The History of Aviation Weather Forecasting in Kansas City

Carolyn M. Kloth
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Aviation Weather Center
National Centers for Environmental Prediction
National Weather Service
Kansas City, MO 64106

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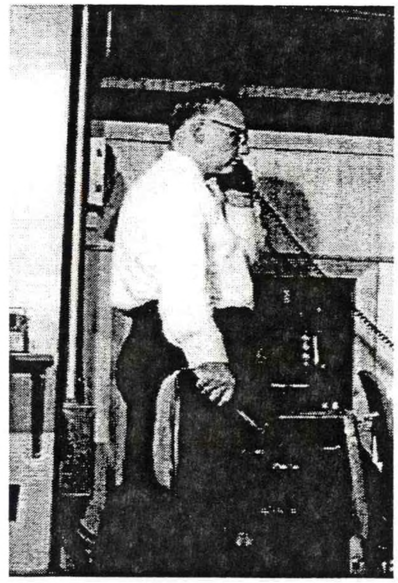
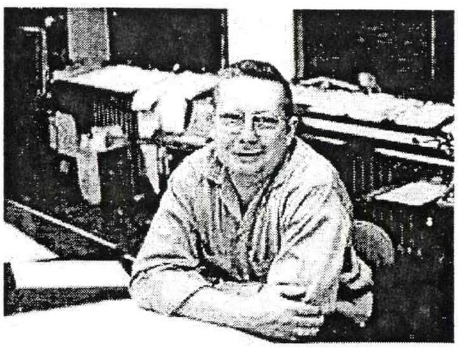
Our Sources...



Bob Baskin



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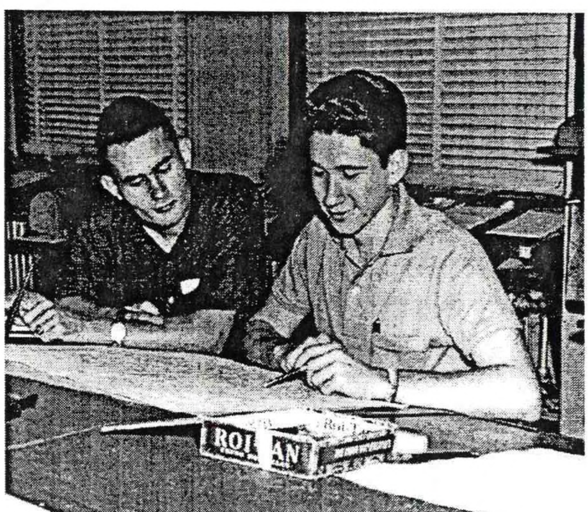

Hugh Jones & Roy Darrah

Acknowledgments

The compilation of information for this document was a team effort involving both past and present employees of the Kansas City weather office(s). The authors are extremely grateful for the input from retirees Bob Baskin and Ed Provost who provided not only their recollections, but also made available material from their personal archives, including a number of the photos used in this report. We also gratefully acknowledge the written material received from veteran forecaster Dick Kerr and retirees Wilbur Wray and Hugh Jones.

The initial impetus for the project came from AWC Director Dr. Dave Rodenhuis who suggested it might be interesting to examine our "roots" as a parallel to the "strategic planning" initiatives underway as we approach the 21st century. The team was originally led by Doug Mathews whose calm, deliberate leadership of the aviation unit laid much of the foundation for the present-day operations at the AWC. Doug retired in July 1997 after 32 years of government service.

Many thanks to Ronni Smith whose expertise and hard work on the final production of this document rescued the authors from possible oblivion. Thanks also to Gary Grice of the Storm Prediction Center, whose guidance and experience in compiling a historical document proved invaluable for this project. A number of the photos in his publication honoring the National Weather Service were included here.

Finally, a tip-of-the-hat to the untold number of forecasters who made it all happen. Without these "unsung heroes" whose dedication and perseverance in all climates (both natural and political) translated all the policies and knowledge of the time into reality...without these heroes whose lives are continually disrupted by the rotating shift work required by the job they love...there would be no **history** of aviation weather forecasting.

PREFACE

In 1995, a major report by the National Research Council, *Federal Aviation Weather Services - A Call for Federal Leadership and Action*, focused national attention on the importance of weather services for aviation. About the same time, the National Weather Service (NWS) and its newly-organized National Centers for Environmental Prediction (NCEP) established a new center specializing in aviation weather forecasting. This action marked the first time in the history of the federal weather services that a national center was devoted exclusively to the needs of the aviation community.

As we attempt to assert the capabilities of this new center and define our role for the next decade, where radical changes in technology and communications appear to lead us away from traditional roles, we have paused a moment to ask, "How did we come to be where we are today?" This history of aviation weather forecasting reveals that the present mandate for modern aviation weather services is based upon a foundation of service in a culture of change. This history also helps define who we are as a professional organization.

Located in the nation's heartland, Kansas City was a natural site for the development of continental aviation weather services around the turn of the century. Since 1888, weather observations have been officially recorded here, and in the 1920s, aviation forecasts became routinely available. During the succeeding years, the city has hosted increasing federal activities to support and manage the growing air traffic. The increase in the number of commercial air carriers and the advent of coast-to-coast flights led to a spectacular "new" downtown airport and a need for expanded aviation services. Thanks in part to modern communications, Kansas City is now the primary NWS facility that receives international data from ocean to ocean, and from the Arctic to the Equator.

This history tells us and all those who will follow that we all draw on the experience, dedication and curiosity of generations of meteorologists and airmen who preceded us. It also reveals that, at one time, the sciences of flight and weather worked intimately together---both fields needed conscientious observers and practical applications of up-to-the-minute information.

As we prepare for the future, this history reminds us where we've been, thus enabling us to build on what we have already achieved. With this knowledge, we are presented with the opportunity to rededicate our professional work to those who fly and manage the National Airspace System. We will achieve the most if we work together, as this history shows---controllers, dispatchers, pilots, researchers, and aviation weather forecasters.

David R. Rodenhuis
Director, Aviation Weather Center
January 28, 1998

The History of Aviation Weather Forecasting in Kansas City

Introduction

Aviation and knowledge of the atmosphere became inextricably linked on the morning of December 17, 1903, with the epic flights of the Wright Brothers (Fig. 1). It has been widely documented that the climatological data provided to the Wright Brothers by the Weather Bureau led to the choice of Kitty Hawk, NC for their pioneering tests.

It is less well-known that the Weather Bureau had been involved in "aerology" even before the turn of the century. Signal Service researchers investigated the use of balloons for obtaining weather data at levels above the surface. In the years prior to 1903, current weather conditions and climatological data were also provided to others interested in the prospect of manned flight. Most notable of these was Octave Chanute[1] whose observations of birds in flight and experiments with gliders were incorporated by the Wright Brothers into the design of their heavier-than-air craft.

Tremendous changes have taken place in the decades since man took to the air in the first powered flight. A review of the history of government weather services reveals several common themes throughout its lifetime. The first is sustained growth despite the delicate balancing act between priorities and uncertain budgets.

Time and time again during the first two decades of the 20th century, requests for additional resources to fund the expansion of weather services were denied. As early as the late 1870s, the Weather Service, under the auspices of the Army Signal Corps[2], suffered budgetary cutbacks. It becomes immediately evident that the battle for adequate funding is **not** a recent occurrence.

