The Golden Anniversary Celebration of the First Tornado Forecast

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1. Introduction

On 23–25 March 1998, Norman, Oklahoma, and nearby Tinker Air Force Base hosted a three-day celebration to commemorate the 50th anniversary of the first successful tornado forecast and the advances that have occurred in tornado forecasting and warning in the past half-century. The event was a cooperative effort of the National Oceanic and Atmospheric Administration (NOAA), the United States Air Force (USAF), and the University of Oklahoma. Participation also included the Norman Chamber of Commerce, as well as the chambers of commerce from surrounding municipalities in central Oklahoma.

A fortuitous series of events that included a daring forecast by air force weather officers Major Ernest J. Fawbush and Captain Robert C. Miller (Fig. 1) ushered in the modern era of tornado forecasting at Tinker Air Force Base (AFB) in the latter part of March 1948. On the evening of 20 March 1948, while under the watch of Fawbush and Miller, a tornado struck Tinker and the surrounding area without warning. The storm caused numerous injuries and more than $10 million in damage as it moved diagonally across the air field, overturning aircraft, toppling power lines, and shattering control tower windows.

Five days later, on the afternoon of 25 March, the same weather officers were once again on duty. Noting that atmospheric conditions over central Oklahoma were somewhat similar to those that had been observed on 20 March, Fawbush and Miller, with the encouragement of Commanding General Frederick S. Borum, issued an unprecedented forecast: they predicted that another tornado might strike the base later in the day. Incredibly, the second tornado in less than a week did indeed touch down at Tinker airfield early that evening. Aircraft had been secured and inbound traffic had been diverted, but the storm still caused $6 million in damage. Nevertheless, the toll would have been much greater had it not been for Fawbush and Miller's amazingly accurate forecast.

Fawbush and Miller became instant heroes. Their forecast techniques were soon adopted throughout the meteorological community; in modified form, their work remains in use today. The golden anniversary celebration highlighted Fawbush and Miller's pioneering efforts as well as the many milestones that have been achieved since their historic first forecast. The event also spotlighted some of the forecast advances likely to be realized in the future as a result of ongoing research into the behavior of severe local storms.

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FIG. 1. Major E. J. Fawbush (left) and Captain R. C. Miller (right) at work at the Air Force Severe Weather Warning Center, Tinker Air Force Base, Oklahoma, circa 1951.

2. Event overview

The celebration began with an open house of NOAA's Norman facilities on Monday 23 March. More than 2200 visitors from throughout Oklahoma and across the nation toured the National Severe Storms Laboratory (NSSL), and the National Weather Service's (NWS) Norman Forecast Office, Next Generation Radar (NEXRAD) Operational Support Facility (OSF), and Storm Prediction Center (SPC) on the North Base campus of the University of Oklahoma.

Visitors especially enjoyed examining some of the instruments used in field investigations of tornadoes, including the Mobile Atmospheric Observatory, the Doppler radar on wheels, and balloon launching equipment of the Joint Mobile Research Facility[1] (Fig. 2). At the forecast office, meteorologists demonstrated the release of radiosonde balloons (Fig. 3) and the use of amateur radio to communicate with storm spotters during severe weather. Animated loops of conventional, radar, and satellite data from around the nation gave visitors an appreciation for the scope of severe weather watch and outlook duties performed daily by SPC (Fig. 4). Outside, a sample mesonet tower erected by the Oklahoma Climatological Survey carried instruments used to continuously monitor surface meteorological conditions throughout the state (Fig. 5). A nearby OSF display of NEXRAD radar hardware included a 750 000-W Klystron radio tube of the type used in today's weather surveillance radars.

Several groups of volunteers helped make the open house a success. The Cleveland County chapter of the American Red Cross provided first aid assistance and showcased EmTRAC, the organization's Emergency Mobile Training, Response, and Communication Center (Fig. 6). Members of the city of Moore, Oklahoma, department of emergency management assisted in traffic control. Musical entertainment was provided by the Tinker Air Force Band "Flying High."

On Tuesday 24 March, the central Oklahoma chapter of the American Meteorological Society and the National Weather Association sponsored a scientific symposium on tornado forecasting and research in Meacham Auditorium on the campus of the University of Oklahoma. Ten scientists, each recognized for their contributions to tornado forecasting and research, delivered presentations on topics ranging from historical perspectives of forecasting and warning to theories and observing technologies that have emerged in recent years (see Fig. 7). A summary of each presentation appears in section 3.

