In the precomputer age, Robert Miller developed a 3D view of the atmosphere that remains central to operational prediction of tornadic storms.

Forecasting severe thunderstorms and tornadoes presents meteorologists with some of their most challenging problems. This forecasting intrinsically requires consideration of all spatial and temporal scales of atmospheric motion and accordingly relies on the amalgamation of conventional data and remotely sensed data from radar and satellite. Newer observational tools such as Doppler radar and output from computer models have helped improve the analysis and prediction of severe storm environments. Nonetheless, we continue to rely on synoptic- and mesoscale analysis techniques that were developed in the precomputer age when rawinsondes and hourly surface reports were the principal data sources. Robert C. Miller (1920–98) was an innovative U.S. Air Force (USAF) forecaster who devised methods to predict severe thunderstorms and tornadoes in that precomputer age.

Miller’s ideas and methodologies continue to be used in operational forecasting more than 50 years after they were developed. In this paper, we trace the steps that led to the development of his methodology, starting with his early education at Occidental College and extending to his forecaster training during World War II (WWII) at Grand Rapids, Michigan. We document his experiences as a military weather officer following the war, and examine his legacy as it relates to the education and training of severe storm forecasters.

EARLY ASPIRATIONS AND EDUCATION AT OCCIDENTAL COLLEGE. As a young man growing up in Los Angeles, California, Robert Miller had an interest in science and mathematics, but never considered a career in meteorology. As he recalled:

I wanted to be a teacher in high school or college. I admired Mr. Orange, my high school math teacher, and had the dream of teaching algebra. (R. Miller 1994, personal communication, hereafter MIL94)

In pursuit of a teaching credential, Miller enrolled at Los Angeles Junior College (LAJC) in 1939.
After 2 years at LAJC, he transferred to Occidental College (Los Angeles) in September 1941, with the intention of obtaining a B.A. degree in both physics and mathematics. Occidental was one of the first accredited colleges in Los Angeles (established 1887) and was known for its exceptional liberal arts and science education. Two professors at Occidental had a long-term impact on Miller: Harry Kirkpatrick (a Ph.D. in physics at California Institute of Technology) and Henry Diekmann (a Ph.D. in mathematics at the University of California, Berkeley). He took differential and integral calculus (Math 5–6) from Diekmann and general physics (Physics 1–2) from Kirkpatrick (Occidental College 1940–41; J. Paule 1997, personal communication). In his reminiscences, he recalls the course in physics:

I took a course in physics from Professor Kirkpatrick. He was chairman of the physics department and he had been involved in oceanography so he often discussed our problems in terms of the ocean. I can remember him talking about submarines nosing down and talking about inversions. He would always draw the surface of the ocean, then the bottom, and finally add the intermediate layers. We would then discuss the inversions, sound propagation, etc., and he’d require us to analyze the processes 3-dimensionally. I can still hear him saying, “If the wind is blowing up here it’s going to have an effect down here, if it’s cloudy up here, it’s going to influence things down here” . . . This professor had a tremendous influence on the way I would later think about problems in meteorology. (MIL.94)

During Miller’s first semester at Occidental, the United States entered World War II (WWII). He decided to delay his education and contribute to the war effort after completion of his junior year. Thus, in summer 1942, Miller entered the U.S. Army Air Force (AAF) and was sent to Chanute Field in Rantoul, Illinois. His first assignments were menial (such as serving on kitchen patrol) and he longed for a more active role in the war effort. His chance came when he spotted a note on the bulletin board that advertised the need for airmen who were willing to be trained as weather forecasters at a school in Grand Rapids. Miller jumped at the chance, but assignment hinged on passing of an eye exam. His poor eyesight led to failure of the vision exam, but he was allowed to keep taking the exam. He remembered with glee the iterative approach he took to passing the exam. The doctor saw little improvement with each attempt to pass the exam, but in a benevolent yet irritated mood one day, this doctor told Miller that he “passed” the test and he never wanted him to darken the door of his examination room again. With that key signature on his physical exam, Miller got his orders to report to the weather school at Grand Rapids.

**WWII FORECASTER. The school at Grand Rapids.** We can partially reconstruct the sense of urgency that accompanied the recruitment of weather officers in 1942 by quoting from Walters (1952), a most-valuable postwar history of meteorological training in the military just prior to and during WWII:

In the autumn of 1942, Brig. Gen. H. M. McClelland, Director of AAF Technical Services, returned from Great Britain convinced that the number of weather officers must be increased prodigiously. On the basis of his report it was estimated that by June 1943 the AAF ought to have a total of 1,350 weather officers, by Sept. 1943 approximately 3,500, by Jan. 1944 about 5,000, and by early 1945 a total of 10,000… By Nov. 1942, Colonel Don Zimmerman, AAF Director of Weather, authorized the implementation of a plan to have 10,000 weather officers by early 1945. Walters (1952, 66, 93)

A July 1940 census revealed that there were 377 weather forecasters in the United States (Walters 1952, p. 62). The affiliations of these forecasters were as follows: U.S. Weather Bureau (150), commercial airlines (94), Army Air Force (62), Navy (46), and educational institutions (25). In view of this shortage of forecasters, a University Meteorological Committee was established in early 1942 with Carl-Gustaf Rossby as chair (see Fig. 1). Its mission was to establish a program of instruction that would significantly increase the number of military forecasters. Five civilian universities [California Institute of Technology (Caltech), University of Chicago, Massachusetts Institute of Technology (MIT), New York University (NYU), and University of California, Los Angeles (UCLA)] and one military school (to be established at Grand Rapids) were chosen to train the “cadets” (as the students were called). A 9-month course of instruction began on 16 March 1942 at the civilian institutions, and on 4 January 1943 at Grand Rapids. Upon completion of the program, the cadets would be commissioned weather officers with the rank of lieutenant in either the U.S. AAF or the Navy.