A second common thread throughout the history of government weather services is the influence of technology on how the atmosphere is monitored, forecast, and how those forecasts ultimately reach the user. Early on, it was the primitive state of remote sensing technology that limited our knowledge of the atmosphere. Dissemination of the little weather

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1 A local footnote: Octave Chanute is famous as the designer and builder of the first bridge to span the Missouri River at Kansas City (1861), and was also involved in the layout of the town of Lenexa, KS, just southwest of Kansas City, MO.

2 Throughout the literature on the subject, the Signal Corps is often also referred to as the Signal Service. It appears to be widely accepted that the names are interchangeable.

data available at the time was limited by the still-emerging communication technologies. Now, we routinely monitor the earth's weather from space and we can transmit weather data around the world literally at the speed of light.

This narrative seeks to trace the evolution of aviation weather forecasting from around the turn of the century to the present. In the first section, we will examine the general state of government aviation weather services in the years leading up to WWII. The second section will examine the growth of aviation weather forecasting from a Kansas City perspective, primarily since WWII. Section 3 will focus on the events following a period of national consolidation that led to the establishment of the Aviation Weather Center.

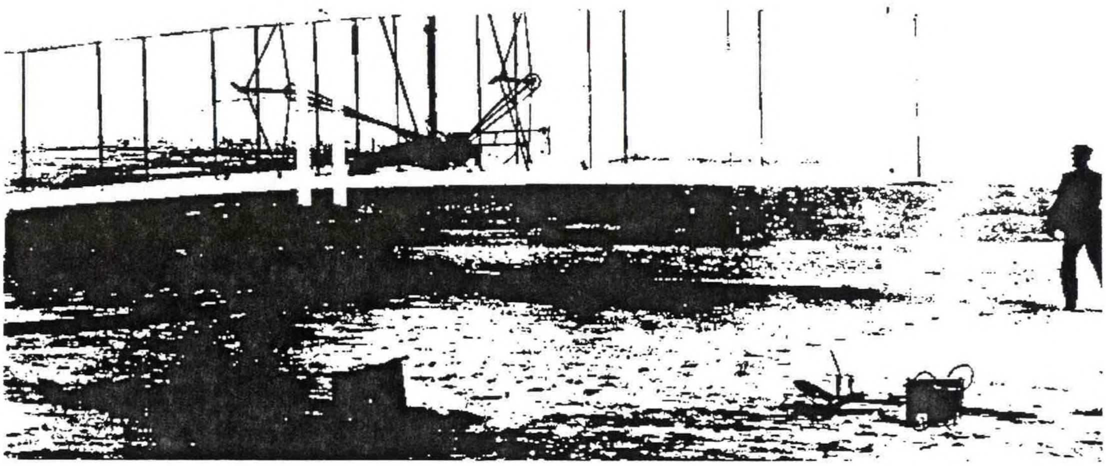

Figure 1. Orville Wright is at the controls as the Wright brothers' plane lifts off the launching track on its historic flight.

-The Smithsonian Institution

1. Aviation Weather Forecasting — The Beginning

Carolyn M. Kloth

1.1 From Signal Corps to Weather Bureau

As mentioned in the Introduction, the Nation's weather service, established in 1870, was initially formed as part of the Army Signal Corps (Fig. 2). This was partly in an effort to save money (i.e., by utilizing personnel already on the government payroll) and partly because it was thought that the military discipline would guarantee reporting uniformity.

The Signal Corps was also a "natural" because it had an established telegraphic network that seemed ideally suited for transmission of the weather data. Coincidentally, the head of the Signal Corps at that time, Colonel Albert J. Myer, was a former Army surgeon who became familiar with meteorological observations when the Medical Corps was directed to record daily weather information by the Surgeon General during the War of 1812.

The Signal Corps Weather Service grew from 24 stations in 1870 to about 178 by 1890. Its initial responsibility was to provide storm warnings for the Great Lakes and coastal areas of the Atlantic and Gulf of Mexico. The first storm warning was issued for the Great Lakes on November 8, 1870, the same day the service was initiated. The responsibility of the Signal Corps was expanded to cover the entire nation in 1872 when Congress passed legislation to that effect on June 10th. However, the sparseness of data west of the Mississippi River meant that the forecasts were most complete for just the eastern third of the U.S. (Fig. 3).

By the late 1880s, pressure was mounting for civilian control of the Weather Service. Legislation was introduced in December 1889 to remove the Weather Service from the military and place it in the newly-formed U.S. Department of Agriculture. This seemed a logical move because of the importance of weather forecasting to farming and other forms of agriculture. That farmers in the newly-settled territories of the west and Midwest needed weather information was evident from the general lack of knowledge of conditions from the Mississippi River westward to the settled areas along the Pacific coast. The legislation, entitled "An Act to Increase the Efficiency and Reduce the Expense of the Signal Corps of the Army and to Transfer the Weather Service to the Department of Agriculture", was passed in September, 1890 and signed into law by President Benjamin Harrison, effective the following July.

Since that time, like most federal agencies, the civilian weather service, by now renamed the Weather Bureau (WB), has experienced periodic changes in organization and emphasis. Initially, all weather data was telegraphed to Washington three times daily, from which all forecasts originated. This was soon reduced to twice-daily for both economic and logistical reasons. After 1890, local weather offices like the one in Kansas City (Fig. 4) were given the

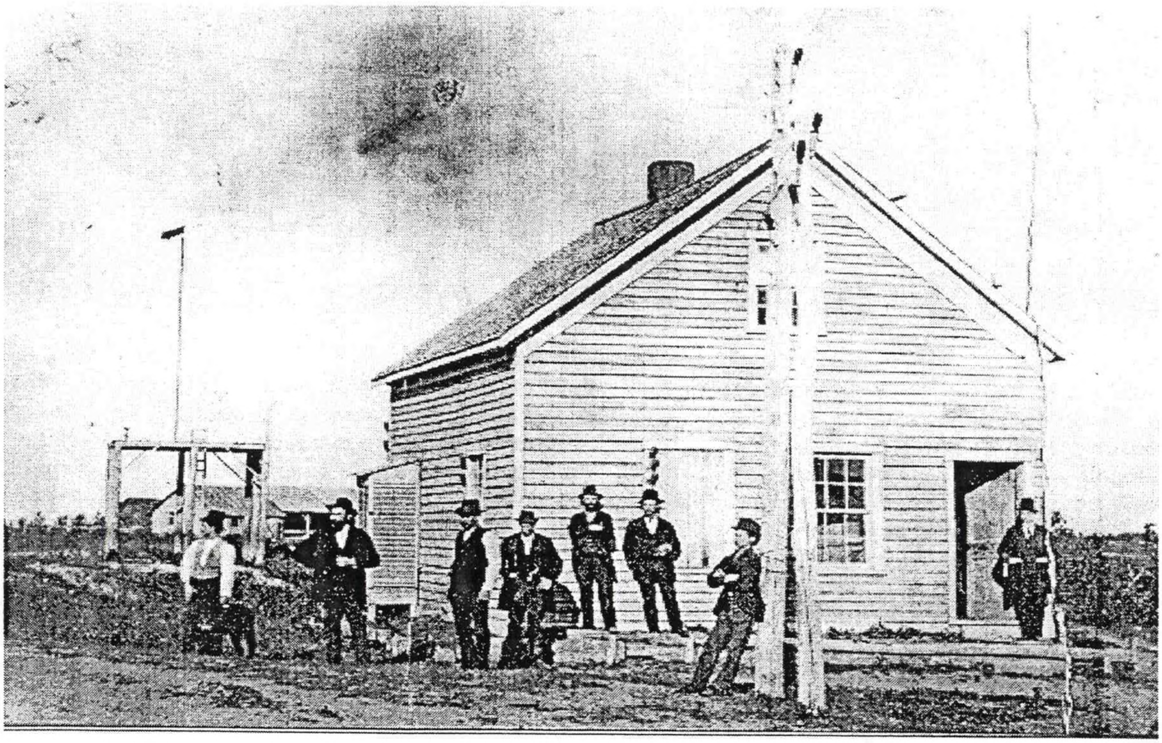

Figure 2. Signal Service office in South Dakota (circa 1890).