Tuesday evening, the University of Oklahoma's Memorial Union Ballroom was the site of a gala ban-

[1]The Joint Mobile Research Facility is a collaborative effort of NSSL, the University of Oklahoma, and the Cooperative Institute of Mesoscale Meteorological Studies. It contains mobile and deployable facilities for use by scientists in the Oklahoma Weather Center.

quet highlighting 50 years of progress in tornado forecasting. The dinner was emceed by Dr. J. T. Snow, dean of the College of Geosciences, University of Oklahoma, and director of the Oklahoma Weather Center. The event included presentations by Dr. R. A. Anthes, president, University Corporation for Atmospheric Research; Brigadier General (Ret.) J. J. Kelly Jr. (USAF), NOAA assistant administrator for Weather Services; Dr. E. W. Friday Jr., director, Oceanic and Atmospheric Research, NOAA; and Dr. D. J. Baker, administrator, NOAA. The musical theatre program of the University of Oklahoma, under the direction of L. Goldberg, provided live entertainment.

A special ceremony in the Air Park on the grounds of Tinker AFB on the morning of Wednesday 25 March recognized air force officers Fawbush and Miller and the 50th anniversary of their historic forecast. Tributes by Baker, Friday, and Kelly, in addition to those by Oklahoma Lieutenant Governor M. Fallin, Vice Commander of the Oklahoma City Air Logistics Center Colonel D. J. Wetekam (USAF); Director of Weather, Deputy Chief of Staff, Air and Space Operations, Brigadier General F. Lewis (USAF); University of Oklahoma President D. L. Boren; and SPC Director Dr. J. T. Schaefer preceded dedication of a granite monument (Fig. 8) bearing the following inscription.

First Tornado Forecast

March 25, 1948

> This memorial is dedicated to the first operational tornado forecast issued on March 25, 1948 by Major Ernest J. Fawbush and Captain Robert C. Miller at Tinker Air Force Base, Oklahoma.
>
> Issued several hours before a tornado struck Tinker Air Force Base, this first forecast proved severe weather could be anticipated with a reasonable degree of accuracy. This focused national attention on forecasting tornadoes and warning the public of their potential danger.
>
> Severe weather pioneers, Major Fawbush and Captain Miller developed tornado forecasting techniques still in use today. The 1948 tornado forecast was the forerunner of today's national severe weather forecasting and research program that protects lives and serves the American people.

Dedicated March 25, 1998

A luncheon banquet at the Tinker AFB Officer's Club followed the dedication ceremony. At the lun-

FIG. 2. Display by the Joint Mobile Research Facility, showing two NSSL Mobile Atmospheric Observatories (left) and the Doppler radar on wheels (right).

FIG. 3. Radiosonde balloon release by the Norman NWS Forecast Office.

FIG. 4. R. Johns (right), science and operations officer of the NWS Storm Prediction Center, conducting a tour of the SPC.

FIG. 5. Mesonet tower of the Oklahoma Climatological Survey.

FIG. 6. Radio room of the Cleveland County, Oklahoma, American Red Cross chapter's EmTRAC.

cheon, master of ceremonies Lieutenant Colonel W. D. Shanor, USAF commander, DET 7, HQ AFWA; Brigadier General Lewis; and Colonel D. J. Wetekam presented a commemorative plaque to the attending relatives of Fawbush and Miller (Fig. 9). Present were Fawbush's daughters C. Goff and F. McCraley, and grandchildren B. Goff, T. McCraley, and T. McCraley. Also in attendance were Miller's daughter, K. Worcester and grandson I. Worcester.

A special edition of *Weather and Forecasting,* published in August 1999, commemorates the 50th anniversary of tornado forecasting. It contains selected papers presented at the Golden Jubilee Symposium as well as other manuscripts on the history and forecasting of severe local storms.