---

1 Kirkpatrick was a spectroscopist who studied under Robert Millikan, and Diekmann was a geometer who studied under Mellon Haskell (Kirkpatrick 1931; Diekmann 1937).
Robert Miller was a member of the first class of cadets at Grand Rapids, which was approximately 586 in number (Walters 1952). The technical director of the school was Colonel Don McNeal (see Fig. 1), an AAF veteran with an M.S. in meteorology from the eminently practical course at Caltech (Fuller 1991; Lewis 1994a). He had numerous disagreements with Rossby regarding the curriculum for the cadet program. As remembered by Colonel William Senter (shown in Fig. 1), Chief of Operations in the Directorate of Weather (AAF) in 1942,

He [Don McNeal] had a chip on his shoulder because these colleges [Caltech, University of Chicago, MIT, NYU, and UCLA] fought like hell to keep us from graduating weather officers out of our own school [Grand Rapids]. He felt that his school was just as good as anybody else’s. Nobody denied it,

---

2 Walters (1952, p. 67) states that there were 586 cadets in the first class at Grand Rapids and 887 in the second class that started on 29 March 1943. A 4 January 1943 article in the Grand Rapids Press gives 700 as the number in the first class. Miller and William Kellogg (an assistant at Grand Rapids for the first class) independently gave the number as 900 (MIL94; W. Kellogg 1993, personal communication).

3 Bracketed information in the quotations has been inserted by the authors.
except that . . . there were remarks made here and there that the graduates weren’t as intellectual as the ones from the colleges . . . [He had a reputation] of making the forecasters toe the line. He kicked them out if they couldn’t do it. He sent us good people, and most of them hated him. (Senter 1986)

Miller remembers the training as rigorous and demanding. Cadets were engaged in classroom work 7 hours a day, 6 days a week, and took additional military and physical training for 1–2 hours each day. Furthermore, they had a compulsory, supervised study period 2 hours each day. The cadets were housed at the Pantlind Hotel in downtown Grand Rapids and classes were held across the street at the Civic Auditorium. A picture of the students working at their desks in the auditorium is shown in Fig. 2.

Miller recalls the scene:

We’d be bent over all those maps trying to analyze a case study when we’d feel one of those instructors behind us. In fact, we used to call Colonel McNeal “Creeping Death” because he’d sneak up behind us and invariably say ‘cadet, that’s wrong!’ (MIL94)

The instruction was excellent, with lectures by Harry Wexler and Jerome Namias [U.S. Weather Bureau (USWB)], Athelstan Spilhaus (Professor of Meteorology, NYU), and John Leighly (Professor of Geography, University of California, Berkeley). Wexler was a Weather Bureau researcher before the war, Namias headed the long-range prediction branch, Spilhaus founded the meteorology and oceanography department at NYU in 1937, and Leighly was a renowned physical geographer. These teachers were commissioned captains in the AAF when the war started and were later assigned to Grand Rapids. A photograph of Spilhaus just prior to his commission is shown in Fig. 3.

These teachers stood on the auditorium stage and lectured to the throng. One of the assistants was William Kellogg, a recent graduate of UCLA’s first cadet class. As recalled by Kellogg,

There were 900 cadets packed into that Pantlind [Civic] Auditorium. It was hard, as you might imagine, for all those cadets to see the blackboard—especially when Harry Wexler was writing [Wexler had notoriously poor penmanship]. Consequently, I was tasked with writing the equations in huge letters on the blackboard. I would write on the back side of the board and at the appropriate time, I’d swing the blackboard around on its coasters to display the equation. I became known as “Wexler’s blackboard assistant!” (W. Kellogg 1993, personal communication).

Kellogg and Spilhaus indicated that the program at Grand Rapids was more focused on weather analysis and forecasting than those at the universities, and more challenging for the instructors because of the sheer size of the classes. The atmosphere was strictly military at Grand Rapids, whereas there was considerable freedom in a cadet’s personal life at the university. “The married cadets couldn’t even see their wives except on op-
composite sides of the fence that surrounded the Pantlind Hotel” (W. Kellogg 1993, personal communication). Miller confirmed the point when he said,

I asked Colonel McNeal if I could get out [of the Pantlind Hotel] to spend the night with my wife who was in the Grand Rapids Hospital expecting to deliver our first child. McNeal said, “Not tonight cadet, you’re on hall monitor duty.” Several days later I got to see my baby (MIL94).

Despite the urgency to get forecasters graduated and into the various operational theaters of war, the attrition rate at Grand Rapids was significant. As recalled by Miller:

Only 267 of [that first class] made it through without the need for remedial training, and fortunately I was among the 267 . . . I recall McNeal yanking several cadets out of the line at our graduation ceremony, apparently remembering at the last moment that they failed to come up to his standards! (MIL94)

Graduation carried a monthly pay increase from $75 to $183 per month and the commission mentioned earlier. Following graduation in September 1943, Miller was sent to March Air Force Base (Riverside, California) as a fledgling weather officer.