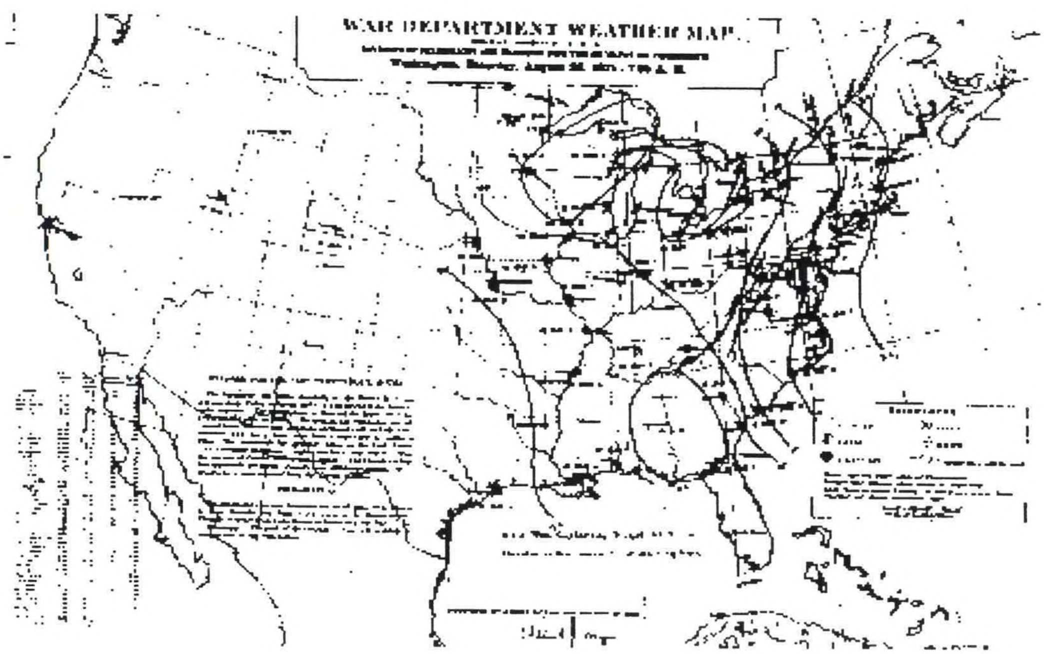

Figure 3. Surface weather map prepared by the Signal Service on August 26, 1871.

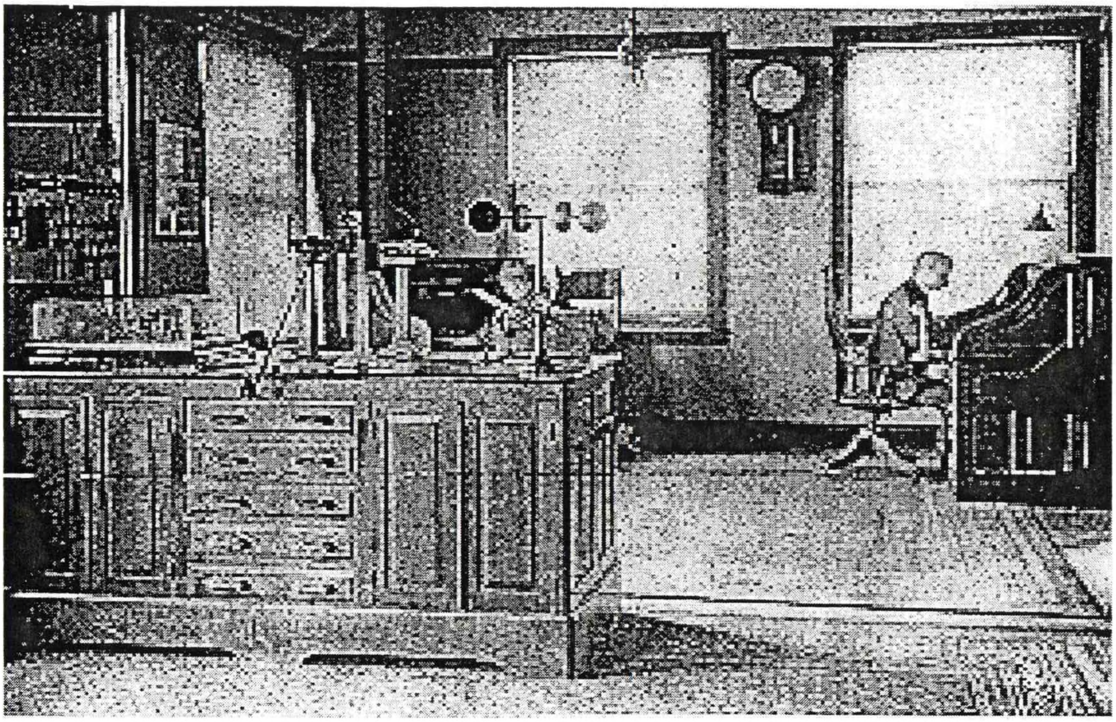

Figure 4. Kansas City Weather Bureau office, mid January, 1891.

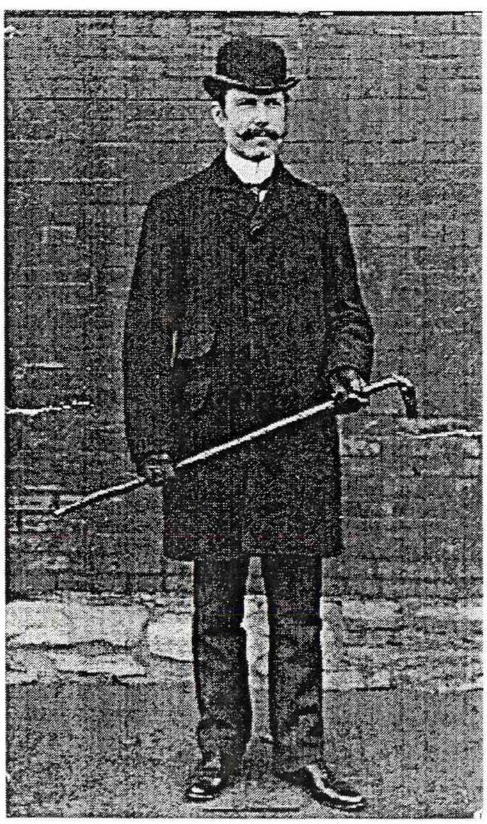

Figure 5. P. Conner was the first Official-In-Charge (OIC) of the Kansas City weather office.

option of amending the forecasts, when necessary, to adapt them to varying local conditions. In 1894, a policy of de-centralization was instituted and a system of district forecast centers was established. At about the same time, the number of trained forecasters was increased ten-fold, from just four in 1891 to forty, in an effort to improve the quality and accuracy of Bureau products (Fig. 5).

