, was assigned to SELS. Meanwhile, four forecasters remained in Washington to handle the forecast operation. On 1 September 1954, the Kansas City group became responsible for forecasting severe weather west of the 90th meridian with the Washington forecasters responsible for activity east of the 90th meridian. Two weeks later, Kansas City assumed forecast operations for the entire country and

the Washington group ceased operations. Two of the Washington forecasters left for Kansas City to complete the transfer of SELS while the other two who had declined transfer were assigned other positions within the Weather Bureau's Washington complex.

4. Warranted criteria changes

Several changes in SELS procedures were made during the early months of 1955. Among these, the phrase "SVR WX FCST" which appeared in the heading of SELS releases was replaced on 1 January 1955 with "WW" to indicate a severe weather product, and the transmission of the morning Severe Weather Discussion began on the Service A teletypewriter system (29 April 1955) instead of TWX. This product was renamed "Convective Outlook (AC)." More importantly, a major change in severe thunderstorm criteria was in progress.

An unpublished paper written in 1954 by Ferdinand C. Bates of SELS and sent to the CAA in December elicited discussion between the Weather Bureau and CAA which led to a revision of the turbulence criteria. Until that time, severe turbulence had been meteorologically designated "as rarely encountered, usually impossible to control the aircraft and may cause structural damage." However, studies by the Weather Bureau and the National Advisory Committee for Aeronautics (NACA) indicated that pilots subjective evaluations of severe turbulence were well below that of the meteorological designation. Bates proposed that severe turbulence be redefined into three categories based on maximum "effective gusts." The effective gust (i.e., the velocity of a "sharp-edged gust" that would produce a normal acceleration equal to that experienced by the airplane) was selected as the defining parameter since it could be used to estimate the effect that turbulence might produce on any given aircraft. The discussions between the Weather Bureau, CAA, airlines, and other agencies concerned resulted in a revised classification of turbulence categories. The "heavy" turbulence category was eliminated and a new category, "extreme," was added. The four turbulence categories became light, moderate, severe and extreme and were based on progressively effective gust velocities. The extreme category assumed the meteorological designation of the former severe category and was associated with maximum effective gusts in excess of 45 feet per second (fps). The range of effective gusts for the newly defined severe category was from 30 to 45 fps. Not long after these categories were established, a new formula for the derived gust velocity was accepted which resulted in a minor increase in the effective gust figures.

Bates (1955) developed a technique for forecasting extreme turbulence based on the following assumptions: (a) a definition of turbulence in terms of effective gusts; (b) a correlation between updrafts and effective

gusts, as determined by the Thunderstorm Project (USWB 1949); and (c) a correlation between positive areas—as evaluated on pseudoadiabatic diagrams—and updrafts. An overlay was constructed so that the potential for extreme turbulence could be read directly from a pseudoadiabatic diagram. The implementation of the new turbulence criteria and the forecasting thereof was initiated 1 July 1955.

Two other events took place in late 1955 and early 1956 which had great impact on SELS operations and eventually on severe thunderstorm criteria. The first was the implementation of the Weather Bureau's Radar Report and Warning Coordination (RAWARC) teletypewriter system on 15 September 1955. This internal system linked the majority of Weather Bureau offices in the contiguous United States for the dissemination of radar reports, warnings, upper-air information, storm reports, etc. The forecast office in Kansas City was designated as the control and relay center for RAWARC. Since radar reports were received directly from the radar site rather than via Service A, this was a boon to SELS operations. RAWARC also allowed more rapid dissemination of SELS products to the field stations. The ready availability of nationwide radar reports led to the formation of the Radar Analysis and Development Unit (RADU) at Kansas City which collected, analyzed, and transmitted an hourly summary of these reports back to the field stations over RAWARC and into the CAA communication system. The RADU rapidly became an important asset to SELS.

The second event was the collocation of SELS and the Air Force's Severe Weather Warning Center (SWWC) at Kansas City in January 1956. Although each unit operated as an independent entity, there was mutually beneficial coordination. However, a discrepancy in the definition of a severe thunderstorm between the units existed. The AWS defined a severe thunderstorm as one accompanied by wind gusts of ≥ 50 kts and/or hail ≥ 0.5 in. diameter (AWS 1954) while the Weather Bureau's definition was an average wind over 1 min of ≥ 50 mph (44 kt) and/or gusts of ≥ 75 mph (66 kt) and/or hail ≥ 0.75 in. diameter. The turbulence category did not differ. This difference would not be resolved for several years.

SELS bulletins/forecasts were formatted in aviation weather terminology complete with standard abbreviations and disseminated on Service A. It was the responsibility of the district forecast office to rewrite them in comprehensible language for distribution to the public and media. It was soon evident that by using RAWARC SELS could compose the severe forecasts in plain language for direct release to the public and national press services. Beginning 1 February 1957, SELS forecasts were prepared in two different formats, one for aviation (in the format used in prior years), and one in terminology designed for the public and media. These were named as an "Aviation Severe Weather Forecast" and "Severe Weather Forecast."