Operational forecasting. Despite the lack of operational experience, Miller was thrust into the job of weather forecaster at March AFB. As remembered by Miller, Two weeks later Miller was on his way to Dutch New Guinea. He first went to Townsville (Queensland, Australia), then to Merauke (Dutch New Guinea), and eventually to the Philippines. A photo of Miller while stationed in New Guinea is shown in Fig. 4. In this equatorial belt, Miller remembered the difficulties he experienced in tracking the weather systems. The scarcity of data in the Tropics, coupled with the absence of theory underpinning the dynamics of the weather systems, was a never-ending source of frustration for these forecasters (Galway 1994, personal communication; Lewis 1996). The enlisted men were indispensable because they generally had more forecasting experience than the officers and had familiarity with the islands. Miller admiringly remembered them:

We [the recent graduates of the cadet program] didn’t know from nothing. I had these great Master Sergeants who had been on the islands and knew the weather. They transferred that info to me. The one event I remember most clearly was the arrival of
the fighter squadron from Australia, led by “Black Jack” Caldwell, the flying ace. They had over 40 Spitfire-9’s land at Merauke on their way to fight over Japan. These planes landed 3-minutes apart, and when two of them crashed and burned on the runway, the others just kept landing as if nothing happened. I later cleared the squadron as they flew north. (MIL94)

By war’s end, Miller had spent over 2 years of forecasting tropical weather. In December 1945, approximately 4 months after Victory in Japan (VJ) Day, Miller returned to the States.

**Entrainment into severe weather forecasting.** Upon his return to the United States, Miller considered three options: remain in the AAF (soon to become the USAF), return to Occidental and finish his last year of undergraduate education, or take responsibility for the family’s sash and door business. “I couldn’t see that business as a life-long proposition, and unfortunately, it caused a great rift between my dad and me” (MIL94). Miller had been challenged by weather forecasting and decided to postpone the college degree and remain a weather officer. He was sent to Fort Benning (Columbus, Georgia) where he continued to forecast weather for military aviation. One event at Fort Benning deserves mention since it folds back to Professor Kirkpatrick’s influence on him:

I began to realize that I could do a better job at briefing pilots if I superimposed the surface, 850, 700, and 500 mb maps. So I started to make these different colored acetates for each level and devised

---

4 On 18 September 1947, Congress created the U.S. Air Force, an equal partner with the Army and Navy.

---

In fall 1947, Miller was sent to UCLA to assist in synoptic meteorology instruction; however, his orders were changed before he began this assignment, and he went to McChord Air Force Base (Tacoma, Washington) to forecast for a fighter unit. This was a short assignment, and he was then sent to the 206th Mobile Weather Squadron at Tinker AFB, Oklahoma City, Oklahoma, early in 1948. Within weeks of his arrival, a tornado swept across the base on the evening of 20 March 1948. This event and a subsequent tornado at the base became pivotal in Miller’s career. As a prelude to discussion of these tornadic events, we review the state of the affairs in severe storm forecasting when Miller joined the weather squadron at Tinker AFB.

**Status of severe storm research/tornado forecasting in the late 1940s.** In Table 1, we summarize contributions to severe storms forecasting that were in existence by the late 1940s. Details related to the entries in this table can be found by reference to the more comprehensive historical papers by Galway (1984, 1985a,b, 1989) and Schaeffer (1986).

Although the work by Fujita, Byers, and Braham did not directly relate to storm forecasting, these contributions marked a promising new pathway into the study of storm dynamics. The work by Chester Newton (1950) typified the new thrust in storm research where organized deep convection in the midlatitudes was linked to storm dynamics and the
larger-scale synoptic conditions that accompanied the storms. In essence, considerable effort was expended on linking the upper-airflow pattern and thermodynamic structure with the surface conditions that accompanied thunderstorms. Prior to Newton’s contribution, a little-known work by Brancato (1942) clarified the origin of the downdraft in thunderstorms. He demonstrated that the downdraft air came from approximately 10,000 ft above the ground.

In his reminiscences, Byers recalls this early work on thunderstorms:

> We had described the morphology and dynamics of individual thunderstorms, but there was still more things to learn about thunderstorms in the meso-scale—squall lines, etc... (H. Byers 1992, personal communication)

And, indeed, to investigate the storm complexes, Byers invited Fujita to join his group at the University of Chicago. Fujita had independently discovered the downdraft and measured it atop mountains near Tokyo, Japan (T. Fujita 1992, personal communication). His recollection of the event follows:

> The president of Meiji College encouraged me and four other professors and five students to investigate the atomic bomb explosion at Nagasaki soon after it took place. Three got sick and died. After our investigation, I got interested in meteorology, partly because I couldn’t continue in physics, no money at the college, and the president said “why don’t you study meteorology—it’s cheap, only pencil and paper needed”, but also because I saw the effect of destructive wind [at Nagasaki]. I began to make measurement of cumulonimbus by climbing to top of mountains. I found the downdraft! I wrote a paper [unpublished] and sent it to Professor Byers. He was impressed and invited me to University of Chicago. But I had to get my D.Sc. [which he completed at the University of Tokyo under Shigekata Syono], I did this in 1953 and then went to Chicago. (T. Fujita 1992, personal communication)

In Fig. 5, Fujita is shown with Syono, his teacher at the University of Tokyo. An elaboration on Fujita’s training at University of Tokyo and his subsequent emigration to the United States is found in Lewis (1993).

**Back-to-back tornadoes at Tinker AFB in 1948.** The tornado of 20 March 1948 led to the largest property loss in Oklahoma’s history to that point in time. Aircraft as well as other valuable property on the base were destroyed and this led to an inquiry by military officials the following week (at Tinker AFB).