Political turmoil and intrigue led to the dismissal of the Bureau's first Chief, Mark W. Harrington, in the mid 1890s. His replacement, Willis L. Moore, expanded WB facilities and services, adding 61 new weather stations and establishing a network of kite stations for obtaining upper air data.

But Chief Moore suffered his own share of political woes, particularly toward the end of his eighteen years of service. Upon his resignation in 1913, Professor Charles F. Marvin was named to the top WB post, and served as it's Chief until his retirement in 1934. During his tenure, Marvin oversaw a steady improvement in general weather services, but more importantly, he ushered in the unprecedented growth of services to aviation.

According to Whitnah (1961), "During the period 1913-1941, support for American aviation involved more innovation, technological development, and opportunities for expansion of Weather Bureau facilities than any other field of weather service." The expansion in WB services was driven primarily by the need to keep up with the rapidly growing aviation industry, particularly during the 1920s and '30s. The coinciding advances in technology helped increase our knowledge of the atmosphere tremendously.

Based upon a study commissioned by President Taft in 1912, the National Advisory Committee on Aeronautics (NACA) was formed in 1915 to recommend government action in support of aviation. Chief Marvin was the first Weather Bureau representative on this committee of twelve. Subsequent Bureau chiefs also served on this panel.

Weather Bureau support to aviation began in earnest during the second decade of the 20th century. In 1914, an aerological section was established at the Central Office in Washington (Hughes, 1970). As a result, pilots could obtain weather forecasts, special bulletins, and warnings from the WB, but these were based primarily on surface data. Very little was known of conditions aloft except for the small amount of data obtained from WB experiments with instrumented kites and manned, free-floating balloons.

Adequate support for aviation was spotty at best during this time period, and often depended on the personal interest and initiative of individual forecasters. In 1916, Los Angeles forecaster Dr. Ford A. Carpenter provided special forecasts for Army fliers on cross-country flights to and from San Diego where the Army had established a major flight training school. Not content with being a mere supplier of weather data, Dr. Carpenter also occasionally accompanied the pilots on actual flights, apparently the first Weather Bureau representative to do so.

It wasn't until 1919, however, that the Bureau began issuing daily flying forecasts, mainly for the benefit of military and air mail fliers. These primarily consisted of the current and forecast weather, with the descriptions of cloud cover, visibility, and winds given in very general terms (e.g., "Good flying weather today; generally clear sky and good visibility; moderately varying winds surface and aloft"). Unlike the more detailed European flight forecasts, the American forecasts did not include expected heights of any clouds. Also, because the WB offices did not yet operate around the clock, no updated weather information was available overnight.

During the 1920s, the Weather Bureau devoted more and more resources in support of aviation. Flight forecast centers were established in 1920 at Washington, Chicago, and San Francisco (Hughes, 1970). In 1921, the Bureau began using the relatively new medium of radio to broadcast flying forecasts three times daily.

Air mail service, initially provided by the military in 1918, moved into the commercial realm in 1925 when Congress allowed the Post Office to grant contracts to civilian pilots. It is generally accepted that this landmark decision led to the eventual birth of the airline industry. Many early pilots, including Charles Lindbergh, got their start in aviation carrying U.S. mail.

The needs of the expanding aviation community quickly outpaced the services provided by the Weather Bureau. By the mid 1920s, pressure on Congress was mounting for increased federal support to aviation. Also, various mishaps, most notably the loss in 1925 of the U.S. Navy's dirigible "Shenandoah" in a thunderstorm, revealed the growing inadequacies in the Bureau's service to aviation.

Thus, in 1926, Congress passed the Air Commerce Act to regulate the use of aircraft and to establish a national air route system complete with its supporting services. This act assigned a new mission to the Weather Bureau, modifying the 1890 organic act that had established the civilian weather service. In the Air Commerce Act, Congress authorized the Bureau to provide weather information in support of air commerce in the United States and to conduct the research necessary to improve that service.

Despite passage of the Air Commerce Act, the now Congressionally-sanctioned expansion of aviation services was slow to unfold. By late 1928, there were only 18 new Weather Bureau airport stations, of which only five operated 24 hours a day. By 1930, however, 50 airway stations provided around-the-clock service, and aviation forecast centers had been established at Newark NJ, Cleveland OH, Chicago IL, Kansas City MO, Denver CO and Oakland CA (Fig. 6). The airway stations became known as Weather Bureau Airport Stations, or WBAS, to distinguish them from the regular city offices.

In 1931, the Bureau began providing trip forecasts for flights on all civil airways one hour before departure. This reflected the WB's desire to respond to the needs of the pilot community. However, the program fell victim to reductions during the Great Depression.

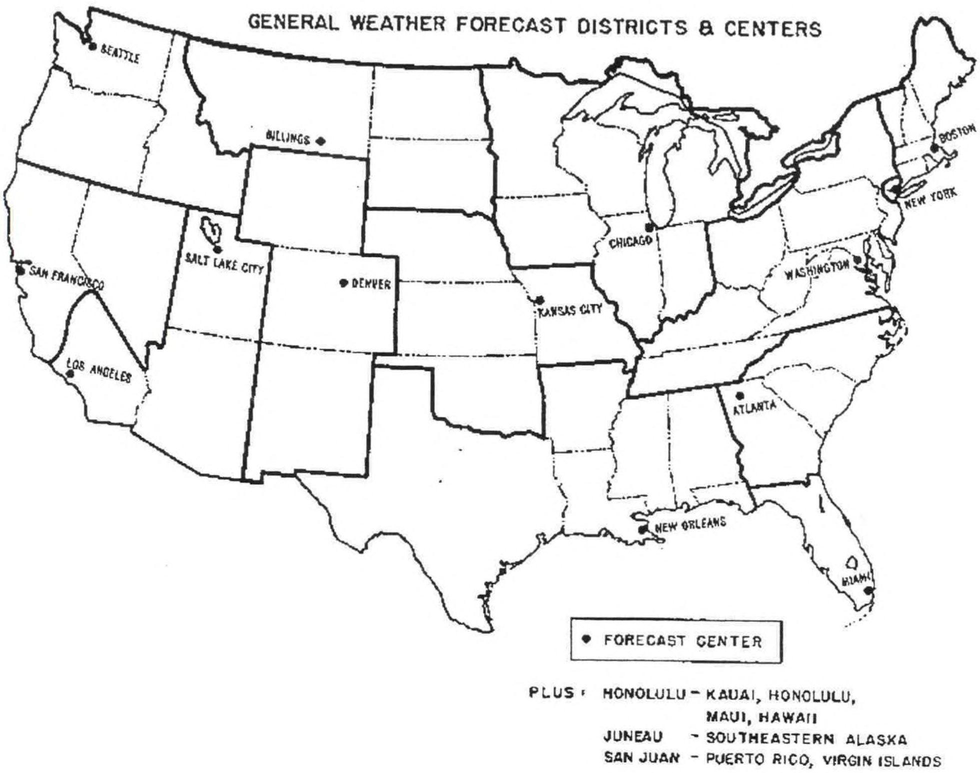

Figure 6. Weather Bureau Forecast Districts and Centers (circa 1930).