3. Session summaries

a. *Session 1: The Tinker tornadoes of 1948 and Robert C. Miller*

R. A. Maddox (Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma) chronicled the events leading to the tornadoes that occurred at Tinker AFB, Oklahoma, on 20 and 25 March 1948. Although the 20 March 1948 tornado was not forecasted, the synoptic situation on 25 March 1948 appeared, according to Fawbush and Miller, similar to that on 20 March. With strong encouragement by the commanding general of the Oklahoma City Air Materiel Area, F. S. Borum, Fawbush and Miller issued a tornado forecast for Tinker AFB later that day. With reanalyses of the 20 and 25 March 1948 upper-air and surface observations, Maddox discussed the Tinker tornado forecast. Drylines were present on both days, although the dryline on 20 March was positioned to the east of Oklahoma City by early afternoon, then retreated westward. At upper levels, a negatively tilted trough was evident in the 500-hPa analysis at 1500 UTC on 25 March, in contrast to a broad, positively tilted trough associated with a much stronger jet on 20 March. Despite several dissimilarities, both situations are recognized today to be supportive of tornadic storms.

The landmark forecast was the result of similar patterns as well as of the psychology of Tinker AFB at that time: a new severe weather response plan had been implemented by General Borum in the aftermath of the very damaging first tornado and it awaited testing. More importantly, it resulted from the "right people, who were in the right place, at the right time."

FIG. 7. Golden Jubilee Symposium on Tornado Forecasting speakers (from left to right): H. B. Bluestein, L. J. Wicker, R. A. Maddox, S. J. Weiss, E. N. Rasmussen, C. A. Doswell III, and A. R. Moller. Not pictured are D. W. Burgess, K. K. Droegemeier, and J. T. Schaefer.

FIG. 8. Dedication of granite memorial to the first tornado forecast on the grounds of Tinker AFB.

If not for this confluence of people and opportunity, and the proof and acceptance that the forecast provided, tornado forecasting would have evolved to its current state more slowly.

Maddox, who was mentored by Miller while at Air Force Global Weather Central (AFGWC), Offutt AFB, Nebraska, shared his reminiscences of severe storm forecasting with Miller. Miller's approach to forecasting consisted of pattern recognition, codified and standardized analysis procedures, composite charts, and monthly climatology of past severe storm occurrences and severe weather patterns. Some of these were necessary components in the Air Weather Service, owing to the frequent turnover of forecasters and a need for quick and effective training. His methods were compiled in AFGWC Technical Report 200, which is still used by meteorologists today.

Personal anecdotes of others who worked with Miller were shared. For example, he was remembered as a leader who "got down in the trenches" with his troops and one who had a "memory like an elephant." L. Wilson, who worked with Miller in Kansas City, Missouri, ended session 1 with his poem entitled "It's Miller Time."

b. Session 2: Tornado forecasting: Past, current, and future

S. J. Weiss (SPC) provided a historical perspective of tornado forecasting in the United States. Early efforts began in 1871 with Cleveland Abbe, under the direction of the Army Signal Corps. In the late 1870s, another pioneer, Army Signal Corps Lieutenant John Finley, began a systematic study of tornadoes that included a survey of the number of tornadoes in the Great Plains and later resulted in experimental tornado predictions and subsequent verifications.

The "dark ages" of tornado forecasting and research spanned the 1890s and early decades of the twentieth century. During this period, the conventional wisdom was that a tornado forecast would do more harm than the tornado itself. As such, tornado forecasts were banned. The success of forecasting techniques of Fawbush and Miller, who built on important earlier work by Albert Showalter and Joseph Fulks, ushered in the "modern era" of tornado forecasting.

The Severe Local Storms (SELS) unit of the U.S. Weather Bureau was formed in 1952 and made its move from Washington, D.C., to Kansas City, Missouri, in 1954. By the end of the 1950s, SELS was given authority for the issuance of tornado and severe weather bulletins, and it was generally recognized as the center of severe weather expertise in the Weather Bureau.

FIG. 9. Family members of Fawbush and Miller receiving commemorative plaque bearing inscription used on the granite monument (from left to right): B. Goff, C. Goff, K. Worchester, I. Worchester, F. McCraley, T. McCraley, and T. McCraley.

J. T. Schaefer (SPC) began his discussion of the current and future activities of the SPC by listing the major advances in knowledge and technology relevant to tornado forecasting. These include operational mesonumerical weather prediction, satellite imagery, knowledge of thunderstorm dynamics, Doppler radars and wind profilers, interactive computers, and improvements in communication and dissemination of warnings. Since 1973, the probability of detecting tornadoes in a region under a tornado watch has increased from 30% to 60%. And the mean lead time between issuance of a watch and occurrence of severe weather is now 1.5 h. The question was raised, What is the *ideal* lead time?