In the first few days following the tornado, Miller (now a captain) and Squadron Commander Major Ernest Fawbush reviewed the synoptic conditions that accompanied the infamous Woodward, Oklahoma, tornado of April 1947, as well as those associated with the 20 March tornado. In the midst of the military inquiry, Miller and Fawbush noted similarities between weather features that preceded the 20 March event and those that were currently developing. Based on these similarities and the knowledge gained from study of the Woodward tornado, these two forecasters issued a tornado forecast for the base on 25 March (with strong encouragement from the base commander, General Borum). This bold forecast verified and brought national attention and acclaim to Fawbush and Miller (events later recounted in the *Saturday Evening Post* 1951, and *Time* 1955).

At the 30th annual meeting of the American Meteorological Society (AMS) in January 1950, the work that led to the forecast was presented. According to Galway (1992), this presentation brought further national publicity to these forecasters. For a detailed retrospective examination of the events surrounding these tornadic storms at Tinker AFB, the reader is referred to the paper by Maddox and Crisp (1999). These unprecedented events led the USAF to establish a Severe Weather Warning Center (SWWC) at Tinker AFB in 1951 (Miller and Crisp 1999).

**Contentious competition between the SWWC and the USWB.** The success of the 25 March 1948 tornado forecast encouraged Fawbush and Miller to examine and analyze most of the severe weather events that
occurred during the following spring and summer. They worked to devise a set of empirical rules and criteria (itemized later) to be used in thunderstorm and tornado forecasting, as well as issuing experimental tornado forecasts.

Media attention in the aftermath of the Tinker AFB tornado forecast bode well for the USAF, but reflected poorly on the USWB. As recalled by Galway (1992),

Fawbush and Miller continued to work on their technique and the experimental tornado forecasts issued for central Oklahoma were very successful (Air Weather Service [AWS], 1952). Although the forecasts were distributed only to air force weather offices, their existence and success became known to the public and especially to the local media, which lauded the efforts of the air force while criticizing the Weather Bureau for its inaction to forecast this weather event.

Considerable ill feeling developed between the SWWC and the USWB when the Kansas City District Forecast Office began to release reworded USAF forecasts to the press without any official military consent [see section 7 of Galway (1992)]. Miller considered this a breach of ethics. It induced a contentious spirit of competition between the SWWC and the USWB. More fundamentally, this piratical action by the Kansas City office led to Miller’s life-long distrust of the Weather Bureau.

Francis Reichelderfer (see Fig. 1), Chief of the USWB, responded to the media criticism by establishing a Severe Weather Unit (SWU) in May 1952 [renamed the Severe Local Storms (SELS) unit in 1953 (Galway 1984)]. The SWU was located in Washington, D.C., and within its mission statement was the job of evaluating the Fawbush and Miller techniques. Based on Galway’s historical research (Galway 1992; J. Galway 1994, personal communication), it is fair to say that the SELS unit adopted many of the Fawbush and Miller techniques. Tables 2 and 3 display some of the Fawbush and Miller criteria used by SELS in the mid-1950s. For an elaboration on USWB’s activities in severe storms forecasting, we refer the reader to Corfidi (1999).

**TR 200.** Before his arrival at Tinker AFB, Miller had already begun to view the atmosphere in its three-dimensional entirety. His view was fortified by the raft of synoptic papers that began to appear in the late 1940s—papers that explored the vertical structure of weather systems. Among the most influential were those that emanated from the University of Chicago where Eric Palmén exerted his influence on a cadre of aspiring young synopticians (Byers 1992, personal communication). Notable among these contributions were those by Newton (Newton 1950, previously mentioned in the section titled “Entrainment into

---

### Table 2. Tornado forecasting guidelines for SELS in the mid-1950s.

Factors listed stem from criteria established by Fawbush and Miller.

**[Courtesy of J. Galway.]**
severe weather forecasting") and Herbert Riehl (Riehl 1947). Riehl’s interpretation of easterly waves in the Tropics benefited from superimposition of wind fields from the surface to the 14,000-ft level, and Newton superimposed his detailed surface analysis over the wind field at 500 mb to better understand the development and maintenance of midlatitude squall lines.

With this wave of publications in synoptic meteorology, it is not surprising that the initial contributions from the SWWC emphasized coupling between upper-air features and surface weather. When we examine the collective work of the SWWC during the early 1950s (Fawbush et al. 1951; Fawbush and Miller 1952, 1953, 1954) there is a common theme. The theme, of course, is centered on the occurrence of tornadic storms; but more fundamentally, the focus is on the identification of common features in the large-scale flow and thermodynamics that accompany the storms. Beyond identification of these features, there was an attempt to rank the relative importance of these elements. This body of SWWC work followed in the path of the pioneering efforts by Lloyd (1942) and Showalter and Fulks (1943) that have been listed in Table 1. Whereas much of Showalter and Fulks’s work was constrained by the lack of quality upper-air observations (mostly obtained from the kite stations), the SWWC team had the benefit of observations from the national network of balloon-borne radiosondes that became available in the postwar period.

Beyond identification and ranking of common features/signatures in the synoptic flow, there was an effort to represent these elements minimally, that is, contract the information and display it on a single chart. These charts became known as “composites” and one of the first public presentations that featured the chart took place at the American Association for the Advancement of Science (AAAS) meeting in St. Louis, Missouri, in December 1952. Major L. J. Starrett, a USAF officer who had been assigned to the SWWC because of his exceptional writing skills, presented the paper. Starrett, in the company of Fawbush and Miller, is shown in Fig. 6. Starrett’s talk was titled “The tornado situation of 17 March 1951,” and it appeared shortly thereafter in the AWS manual (Air Weather Service 1952) and the Bulletin of the American Meteorological Society (Fawbush and Miller 1953). The composite chart presented at the AAAS meeting is shown in Fig. 7. A tornado was forecast to form within the boxed-in area, and indeed that was the case (forecast made 6 h before the event). Another tornado formed 50 miles to the north of this area. As depicted on the composite, the synoptic features deemed critical to the successful forecast were

1) a deep layer of dry air aloft (represented by the relative humidity field at 700 mb),
2) a lower layer of moist air where the mixing ratio is high relative to the dry air aloft (indicated by the moisture ridge at 850 mb),

<table>
<thead>
<tr>
<th>FORECASTER</th>
<th>TIME</th>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Forecaster’s checklist used at the Kansas City District Forecast Office in 1953. [Courtesy of J. Galway.]
3) a core of strong winds in the 10,000–20,000-ft layer (displayed as the axis of maximum winds), and
4) a low level of free convection normally below 650 mb [level of free convection (LFC)].