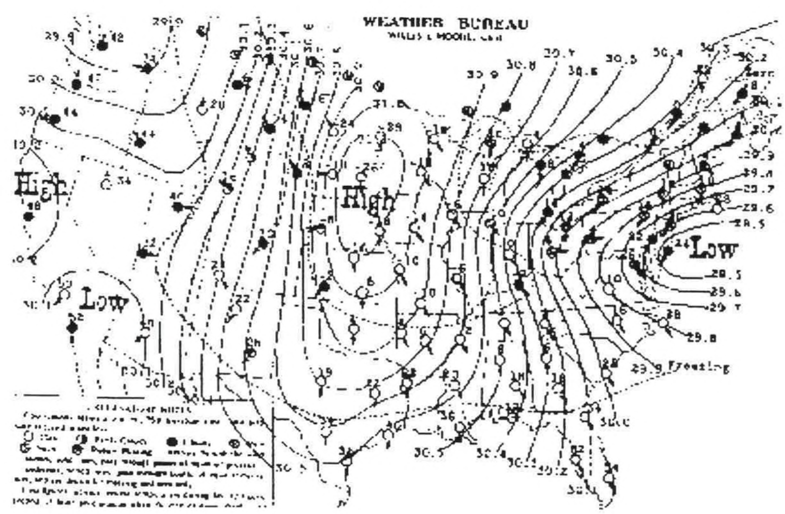

Figure 7. Surface weather map for January 25, 1905. Solid lines are isobars; dashed are isotherms. Note the absence of "fronts" in this pre-air mass analysis era map.

Upper air maps became available in July 1933, providing wind velocity and direction data for various levels up to 13,000 feet (Whitnah, 1961). Two years later, the WB began issuing aviation weather maps every six hours, coinciding with the availability of synoptic data from surrounding countries. Each new forecast covered the next 8-hour period, with intermediate reports issued when conditions warranted.

Despite the fact that the technique had been around for over a decade, the Weather Bureau was slow to adopt the concept of air-mass analysis developed by Jakob Bjerknes in 1919. Under the leadership of the instrument-oriented Marvin, the Bureau's approach tended to emphasize "intuitive extrapolation of the movement of pressure centers and squall lines" (Bates & Fuller, 1986). Bureau forecasters tended to rely on their study of previous weather systems and local experience as an observer or forecaster (Cartwright & Sprinkle, 1996). This method, known as "analog forecasting", was practiced throughout the '20s and '30s (Fig. 7).

This mind-set gradually changed, however, during the late 1930s. Willis R. Gregg, a WB career man, succeeded C.F. Marvin as Bureau Chief upon the latter's retirement in 1934. Gregg had served as chief of the WB's aerological division since 1917, after having started his career as an observer in 1902 (Whitnah, 1961). He was also responsible for organizing the Bureau's early aviation services (Hughes, 1970). With this operationally-oriented background, Gregg proved to be a bit more receptive to the new forecasting concepts.

Gregg's untimely death in September 1938 led to the appointment of Frances W. Reichelderfer, a commander in the U.S. Navy. Reichelderfer previously had supervised the reorganization of the Navy's weather service from 1922 to 1928 and its adoption of the Norwegian's methods of air-mass analysis. In 1931, he spent half a year in Norway studying the new techniques, but his subsequent report was marked "restricted" by the Navy because it was not yet in final form. This classification led to a flurry of rumors about the content of the report. In the end, according to Bates and Fuller (1986), "a copy was bootlegged outside the Navy, and soon hundreds [of Bureau meteorologists] were avidly reading his report."

Meanwhile, in 1935, a new air-mass analysis section was created at the Central Office in Washington, D.C. from money originally intended for salary increases (Whitnah, 1961). But it literally took an act of Congress to get the Weather Bureau to officially adopt the Norwegian forecasting techniques. The Civil Aeronautics Act of 1938[3], mandated the training of WB employees in air-mass analysis techniques at government expense, "...within the limits of available appropriations made by Congress..." (Whitnah, 1961). Thus, the Bureau had to be nudged by legislation into the realm of three-dimensional weather analysis and forecasting. Unfortunately, the money for the training had to come out of existing funds.

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3 One of the primary results of this legislation was the formation of the Civil Aeronautics Administration (CAA), the direct predecessor of today's Federal Aviation Administration (FAA).

By the late 1930s, the resources allocated for the support of aviation weather services far outstripped those for other specialties, much to the growing displeasure of those Congressional representatives from agricultural areas. In 1940, after months of acrimonious Congressional hearings on the matter, the Weather Bureau was transferred from the Department of Agriculture to the Commerce Department in a fairly logical consolidation of aviation-related services. This also provided official recognition of the importance of weather information for the nation's air commerce.

1.2 Budget Battles

The budget history of the federal weather services reflects the very nature of weather itself — alternating between fair and stormy. The process of budgeting expenses in general is a delicate balance of "wants" versus "needs". At the federal level, however, it is occasionally clouded by political foul weather.

Since the inauguration of a national weather service in 1870, appropriations have generally risen steadily over the long term. But much like the patterns on a weather map, the periodic highs and lows have reflected both the prevailing economic times and the whims of politics (Fig. 8).

The initial allocation for fiscal year 1871 was just $15,000. This seems an incredibly small sum by today's standards, but it mirrors both the state of technology and our understanding of atmospheric processes at that time. In 1870, the "national network" consisted of only 24 regular observing stations. That number was more than doubled within the first year of operation to nearly 60.

By 1873, funding for the Weather Service had risen to $250,000, a phenomenal increase in just two years. Alas, this trend was short-lived beginning in 1875 when requests for additional funding were turned down. General reductions were forced onto the Signal Corps in 1876 when $115,000 was cut from the budget for the next fiscal year. This resulted in the closure of a number of weather stations and a reduction in the number of daily observations from others around the country. Numerous commercial and agricultural interests complained about the reductions in services to no avail.

This was but the first of several retrenchment drives which have frustrated the growth of the national weather services over the years. All resulted in much public criticism of the curtailed services (Whitnah, 1961).

Political considerations rather than economic ones accounted for reduced appropriations during the mid 1880s. A scandal erupted in the summer of 1881 with the arrest of Signal Corps disbursing officer Captain Henry W. Howgate for embezzelment of government funds. This led to considerable Congressional displeasure and hostility toward the Signal Corps. Initially, Congress proposed reducing the appropriations for the Weather Service by the