The latter was changed to "Public Severe Weather Forecast" in 1958. Both aviation and public forecasts were sent via RAWARC to the field stations, and Service A only contained aviation forecasts. Knots¹ instead of miles per hour were used in all aviation products and the criteria for a nontornadic severe thunderstorm changed to

- 1) Surface winds of ≥ 44 kt (≥ 50 mph) averaged over a 1-min interval, and/or instantaneous wind gusts of ≥ 66 kt (≥ 75 mph)
- 2) Hail, surface or aloft, of ≥ 0.75 in. diameter
- 3) Extreme turbulence

When wind gusts of ≥ 66 kts and/or surface hail of ≥ 0.75 in. diameter were anticipated both public and aviation severe weather forecasts were issued. There was an "Aviation Only" subdivision to the forecasts which was used when the hail and turbulence criteria were expected to remain aloft. Implied, but not stated in the "Aviation Only" criteria, were surface wind gusts of 44–65 knots.

The duplication of forecasting severe weather by both the Air Force and the Weather Bureau ceased in February 1961 when SELS forecasts became the official release for both civilian and military purposes. Since the Air Force required not only gusts speeds (including the retention of their 50 kt lower limit) and hail but also turbulence intensity and maximum thunderstorm tops for their operations, the Weather Bureau raised the lower limit of severe thunderstorm speed (sustained or gust) from 44 kt to ≥ 49 kt (56 mph) in aviation severe weather forecasts. The Air Force acquiesced to the ≥ 0.75 in. diameter hail criteria.

The criteria for public severe forecasts remained the same, i.e., hail ≥ 0.75 in. diameter, surface wind gusts of ≥ 75 mph, etc. There was a minor change to the wind criteria for "Aviation Only" forecasts in 1962. It was restated as "sustained wind or gusts of 50 to 65 knots (58 to 75 mph)" instead of ≥ 49 kt, etc.

A major change in the format of the aviation severe weather forecast resulted from this agreement. The new format first listed the type of forecast (tornado or severe thunderstorm) followed by four sections. Section A outlined the forecast area, and valid times, and stated whether a public forecast would be issued. Section B gave the specifics on hail, wind gusts, and turbulence. Wind and hail were normally given as a range, e.g., 50K ISLD 65K; HAIL UP TO 2 IN DIA. Density or coverage of thunderstorms in the area (few, scattered, numerous) and maximum tops were also mentioned in this section. Section C contained information on formation time and speed and direction of movement of line(s), area(s) and/or cell(s). The fourth section was labeled "General Thunderstorms" and listed areas

¹ The measure for wind speeds reverted to knots in 1956.

of thunderstorms and their formation times not expected to reach severe limits. On occasion this section listed areas with future potential for severe thunderstorm activity that day.

The overall operations of SELS remained stable until March 1964 when the victory over duplication, as prompted by the George Report ended. The Air Force requirements for severe weather forecasting were changed. In addition to severe local storms, they now needed specific forecasts of heavy snow, heavy rain, freezing precipitation, dense fog, strong surface winds (not associated with thunderstorms), sand and dust storms, etc. The discussions and correspondence between the Weather Bureau and Air Force on this turn of events is a narrative in itself and shall not be elaborated on here. SELS continued to operate without change in severe thunderstorm criteria as the Air Force established its Military Weather Warning Center (MWWC) in Kansas City. The pre-1961 rapport that existed between the forecasters of SWWC and SELS was soon revitalized in the MWWC/SELS relations. These relations continued after MWWC operations were moved to the Air Force Global Weather Center (AFGWC), Offutt Air Force Base, Omaha, NE in 1970, via hot-line telephone with SELS.

Two unrelated events that would ultimately influence the future program at SELS occurred in 1965. The first was the Palm Sunday tornado outbreak of 11 April 1965. This outbreak of 51 tornadoes produced a death toll of 256 across six midwestern states. It was the nation's worst tornado disaster in 40 yr. While the SELS forecasts covered the situation reasonably well, a survey team appointed by Dr. Robert M. White, Chief of the Weather Bureau, (Dr. White was named Chief of the Bureau in October 1963 to replace the retired F. W. Reichelderfer) found disturbing inadequacies in the areas of communications, public awareness, severe storm reporting networks, and radar coverage (USWB 1965). The survey team also found an air of public apathy toward severe weather forecasts and warnings. They noted that "Even perfect forecasts and warnings, were they possible, are still of only limited value unless they are communicated to someone who has a need for them and uses the information as a basis for action."

The survey team's recommendations to correct these and lesser deficiencies fostered a plan for a Natural Disaster Warning (NADWARN) System. An important phase of NADWARN was the development of preparedness plans to help communities and areas deal with disasters caused by tornadoes and severe thunderstorms. These plans ensured coordinated action by those involved (e.g., warning services, local officials, law enforcement agencies, news media, etc.). A major ingredient of the preparedness activities included a widespread public education program on the threat of tornadoes and severe thunderstorms, and on measures that individuals could take to safeguard themselves. The tornado preparedness program developed by the

Weather Bureau which addressed itself to the foregoing concepts was named SKYWARN.