As would later be explained and discussed by Miller (1967), the likelihood of severe weather increases as the strength/intensity of these fields/parameters increase—not only increase, but increase in the context of preferred juxtaposition of the fields relative to one another. Clearly, despite guidance from the “four-pronged stencil” (the four synoptic features itemized above), there is an element of forecast uncertainty that can best be overcome by reliance on experience and intuition. In the presence of this uncertainty, Miller and Fawbush exhibited confidence and filed the following claim:

The authors’ method [Fawbush et al. 1951] of severe-weather forecasting comprises meticulous analysis and prognosis with particular attention to the probability of occurrence of the above conditions [the four items listed above]. On these bases, it is possible to issue warnings of impending destructive storms up to 24 hours in advance with reasonable confidence. [Fawbush and Miller (1953)]

Miller’s deft strokes used in the construction of composite charts are shown in Fig. 8. The boldness and character of the lines in this sketch are not unlike those found in the creative works of well-known scientists/artists and architects.⁶

There was a curtailment in formal publications by the SWWC team in the mid-1950s. With Fawbush’s departure from the SWWC in 1955, we suspect that the precipitous decline in publications stemmed from Miller’s reluctance to share his forecasting philosophy (his “secrets”) with the USWB. He feared that SELS would adopt the military’s weather warning procedures in toto.

Despite the lack of publications from SWWC during the mid- to late 1950s, Miller continued to refine his methodology to include “synoptic typing.” These ideas stemmed in part from the work of German synoptician and climatologist Franz Baur—analyses that he labeled Gross-Wetterlagen or quasi-persistent large-scale weather patterns (Baur 1948, 1951). Additionally, the practical forecasting that came out of Caltech in the late 1930s and early 1940s relied on the classification of synoptic weather regimes (Lewis 1994a,b). In Miller’s case, the large-scale weather features, for example, relative positions of the lower- and upper-level jets in relation to the sources of moisture (or dry air), were used to identify five patterns or “synoptic types” that were favorable for tornado occurrence (Miller 1959).

Thus, by the mid- to late 1950s, Miller’s vision of a practical severe storm forecasting procedure was in place. According to Larry Wilson,

“... by the time that the SWWC was relocated to Kansas City in 1956, the specifics of the severe

---

₃ See Wallace and Hobbs (1977) for elaboration on this concept related to atmospheric stability.
₆ See, for example, sketches by Leonardo DaVinci (Bergamini 1963) and Frank Lloyd Wright (Wright Foundation 1987).
weather composite chart had been completely defined and... its use in the forecasting process was the essential component of operations at the SWWC. (L. Wilson 2003, personal communication)

And by the early 1960s, Miller acquiesced to AWS pressure and consented to produce a technical report that would embody his conceptual ideas and philosophy regarding severe storm forecasting. It finally appeared in the late 1960s (Miller 1967) after Miller began working for the AWS as a civilian forecaster (discussed in the section titled “Civilian forecaster”). It simply and affectionately became known as “TR 200” (Technical Report 200) by those in the severe storm forecasting community, including some in academic institutions. This work became the quintessential companion to the severe storm forecaster or the novice at operational centers such as the SWWC, MWWC, and SELS. It also served as a practical supplement to the more theory-oriented texts used in academia. Retrospectively examined, TR 200 inspired severe storm forecasters in much the same way that Harald Sverdrup’s *The Oceans* (Sverdrup et al. 1942) and Frank Lloyd Wright’s *An Organic Architecture* (Wright 1939) inspired a generation of oceanographers and architects, respectively.8

7 The SWWC was restructured to be the Military Weather Warning Center (MWWC) in 1964 because of expanded forecast responsibilities (see Corfidi 1999).

8 See Tafel (1979) and Munk (1992) for viewpoints from protégés of Wright and Sverdrup, respectively.
APPRENTICESHIP UNDER MILLER. A rather detailed questionnaire was sent to Miller protégés in 1996. We draw upon responses to this questionnaire to understand the interaction between Miller and his students. Names of the forecasters follow the quotations. To set the stage for evaluating Miller’s approach to teaching, we emphasize the fact that he worked with military personnel, both from the enlisted ranks as well as officers. Miller’s most trusted forecasters were usually seasoned enlisted personnel. These personnel often requested assignment, or reassignment, to the weather warning centers, first located at Tinker AFB, Oklahoma, subsequently located within the Federal Building in downtown Kansas City, Missouri, and finally located at Offutt AFB, Nebraska.