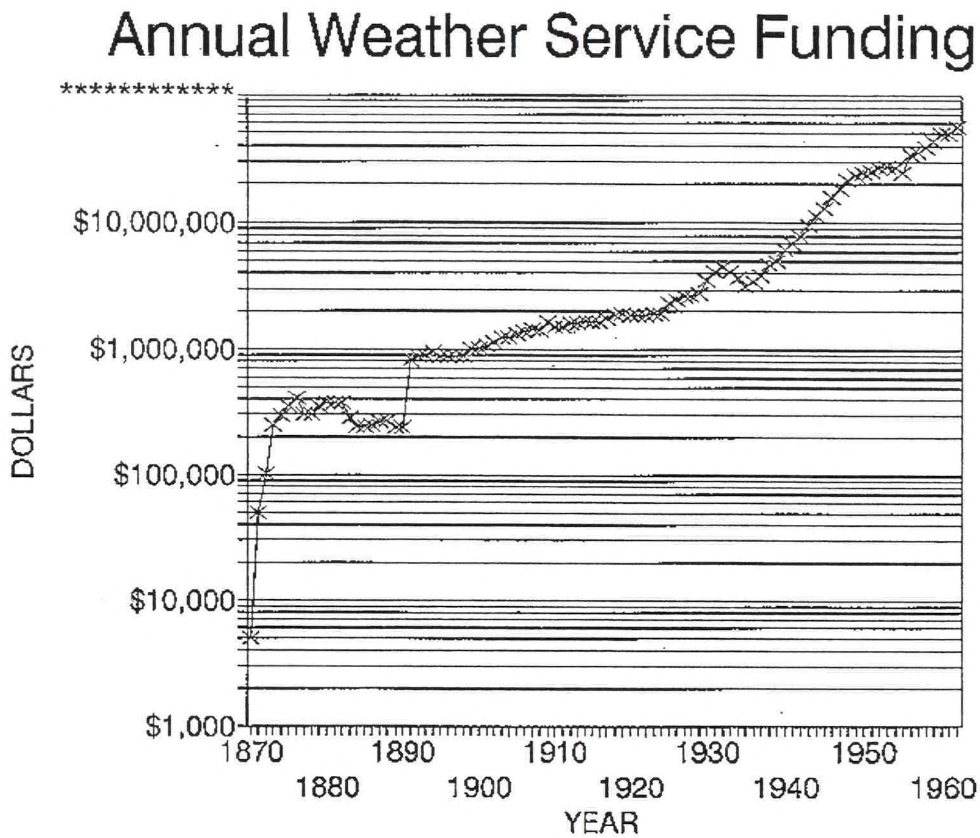

Figure 8. Annual funding for Signal Service/Weather Bureau 1871-1960.

amount of missing funds. Instead, beginning in 1883, funding for all functions of the Weather Service (except salaries) was reduced from approximately $375,000 in 1882 to around $311,570 in 1885. This forced the closing of 18 stations, including those at San Antonio TX, Tucson AZ, Springfield MO, Burlington VT and Santa Fe NM.

Nevertheless, the 1883 allocation of just under one million dollars reflected a substantial increase over the initial budget of $15,000. This increase illustrates just how important the task of collecting and disseminating weather information had become to both civilian and military interests.

The first Weather Bureau budget following the transfer to the USDA amounted to $899,753.50 for FY92. Under military control, the annual Weather Service budgets had run a deficit between 1884 and 1891. These deficits were reversed under civilian control and became annual surpluses for the years 1892-93. A period of economic depression during the mid 1890s led to the next round of funding cuts. After rising to more than $950,000 in 1894, appropriations for the WB dropped to $876,832 in 1895 and to $860,610 in 1896.

By the turn of the century, however, Bureau appropriations were routinely in excess of a million dollars. Regular weather offices numbered about 173 with nearly 550 full-time employees (FTEs). During the first decade of the 20th century, the WB expanded to almost 200 offices and about 800 FTEs.

Political turmoil once again played a role in the allocation process toward the end of Willis Moore's tenure as Bureau Chief. In the wake of repeated rejections for increased funding, Moore himself sought the appointment of Secretary of Agriculture under the assumption that by becoming the head of the Department, he could ensure adequate funding for the Weather Bureau. Unfortunately, Moore was accused of using Bureau personnel and resources to establish his political base of support. Following a period of acrimonious exchanges with Congressional and administrative adversaries, Moore was removed from office by President Woodrow Wilson on April 16, 1913.

His successor, C.F. Marvin, ushered in a period of relative tranquility and unprecedented growth. The latter was due, in part, to the general expansion of aviation but, especially, to the need for increased support to the military in the years leading up to U.S. involvement in World War I.

With the expansion of aviation came the need for more precise and more frequent weather data, both at the surface and aloft. Yet, it wasn't until the U.S. entry into WWI that Congress granted a substantial increase in funds to meet these needs. The Army Appropriations Act of 1918 provided $100,000 annually to the WB for the collection of upper air data throughout the country. This resulted in the establishment of five instrumented-kite stations and several pilot-balloon (pibal) stations over the next two years.

By 1919, the Weather Bureau budget was just short of two million dollars, but this was primarily due to the continuing support from the military rather than increased Congressional generosity. Requests for additional funds to expand the upper air network were repeatedly rejected as were requests for additional airport stations and a proposed expansion of forecast services for aviation.

Nevertheless, the Weather Bureau managed to establish flight forecast centers at the regular city stations in Washington, D.C., Chicago, and San Francisco. Twice-daily pibal observations were added at San Francisco CA, Burlington VT, and Denver CO in 1920-21 (Whitnah, 1961). And in addition to supporting military and air mail operations, the WB also provided special data and forecasts for the increasing number of transcontinental and trans-Atlantic flights, both military and civilian. Much of this support came out of existing "miscellaneous" funds and because of the dedication of some WB employees who occasionally worked overtime without compensation.

In the early 1920s, NACA recommended an additional appropriation of $200,000 for new aeronautical observing stations, but this did not materialize until 1924 when the Weather Bureau was given funds for eight new stations.

During this period of slow, almost grudging growth, the expansion of the aviation industry began to outpace federal spending in support of aviation services. Criticism of the inadequate support for fliers became more public and more insistent during the early 1920s. Former Chief Moore voiced the sentiment that "it was criminal for the federal government to fail to keep pace with the demands for aid to aviation" (Whitnah, 1961).

Meanwhile, the nation's fledgling air force continued to develop under the umbrella of the Army Air Corps. While the Weather Bureau struggled with repeated rejections for additional funding to expand its aviation services, the Army began to shift more and more resources in support of its own pilots. The Signal Corps Meteorological and Aerological Service had been established shortly after the U.S. entry into WWI, with considerable assistance and equipment from the WB (Bates & Fuller, 1986). A panel convened after the war concluded that both major branches of the military (Army and Navy) had a peacetime role to play with regard to weather, but close coordination and cooperation with the WB was necessary in order to maximize resources and minimize duplication of effort (Bates & Fuller, 1986). This cooperation continues today, especially between the AWC and the Air Force Weather Agency.

As mentioned earlier, the continuing criticism of inadequate federal support for civilian aviation culminated in the passage of the Air Commerce Act in 1926. A subsequent "deficiency bill" granted $75,000 to expand the number of Weather Bureau facilities and ensure that experienced forecasters were present at all major airports. Chief Marvin successfully obtained an additional $45,000 and 18 new employees for FY28 in order to carry out the provisions of the Air Commerce Act.

The wording of the Act, however, included the caveat "...within the limits of appropriations which may be made for such purposes...". This unfortunate choice of words pretty much guaranteed that the funding battles would continue.

During this time period, aviation meteorology received a boost from the Guggenheim Fund for Meteorology which financed research into weather hazards along the west coast, such as fog and haze, and helped develop a "model airway" system between Los Angeles and San Francisco. The Fund also arranged for Norwegian Professor Carl-Gustav Rossby to come to the U.S. to lecture on ways to improve forecast services for aviation.

About the same time, the Weather Bureau was receiving assistance from the Radio Corporation of America (RCA) in the form of twice-daily ship observations from the Atlantic that were relayed free of charge. These special reports were essential to the weather support provided for the many trans-Atlantic flight attempts during the late 1920s.