National hazardous winter weather outlooks are now issued by the SPC, and soon "fire weather" forecasts will be issued as well. The SPC is now experimenting with probabilistic convective outlooks, and in the future, tornado and severe thunderstorm watches will be issued on a county-by-county basis.

c. Session 3: Doppler radar for tornado research and detection

D. W. Burgess (OSF/Operations Training Branch) reviewed the advances in the use of Doppler weather radar for tornado and tornadic storm research and detection. He noted that conventional radar has served numerous meteorological purposes since World War II. For example, the 1948 Tinker tornadic thunderstorms were observed with conventional radar, and Keith Browning and Ralph Donaldson used conventional radar during the National Severe Storms Project (NSSP) in the early 1960s to ascertain the structure of supercell storms. (NSSP became the NSSL in 1964, which in subsequent years has played a major role in the development of Doppler radar.)

In 1958, Robert Smith and David Holmes used a (continuous wave) Doppler radar to obtain wind (spectra) information from the El Dorado, Kansas, tornado. Observations in 1971 and 1972 by NSSL's 10-cm wavelength pulsed-Doppler radar confirmed ideas that a cloud-scale rotation would manifest itself as a Doppler velocity "couplet" or mesocyclone "signature." Later, a smaller-scale "tornadic vortex signature" (TVS) was discovered in Doppler velocity scans of the Union City, Oklahoma, tornadic storm in 1973. The TVS developed aloft approximately 30 minutes prior to tornado formation. Storm intercept teams provided visual verification of cloud-base rotation and tornadogenesis in this and other storms.

The NEXRAD program began in 1980. Meanwhile, efficacy tests continued, and efforts to develop automated radar algorithms were well under way. A NEXRAD prototype provided remarkably successful warnings of the tornadoes that occurred near Ada, Oklahoma, and Red Rock, Oklahoma, in 1991. This was critical in bringing the implementation of the Weather Surveillance Radar-1988 Doppler (WSR-88D) network to fruition.

Improvements to the radar products generator and radar data acquisition system are currently in progress. In the future, there are plans to integrate radar data with satellite data, three-dimensional lightning mappers, and output from numerical weather prediction models.

d. Session 4: Storm spotting and public awareness

C. A. Doswell III (NSSL) highlighted important events in the history of public awareness, education, and volunteer "spotting"of tornadoes and severe weather. As an example, the number of U.S. tornado deaths changed dramatically in 1925, after the 18 March 1925 "Tri-State" (Missouri–Illinois–Indiana) tornado outbreak, owing to increased awareness of tornadoes and the advent of household radios. The number of tornado reports increased with the formation of SELS in 1952, as tornado reporting became more systematic.

Storm spotting in the United States began with John Finley (see section 2b) and reappeared in the 1940s as a need for observers near munitions plants was recognized. Several events, including the 3–4 April 1974 (Xenia, Ohio) outbreak of tornadoes spurred action to improve spotter programs. Spotting still plays a major role in severe weather warnings.

Doppler weather radar, numerical simulations of thunderstorms, and storm intercept programs helped advance the knowledge used to educate the public. Safety rules have also advanced (e.g., the public is no longer advised to seek shelter in the southwest corner of a building or to open windows in buildings). Continued public awareness is important, especially since it had been 30 years since a large city had been struck by a strong or violent tornado prior to the Oklahoma City tornado on 3 May 1999.

A. R. Moller (NWS, Fort Worth, Texas) continued the discussion on public awareness and education by outlining the components of the integrated warning system: forecast and detection, warning dissemination, and public response. NOAA weather radio and local television and radio stations play important roles in this system. More meteorological information is now given to emergency managers and storm spotters, as their level of understanding has increased.

A composition of films and videos, illustrating "Tornado Safety through the Years," was shown by Moller. This included segments from "Tornado," "Day of the Killer Tornadoes," "Terrible Tuesday," "Spotters Movie," and "Storm Watch." The contents have evolved from basic safety rules (some now known to be erroneous as noted above) and tornado identification to identification of visual clues that may foreshadow tornadogenesis and updated safety rules.

e. Session 5: Numerical modeling

L. J. Wicker (Department of Meteorology, Texas A&M University) reviewed past and current efforts to numerically simulate thunderstorms and tornadoes. Results of supercell storm simulations were first reported by R. Schlesinger in 1975, A. Thorpe and M. Miller in 1975, and J. Klemp and R. Wilhelmson in 1978. These and others focused on issues of storm structure and motion, and also of storm rotation and splitting, and of the control of the large-scale environment on storm type. In order to verify the models, simulations of specific storms were compared with dual-Doppler radar analyses of the same storm.