The Air Force began to view these assignments, especially after the MWWC was moved to Offutt AFB, as intermediate stops on the path to developing well-rounded military officers or airmen. After the move to Offutt AFB, a tour of duty was seldom more than 4 years. However, at Kansas City, when Miller had nearly complete control of the MWWC, he was able to keep some forecasters for as long as 8 years before they were transferred. He was often able to have them reassigned back to MWWC for additional tours of duty. One only needs to examine the process of developing a premier forecaster in the current National Weather Service (NWS) to realize the serious constraints these policies placed on Miller. At the NWS Storm Prediction Center (SPC) in Norman, Oklahoma, roughly 10 years of experience is required before a forecaster is considered for a lead forecaster position (S. Weiss 2004, personal communication). 9

As Zuckerman (1977, p. 127) stated in her study of mentorship, search for the “important problem” and appreciation of stylish solutions are often central to the training of research scientists. In severe weather forecasting, the problems are already in place and they rarely yield to elegant theoretical solution. Nevertheless, there is overlap in the fundamental tenets that govern mentorship of research scientists and weather forecasters. Namely, “. . . the masters’ own performance provided a model to be emulated; the masters evoked excellence from the apprentices working with them . . .” (Zuckerman 1977, p. 125). And in Fig. 9, we observe Miller’s style, which is almost as if he were a cabinetmaker or craftsman who demands that the apprentice watch the master. Within the USWB at this same time (late 1950s through the early 1960s) there were at least two other senior forecasters who exhibited this form of mentorship: Gordon Dunn (see Burpee 1989) and Clayton Van Thullnar (“Mr. Van”), director of the Bureau’s National Severe Storms Project.

As might be expected, the novitiate under Miller was admonished to study TR 200:

MWAF [Military Weather Advisory Forecaster] training was primarily a learn-by-doing process. First a detailed study of chapters three through six and appendix F of AWSTR-200 [TR 200] and the MWAF reference file was required:

- Ch. 3: Severe Weather Synoptic Patterns
- Ch. 4: Squall Line Development
- Ch. 5: Forecasting Parameters
- Ch. 6: Forecasting for Summer Months
- Appendix F: Use of Automated Products

Fig. 9. Miller instructs protégé Larry Wilson at the SWWC (Kansas City, MO) in April 1967. Individuals pictured (left to right): Capt. William Huggins, Wilson, Miller, Maj. Vera Fink, Sgt. Jess Hixson, and an unidentified airman. The poster shown in the upper-left corner of the photo lists symbols used in the construction of composite charts. [Photo provided by L. Wilson.]
MWAF reference file contained the following:
  - Winter storms
  - Heavy rain
  - Notorious wind boxes over USA
  - Case studies
    (C. Crisp 1996, personal communication)

While studying the material in TR 200, the fledgling forecaster was directed by a senior forecaster [either a point weather warning forecaster (PWWF) or the MWAF]. The hierarchy of military personnel at SWWC/MWWC was as follows: Miller, MWAFs, PWWFs, and observers/map plotters. The path to MWAF passed through training under a PWWF, assignment as a PWWF, training under a MWAF, and assignment as an MWAF:

  The PWWF mostly gave instructions on the basics … the MWAF would point out errors, possible alternate ways of analyzing things or features of special interest. (G. Riley 1996, personal communication)

I read all the references and they were very good background material but I really learned most of what I needed by observing RCM [Robert C. Miller] and MWAF forecasters. (D. Trask 1996, personal communication)

At the more advanced stage of training, that is, while serving as a PWWF or higher level, the one-on-one interaction with Miller appeared to have the most impact on the protégés. The following quotations attest to this fact:

  The ultimate experience for me in 1965–66 was to be an apprentice to RCM. I admired the man and his ability to transfer his knowledge of SVR TSTM [Severe Thunderstorm] forecasting. He instilled confidence in me and gave me the tools to work alone as a SVR storms forecaster. (L. Wilson 1996, personal communication)

Later in his career, Wilson worked as a lead forecaster for the SELS unit. He discussed this work in light of his experiences under Miller:

  The first forecasters in SELS to successfully use forceful language in public forecasts were myself, [Jack] Hales, and [Robert] Johns in the late 1970s and early 1980s (i.e., writing public weather bulletins for anticipated “big days” . . . and having the confidence to stress “particularly dangerous situation” in tornado watches when higher F-scale [Fujita scale] tornadoes were expected.) I attribute this late-blooming confidence to the early experiences with the RCM techniques. (L. Wilson 1996, personal communication)

Miller exhibited extreme self-confidence, was at times uncompromising, and had frequent disagreements with commanding officers on issues related to tenure of his forecasters and their involvement in military activities aside from forecasting. “He [RCM] was a huge rock in the stream of military bull . . . we were sheltered in his wake” (J. McGinley 1996, personal communication).

During the period when the military’s weather warning center was collocated with SELS in the Federal Building in downtown Kansas City (1956–69), interactions between these two units were especially strained. A green-colored telephone resided on Miller’s desk at the Kansas City office and also at Offutt AFB. Lifting the receiver of this telephone put Miller in immediate contact with the SELS unit. McGinley remembers him “. . . throwing that green phone around the office” many times following conversations with the civilian forecasters. Wilson reflects on the competitiveness that existed between the units:

  On the upside, or downside, he [Miller] was always in a competitive role with the civilian side . . . he always wanted to be first to forecast a big TSTM [Thunderstorm] situation. He did not want to reveal his true intentions to the SELS side until the USAF forecast was produced. (L. Wilson 1996, personal communication)

CIVILIAN FORECASTER. After 23 years of service in the Air Force, Miller retired from active duty on February 28, 1965. He was 44 years old at the time and would go on to serve as a government civil service forecaster and consulting meteorologist for another 16 years. In an effort to more-easily track the stages of Miller’s career, Table 4 has been constructed. We note that he served as a civilian forecaster for 12 years (1965–76), and then entered the private sector (consulting meteorology) for approximately 5 years. We categorically group the consulting companies together since we are uncertain of Miller’s length of service for each company. Before retirement from weather-related work, Miller briefly returned to federal civil service as a forecaster at Cheyenne, Wyoming.
### Table 4. Career timeline and awards for Robert C. Miller.