The economic depression of the 1930s had a substantial impact on Weather Bureau services. From an all-time high of nearly $4.5 million in 1932, a quarter of which was devoted to aviation, the WB budget dropped to a little over $2.5 million for FY33, with nearly a third of the 1,600 employees dismissed. This massive reduction resulted in the closure of 16 first-order airway stations.

Ironically, aviation continued to expand despite the Great Depression. Many fledgling airlines were established during the 1930s and commercial air mileage rose 28%. Meanwhile, WB services to aviation were being reduced. The airway service appropriation for FY37 was 13% less than for FY32, yet miles flown were 50% higher (Whitnah, 1961).

By the late 1930s, with the U.S. finally recovering from the Depression and with war looming in Europe, the fortunes of the Weather Bureau turned around yet again. From 1938 to 1941, services to aviation expanded rapidly. Three additional airway forecast centers were opened, each with three new assistant forecasters. The number of first-order airway stations increased to nearly 100. An aerological division was established in Washington headed by Delbert M. Little, a veteran of the airway service and a participant in the Guggenheim Fund's model airway on the west coast.

Despite the tremendous expansion in Bureau services, the aviation community continued to complain about inadequate support. The WB was not wholly to blame for these inadequacies, however. Bureau scientists and forecasters were well aware of the system's shortcomings, and the annual requests for budget increases during the mid '30s reflected this concern. Yet the fact remained, the needs of the industry continued to outstrip the Bureau resources allocated for aviation services.

Two other pivotal events came into play during this period. In the mid '30s, the airlines began to hire their own meteorologists. The reason was not entirely due to a perceived lack of service on the Weather Bureau's part. In actual fact, the airline meteorologists supplemented the service provided by the WB, taking the Bureau's "generalized" forecast and refining it for their specific use (Popkin, 1967).

Meanwhile, Congressional displeasure toward the Weather Bureau was on the increase in the late 1930s. There was a growing perception that the Bureau was biased in favor of the aviation industry at the expense of service to agriculture and other commercial interests.

Expenditures for aviation services now far exceeded those for general weather services. The acrimony stemmed from the fact that the WB remained in the Department of Agriculture while all aviation-related services were administered by the Department of Commerce. The appearance of a rivalry between agriculture and the young, "upstart" aviation industry prompted one Congressional Representative from Missouri to remark, "You know, agriculture out of the goodness of its heart has taken in also this stepchild of aerology."

The decision to transfer the Weather Bureau to the Commerce Department in 1940 reflected official recognition of the fact that Bureau service to aviation had surpassed that of aid to agriculture or any other economic activity, insofar as the budget was concerned.

Bureau service to other sectors did not suffer, however, as a result of the increasing expenditures on behalf of aviation. The expansion of the surface and upper air networks, the incorporation of Norwegian forecasting methods, and the increase in the number of trained personnel benefitted all aspects of Bureau services, not just those for aviation. But it was the pressure from the expanding aviation industry for better weather information and services that provided the impetus for the improvements throughout the WB. Clearly, aviation was the **driving force** that led to modernized weather services.

1.3 The Influence of Technology

As was mentioned earlier, technology has played a major role throughout the development of the nation's weather services, from how the atmosphere is sampled to how the forecast reaches the public. Early on, the relatively crude state of technology severely limited our means of measuring the atmosphere. By the same token, our limited understanding of atmospheric processes affected how and what we looked for in assessing the state of the atmosphere, both present and future.

Early instrumentation for observing the weather was fairly rudimentary. In 1871, a year after its inauguration, equipment at a typical Weather Service office consisted of: a barometer, thermometer, hair hygrometer, Robinson 4-cup anemometer, wind vane, non-recording rain gauge and a clock, along with the various forms for recording the data and a toolbox. The observations were then sent to Washington via telegraph three times a day, at 7:35 am, 4:35 pm, and 11:35 pm EST. After 1888, this was reduced to twice daily at 8 am and 8 pm EST.

During the latter part of the 19th century, the standard surface observation consisted of the following elements:

- barometric pressure and its change from the last report
- temperature and its change in 24 hours
- relative humidity (not dewpoint temperature)
- wind direction and speed
- wind pressure in pounds per square foot
- amount of clouds
- the state of the weather.

The critical elements of ceiling height and visibility did not appear in the standard observation until 1929, and even then they were given only in plain language. Dewpoint temperatures, essential for indicating potential fog or ice formation, finally began appearing in the standard surface observation around 1930 (Whitnah, 1961). Incredibly, actual cloud heights and visibility in miles were not routinely available until the mid 1930s.

All observations and forecasts were sent in a coded-word format using a cipher manual that, by 1877, contained over 5,000 words. A typical forecast might read as follows:

"Paul diction sunk Johnson imbue hersal".

Decoded, this becomes:

"St. Paul, barometer 29.96", temperature -4 deg, wind 6 mph, max temperature 10 deg, dewpoint -18 deg" (Whitnah, 1961).

The Central Office in Washington then sent the forecasts back to the weather stations as well as to railroad stations and the Associated Press. Copies of the forecast were printed by the Signal Service and sent to about 2,000 post offices where they were displayed for the public's benefit. Upon receipt of the forecast data, various local means of dissemination were used, including flags, search lights, fire alarms, whistles, etc (Figs. 9 and 10). In 1910, the Weather Bureau began installing kiosks in 29 major cities specifically for the display of daily weather information. It wasn't until the early 1920s that radio began to replace the variety of methods for relaying forecast information.

The fact that the Signal Corps was using its own telegraph circuits to relay the data meant that it arrived in a fairly timely manner. Later, under civilian control, weather data had to compete with other commercial traffic on Western Union telegraph lines. In fact, as late as the 1920s, one of the major criticisms leveled at the Weather Bureau concerned the untimely nature of weather data for aviation. The existing observation times were not early enough to be of use to pilots since, by the time the forecast data arrived, most early morning flights had already departed (Whitnah, 1961).

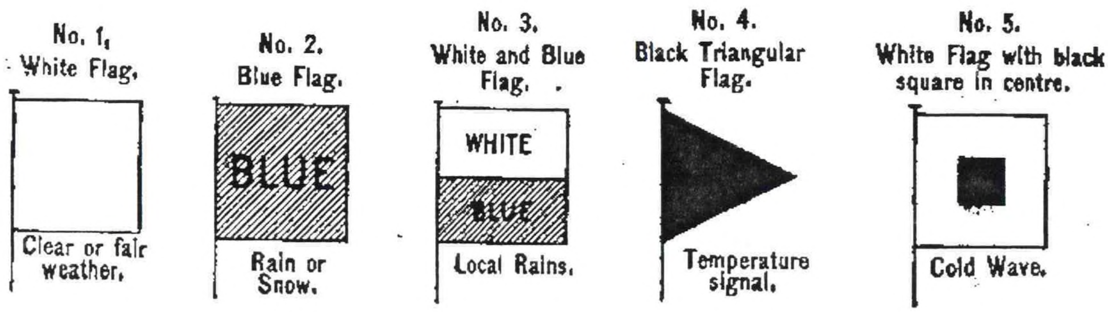

Figure 9. Weather bureau signal flags used during the 1890s.