The second event was the creation of ESSA in July 1965. Dr. Robert White was appointed as the Administrator. White, while chief of the Weather Bureau, had been urging D.C. House, then the meteorologist in charge (MIC) of the Kansas City forecast office (a position he assumed in November 1960), to become a member of his staff in Washington, D.C. In March 1965, with the formation of ESSA imminent, House relented and accepted a position with the about-to-be-born organization. Since the favorable national publicity that SELS had been receiving prior to the Palm Sunday tornadoes increased in the wake of that disaster, House's promotion presented the bureau with an excellent opportunity to promulgate SKYWARN by the appointment of an ardent supporter of the program to the MIC position in Kansas City.

Accordingly, in August 1965 a member of the Palm Sunday tornadoes survey team, Allen D. Pearson, head of the Emergency Warnings Branch (EWB) of the Weather Analysis and Prediction Division (WXAP) at Weather Bureau Headquarters, officially became the MIC of the Kansas City forecast complex and third SELS supervisor. As head of EWB, Pearson had been chagrined by some of the events connected with the Palm Sunday tornadoes. He came to SELS with an intense interest in the implementation of the bureau's tornado preparedness plan, especially in the education of the public and the strengthening of the tornado reporting networks. Pearson made media relations an important aspect of the SELS program.

In an effort to reduce public confusion, the word "watch" was substituted for "forecast" in SELS public releases in 1966. The Hurricane Forecast Center in Miami, Florida had been using "watch" and "warning" terminology since the mid 1950s. (Incidentally, the use of "watch" for "forecast" for SELS issuances was suggested to the Weather Bureau Central Office by R. A. Garrett, the MIC of the Topeka, Kansas weather office in January 1956 and again in February 1958 by G. N. Brancato who was the MIC of the St. Louis, Missouri office.) Also, in February 1966, the Kansas City forecast complex was renamed the National Severe Storms Forecast Center (NSSFC).

5. Present status

The first Interdepartmental Severe Storms Conference was held in Kansas City on 24-26 October 1967. Participants included the Weather Bureau, Federal Aviation Administration (FAA), Army, Navy, and Air Force. The purpose of the conference was to resolve problems ranging from communications to terminology. The conference officially defined a severe thunderstorm as "one with wind gusts of 50 knots or greater and/or $\frac{3}{4}$ inch diameter hail or greater." (Extreme turbulence would be implied.) The Air Force, in particular,

was quite vocal for this definition. It was agreed that Weather Bureau public watches would continue with a wind gust criterion of ≥ 65 kt (75 mph). The conference also recommended that "watch" be inserted in the Aviation Severe Weather Forecasts released by SELS. The recommendations were adopted and became effective in 1968.

The different criteria for public and aviation watches continued through the 1968 and 1969 severe storms seasons. At the Intra-Weather Bureau Severe Storms Conference in October 1969, a recommendation sponsored by NSSFC and the Emergency Warning Section of WB Headquarters requested the same severe thunderstorm criteria for wind gusts (≥ 50 kt) be used for both public and aviation watches. The rationale was to eliminate one message in the distribution process. Even though this was opposed by both the SELS forecasters and the field stations, the recommendation was adopted for the 1970 season. The SELS forecasters petitioned for a return to the dual criteria at the next Intra-Weather Bureau Conference in the fall of 1970, but to no avail. The result was a substantial increase in the number of public releases.

The one-watch release for public and aviation watches was an Intra-Weather Bureau decision, not an interdepartmental one. While the objections of the field and the SELS forecasters could easily be side-stepped, those of FAA could not. The FAA had never permitted "plain" language weather transmissions on their Service A circuits. While FAA plans called for a massive collection and distribution center in Kansas City of weather information which would be able to accommodate plain language messages, its implementation was some two to three years in the future. So the FAA refused to transmit the plain language portion. Thus, while the same criteria for a severe thunderstorm took effect for both watches in 1970, two messages were still required for distribution. This procedure continued for three years when FAA's new switching facilities became operational. While format composition and dissemination of SELS products have been adjusted and/or varied since 1973, the defining criteria for severe thunderstorms have remained stable.

6. Implication

In retrospect, there is one interesting facet in the evolution of the weather services severe thunderstorm criteria. The majority of the actions leading to the establishing criteria came from the operational, i.e., grass roots level. Viewing the actions chronologically, it almost appears that the forecasters were forcing the hand of the decision makers. Consider the following: Although no official criteria for a severe thunderstorm were in effect when the unit for forecasting severe weather was formed, the use of gust figures appeared in the initial bulletins. The first semiofficial gust limit

for a severe thunderstorm appeared in a memo (January 1953) to the severe weather forecasters from their immediate supervisor. In a bolder move, the SELS supervisor petitioned his superiors in July 1953 with specific criteria for wind speeds and hail size. Even then, it was another year (almost two years after the inception of severe local storms forecasting) before the Weather Bureau Central Office formally defined a severe thunderstorm in March 1954. Also, the change in turbulence categories emanated from the ranks of the SELS forecasters. This method in the development of a definition of a weather event may have been a first.

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