<table>
<thead>
<tr>
<th>Positions and awards</th>
<th>Year(s)</th>
<th>Organization/location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student</td>
<td>1939–41, 1941–42</td>
<td>Los Angeles Junior College, Occidental College</td>
</tr>
<tr>
<td>Enlisted (AAF)</td>
<td>July 1942</td>
<td>Chanute AFB (Rantoul, IL)</td>
</tr>
<tr>
<td>Cadet Program</td>
<td>1943</td>
<td>Grand Rapids, MI</td>
</tr>
<tr>
<td>Commissioned Weather Officer (AAF/USAF)</td>
<td>1943–65</td>
<td>March AFB (CA), Pacific Theatre (WWII), Fort Benning (GA), McChord AFB (WA), Tinker AFB (OK), Kansas City, MO, High Wycombe AFB (UK), Kansas City, MO</td>
</tr>
<tr>
<td>Retired (Active Duty) USAF</td>
<td>February 1965</td>
<td></td>
</tr>
<tr>
<td>Severe Storm Forecaster (Federal Civil Service)</td>
<td>1965–76</td>
<td>Kansas City, MO, Offutt AFB (NE)</td>
</tr>
<tr>
<td>Weather Forecaster (Federal Civil Service)</td>
<td>1980–81</td>
<td>Cheyenne, WY</td>
</tr>
<tr>
<td>LeRoy Meisinger Award</td>
<td>1956</td>
<td>AMS</td>
</tr>
<tr>
<td>Losey Atmospheric Sciences Award</td>
<td>1964, 1974</td>
<td>American Institute of Aeronautics and Astronautics (AIAA), AMS</td>
</tr>
</tbody>
</table>

Although Miller experienced great difficulties with the USWB for over two decades, he became one of five lead forecasters at SELS in May 1965. He retired from the Air Force with the knowledge that the Department of Defense (DoD)/AWS would hire him into the civilian position of chief forecaster. However, before he could be hired into this position, civil service regulations required that he be in military-retired status for at least 6 months. Thus, in October 1965, after only 5 months in the SELS position, he resigned and returned to his work as leader and chief forecaster of the MWWC.\(^9\) In view of TR 200’s publication in 1967, Miller’s initial effort at AWS must have been devoted to publication of this report.

In 1969, the USAF deactivated the MWWC and transferred key personnel from Kansas City to Offutt AFB. Miller remembered the events as follows:

\[^9\]J. Hart’s (1995, personal communication) historical data verifies that Miller worked as a SELS lead forecaster from May to October 1965.

[We] became part of the USAF’s Air Force Global Weather Central (AFGWC). The move was designed to take advantage of the AFGWC’s worldwide data gathering ability and large computer capacity. I was designated AFGWC Chief Scientist and charged with responsibility of training forecasters in the specialized methods used in severe [storm] procedures that could be adapted to computers. This had to be done while we continued to provide warning service to the military . . . Computer processing significantly reduced the time interval between data receipt and chart availability and many time consuming and laborious tasks were entirely eliminated. Miller (1978)

It is clear from Miller’s discussion that he viewed the computational resources at AFGWC as a means to automate and speed-up his forecasting procedures rather than as an opportunity to complement his methodology with numerical weather prediction (NWP) products.

In September 1976, Miller left government service and entered private meteorology. This phase of his
professional life is difficult to reconstruct because of limited documentation. However, the known record would indicate that he moved quickly from one consulting company to another. We do know that his position at Management and Technical Services Company (MATSCO), a subsidiary of General Electric (GE), involved application of satellite-derived products to the problem of severe weather forecasting [a project supported by the National Aeronautics and Space Administration (NASA)]. Viewed macroscopically, it is fair to say that these last years of Miller’s professional career were problematical; in effect, he had a difficult time finding a way to use his considerable analytical talents and forecasting skill in areas other than severe weather. This situation was probably exacerbated by his dominant personality and his penchant for challenge and leadership in groundbreaking work.

Following his career in meteorology, Miller worked part-time at a hobby shop near his home in Laurel, Maryland. In 1994, he was invited to the National Severe Storms Laboratory in Norman to retrospectively examine his celebrated tornado forecast at Tinker AFB. Although he was obviously weak, he delivered a spirited 30-minute talk that displayed his rough-hewn nature coupled with his undeniable charm. Shortly after his return home, he fell ill and was bed-ridden for the remaining few years of his life.

EPILOGUE. Robert Miller was an outstanding analyst, weather forecaster, and teacher of forecasters. His first encounter with weather forecasting came under Colonel Don McNeal whose approach had its roots in the Caltech tradition, that is, science in service to society. Despite his memory of a harsh instructor, Miller came to emulate McNeal in his approach to forecaster training. This harshness was ameliorated to a certain degree through his association with Ernest Fawbush, a competent leader who served as the guiding light and organizer of the USAF’s Severe Weather Warning Center.

Miller engendered respect, admiration, and allegiance from his protégés. Yet, he was a rugged taskmaster and that same fear that he experienced under the watchful eye of McNeal was felt by his troops. Miller had the gaze of a basilisk and the temper to match. The Military Weather Advisory Forecasters trembled at the sight of Miller’s public “purple pen” critiques of their forecasts. These critiques were written boldly in purple marker on the forecast maps that hung in plain view of everyone who entered the center. A forecaster reached the pinnacle of success when the critique read “GREAT JOB,” but a comment like “YOU DUMMY! How could you miss this??” dropped the protégé into the pits of despair.