During the 1980s, much progress was made toward the understanding of thunderstorm dynamics. Simulated storm type (supercell, multicell) was found to be a function of convective available potential energy (CAPE) and vertical wind shear. This led to subsequent efforts at local prediction of storm type in an experimental forecast setting.

Owing to advances in supercomputer technology and techniques of "grid nesting," researchers have been able to simulate a "tornado vortex" within its parent thunderstorm. These studies complement two-dimensional, axisymmetric numerical modeling of tornadoes, from which much has been learned regarding tornado dynamics and structure. Three-dimensional, large eddy simulation models have recently been used to investigate suction vortices.

K. K. Droegemeier [Center for the Analysis and Prediction of Storms (CAPS), and School of Meteorology, University of Oklahoma] presented information on meso- and storm-scale numerical weather prediction (NWP). Mesoscale NWP models try to forecast broad features of a mesoscale convective system, for example. Stormscale NWP models, which are initialized with Doppler radar data, attempt to resolve and forecast individual updrafts and downdrafts. Predictability at both scales is currently limited by availability and effective use of observations, adequacy of physical parameterization at small scale, and computing speed.

A few applications of CAP's Advanced Regional Prediction System were shown. Currently, there appears to be some skill at predicting storm-scale events that are strongly forced, although modeling the details of individual events is problematic. Model forecasts of a hailstorm and a tornadic supercell fared better when the model was initialized with three-dimensional velocity retrieved from Doppler radar data.

In the future, these NWP models will make better use of data collected by WSR-88Ds, satellites, surface mesonetworks, and perhaps polarimetric radars. Techniques to assimilate these data continue to be improved, as are forecast methods using model ensembles.

f. Session 6: Tornado observations and research

H. B. Bluestein (School of Meteorology, University of Oklahoma) provided an overview of storm and tornado intercept efforts. Such efforts apparently began in the 1950s and early 1960s with the earliest known "storm chasers," including Roger Jensen, David Hoadley, Neil Ward, and Fred Bates. The NSSL/University of Oklahoma Tornado Intercept Project, which began in 1972, resulted in detailed schematics of supercell thunderstorm structure, including low-precipitation and high-precipitation supercells. Nonsupercell tornadoes were also documented.

Several important observing instruments were developed and used during these and other field campaigns to make in situ measurements of storms and tornadoes. These include the Totable Tornado Observatory, instrumented rockets, portable radiosondes and later the Mobile Cross-chain Loran Atmospheric Sounding System, mobile ballooning with electric field meters, lead-encased instrumentation packets ("turtles"), the Los Alamos National Laboratory portable CW/FM-CW Doppler radar, airborne Doppler lidar, airborne Doppler radar, mobile high-frequency Doppler radar, a "mobile mesonet," and the Doppler radar on wheels (DOW). The latter four instruments, directed from a mobile field coordination vehicle, were the primary observing platforms during the Verification of the Origins of Rotation in Tornadoes Experiment (VORTEX) in 1994 and 1995.

E. N. Rasmussen (NSSL and Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma) continued the discussion of VORTEX and also commented on the future of tornado intercept efforts for research. To understand tornadogenesis and maintenance, it is essential to combine several different data sources because of the limitations of individual observing tools. Airborne Doppler radar did well during VORTEX at capturing the overall structure of storms, but the data resolution is relatively coarse, synthesized winds are uncertain when the flow is highly unsteady, and winds are not measured very close to the ground. Supplementing the airborne Doppler radar data with surface data collected by the mobile mesonet, data from the DOW, and information extracted from cloud photogrammetry greatly improved the wind field analysis of the 2 June 1995 Dimmitt, Texas, tornadic storm. Following this analysis methodology, a study of the Dimmitt, Texas, case and others are in progress to assess various tornadogenesis hypotheses.

Future observational studies of tornado kinematics will require a narrow beamwidth radar to resolve the "corner" region. High-resolution, three-dimensional wind fields obtained by two DOWs can be used to investigate tornadogenesis. Plans are under way to couple these with instrumented missiles and an instrumented, pilotless "drone" to learn more about the dynamics and thermodynamics of the rear-flank downdraft.

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