What are the inherent traits that portend success as a forecaster? Furthermore: What constitutes ideal training for that student who wishes to become a forecaster? For those who have taught synoptic meteorology, there comes the realization that many of the potentially gifted forecasters possess an ability to view the complex phenomena of the atmosphere with limited reliance on the theoretical underpinning of meteorology. This gift, as if from birth, has been found in celebrated forecasters such as C. K. M. Douglas, Charles Mitchell, and Gordon Dunn [see Petterssen (1974, 2001), Lewis (1995), and Burpee (1989), respectively]. These forecasters were human analog machines with phenomenal memories of synoptic weather regimes (and mesoscale structures, in the case of Douglas). And it is not surprising to find that Miller stressed the importance of this natural talent. As stated in Fawbush and Miller (1953), the potential severe storm forecaster was judged on native ability and experience. We quote,

The forecaster must carry a set of mental analogs and, either conscientiously or unconscientiously, refer to them constantly. [And] quite aside from general ability, some seem to have a natural “feeling” for forecasting and this is needed in every step to interpret and evaluate future trends.

Miller searched for these specific traits in his novitiates. Those who showed promise advanced under his stern supervision. However, he demanded that they adhere to his philosophy and practical approach to forecasting. Further, he discouraged exploration of alternate approaches to severe storm forecasting, for example, those guidelines on tornado initiation that stemmed from Fujita’s work [section 7 of Fujita (1955)], Ferdinand Bates’ techniques for forecasting extreme turbulence in the presence of convective storms (Bates 1955; Galway 1989), and Reginald Sutcliffe’s “... framework for practical consideration of 3D flow and synoptic development in middle latitudes” (B. Hoskins 1995, personal communication; Sutcliffe 1947). Yet, Miller’s attitude could be understood, at least in part. The military severe weather centers had a job to do everyday, a product to be delivered around the world in time-critical manner, and tragic consequences were likely—loss of life and property—in the event of an egregious error. In short, Miller would not tolerate an alternate methodology that had not undergone the extreme scrutiny of his method.

AMERICAN METEOROLOGICAL SOCIETY

APRIL 2006 | 461
In an age that overflows with abundant data from new technology, data that include multitudinous products from operational numerical prediction models, forecasters can easily become overwhelmed. If Robert Miller were training forecasters today, we suspect that he would exhibit a reluctance to embrace the full complement of products that stem from this new technology. His focus would begin with detailed analyses and interpretation of current observations as a necessary precursor to evaluation and use of model and radar products. Yet, he would not allow these abundant resources to distract him or his students. He would still demand sufficient time for that exchange between himself, senior forecaster, and apprentice. The apprentice would learn by watching the master, slowly absorbing, and eventually gaining confidence, and in some cases, exhibiting independence.

ACKNOWLEDGMENTS. In 1994, we conducted oral history interviews with Colonel Miller and Joe Galway. We are indebted to these two pioneers of severe storm forecasting—one from the military side and the other from the civilian/government side. Their first-hand accounts of operational forecasting in the 1940s-1950s were germane to this study. A group of forecasters who followed in the footsteps of Miller and Galway also contributed. Among these were Miller protégés: Richard Anthony, Arthur Bidner, Les Coleman, Charlie Crisp, Chuck Jones, Bob Maddox, John McGinley, Gary Riley, David Trask, and Larry Wilson. Further, SELS forecasters provided us with valuable information: Bob Johns, Richard Thompson, Steve Weiss, and Larry Wilson. Wilson’s perspective was invaluable—a view that angled from both sides of the nearly impenetrable barrier that separated the military and civilian sides of operational severe storm forecasting.


Librarians and archivists searched their institutional records to find documentation in support of this research. We commend the following: California Institute of Technology (Bonnie Ludt), University of California, Berkeley, National Weather Service, Las Vegas (Kim Runk), Desert Research Institute (Jackie Jackson), and Occidental College (Jean Paule).

Bob Bundgaard graciously translated information regarding C. K. M. Douglas from Petterssen’s autobiography, Kuling fra Nord (Wind from the North), and SPC forecaster John Hart allowed us to use his unpublished roster of personnel at SELS. The formal reviewers’ cogent suggestions for revision contributed to an improved presentation. We thank the three anonymous reviewers for their help.

Mike Lloyd, editor of the Grand Rapids Press, allowed us to quote from the newspaper and reproduce the photograph of military students working in the Grand Rapids Auditorium. We are grateful for this permission.

Finally, we express our deepest gratitude to Beverly Miller, Colonel Miller’s widow, for talking to us about her husband’s career and allowing us to reproduce photographs from her collection.

REFERENCES


Grand Rapids Press, 1943: Classes start at air school. 4 January, front page.


Senter, W., 1986: Oral history interview. Interview by J. Fuller, transcript, Maxwell AFB, USAF Historical Research Center, 250 pp.


Time, 1955: Predicting a Tornado. 27 June, 63.


This monograph pays tribute to one of the leading scientists in meteorology, Dr. David Atlas. In addition to profiling the life and work of the acknowledged “Father of Radar Meteorology,” this collection highlights many of the unique contributions he made to the understanding of the forcing and organization of convective systems, observation and modeling of atmospheric turbulence and waves, and cloud microphysical properties, among many other topics. It is hoped that this text will inspire the next generation of radar meteorologists, provide an excellent resource for scientists and educators, and serve as a historical record of the gathering of scholarly contributions honoring one of the most important meteorologists of our time.