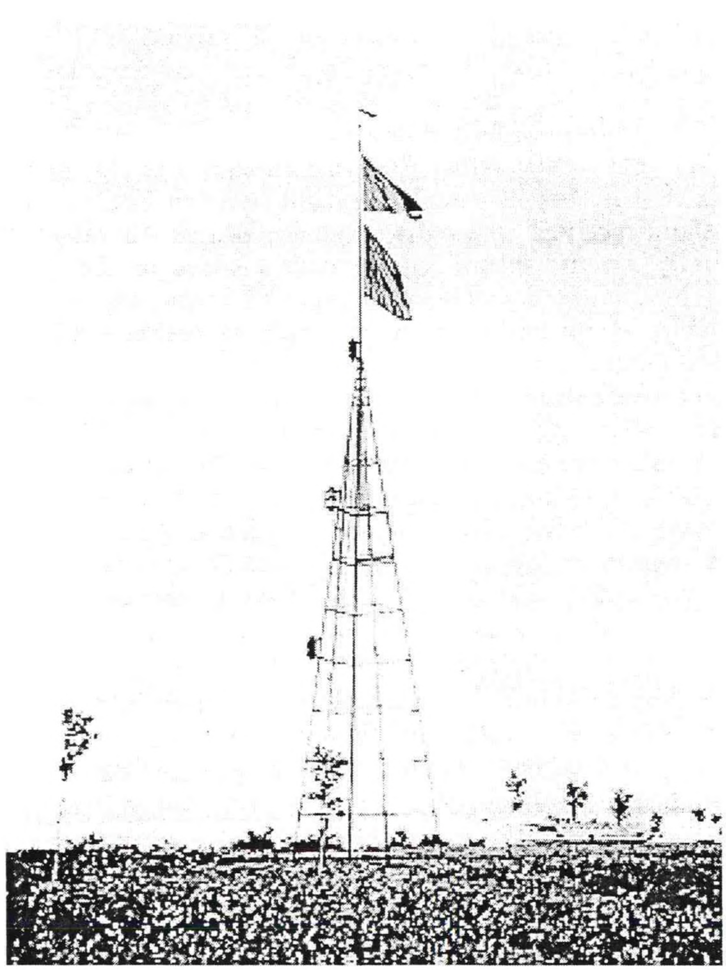

Figure 10. Storm signals fly from a tower on the Potomac River south of Washington, D.C.

The major impediment to providing earlier forecasts was said to be the cost of adjusting the telegraph timetables to allow for earlier transmission of the surface obs. Typically, Western Union began relaying the data at 8 am EST, reserving its commercial lines for 90 minutes just for this purpose (Whitnah, 1961).

This lack of timeliness resulted in a number of accidents and more than a few fatalities. The results of the naval inquiry into the loss of the "Shenandoah" suggested that "better or more rapid airway-weather service might have prevented the tragedy" (Whitnah, 1961). In another instance, a pilot flying the overnight mail crashed into a fog-shrouded hill in Pennsylvania when the information alerting him to the hazard arrived after he'd taken off.

Developments in technology have often been spurred by tragedies such as these. The advent of ground-to-air radio led to a fairly significant reduction in this type of accident, and also led to a valuable new data source for forecasters: pilot reports of weather conditions aloft. During the 1930s, the use of radio was expanded to include routine broadcasts of weather data along major air routes. Wider use of two-way radio toward the end of the decade allowed a pilot en route to talk directly to a forecaster and obtain updates on weather conditions along his route. Even today, "pireps" continue to be a critical source of real-time weather information for AWC forecasters, although now they are relayed to the National Weather Service (NWS) by FAA personnel who now have the most direct contact with pilots.

Technology transfer does not occur spontaneously, however, and Bureau scientists did not sit idly by waiting for the next new development to tap them on the shoulder. One must actively seek out and explore new frontiers in order to progress. Therefore, even before the turn of the century, research and development was essential to advance the science of meteorology.

The need for more accurate measurements led the Weather Bureau to actively promote research along these lines. Toward the end of the 19th century, the mercurial barometer was the most accurate of the primary weather instruments. Wind anemometers required additional testing to correct for inaccuracies, especially at higher wind speeds. Bureau Chief-to-be C. F. Marvin developed an improved wind recorder that helped minimize this problem.

The hair hygrometer had been in use for years, but it tended to react too slowly for accurate humidity data (Whitnah, 1961). Sling-psychrometers were available and provided the best readings of wet-bulb and dewpoint temperatures, but obtaining these readings at below-freezing temperatures was extremely difficult.

Professor Marvin invented or perfected a number of instruments for use by the Weather Bureau (Hughes, 1970). In addition to the wind recorder, he also invented a theodolite for measuring cloud movements and an electrical-resistance thermometer for measuring the intensity of solar radiation. He even designed a lightning rod for the White House (Whitnah, 1961).

The advent of the triple-register recording device in the mid 1890s was a major technological breakthrough in its day. Prior to this, the Weather Bureau had very few self-recording instruments. The triple-register provided a way to convert various data into a continuous record. Operated by six-volt batteries and linked by wires to the sunshine recorder, tipping-bucket rain gauge, and wind instruments, data was recorded on a chart attached to a clock-driven drum. This instrument, in modified form, continued to be used well into the 20th century Fig. 11).

Bureau Chief Willis Moore pushed hard to ensure that all first-order weather stations had recording instruments. By 1910, he had increased the number of fully-equipped stations to nearly 100% from around 60% in 1902.

Professor Marvin, the Bureau's instrument expert, was also closely involved with early experiments using instrumented kites to obtain upper air data during the mid 1890s (Fig. 12). In 1898, a network of 16 stations, all equipped with the Marvin kite meteorograph (Figs. 13 and 14), was established across the Midwest (Fig. 15). Ascents were made from April through November, attaining a maximum height of 8,000 feet (Whitnah, 1961).

Experiments with instrumented balloons were also carried out using both captive and free or "pilot" balloons (hence the term "pibal") (Fig. 16). This research yielded useful results, but until the refinement of radio and other tracking technology, both balloons and kites proved to be ineffective during bad weather due to icing problems or obscuration by clouds or fog. Nevertheless, by 1930, 45 airport stations were providing pibal data (wind speed and direction only), the majority on a schedule of four times a day. Within two years, the number of stations had doubled to around 90.

The continuing search for reliable upper air data led the Weather Bureau to experiment with using instrumented aircraft beginning in 1925. It wasn't until six years later, however, that airplane observations, or "apobs", were inaugurated at Cleveland, Chicago, Dallas and Omaha. Local pilots were employed to make the flights using the Marvin meteorograph affixed to the aircraft each time by a WB employee (Figs. 17 and 18). By May 1934, 22 "apob" stations were in operation (both WB and military), and were the primary source of upper air data (the kite network having been completely shut down in July 1933). This number was increased to about 30 in 1937 (Hughes, 1970).

Apobs were a fairly hazardous undertaking, however, and at least a dozen pilots were killed during the years 1931-38 (Whitnah, 1961). In the beginning, the WB contract stipulated that the pilot could not collect the $25 fee unless he reached an altitude of at least 13,500 feet; above that he received a 10% bonus for each additional 1,000 feet. By 1938, the minimum altitude for receiving payment had risen to 16,500 feet, and it was not uncommon for a pilot to lose consciousness due to lack of oxygen. It is now known that the effects of hypoxia set in above about 14,000 feet, but even in the 1930s, very few aircraft were equipped with supplemental oxygen.

Figure 11. Observer logging a surface observation at a Weather Bureau Airport Station (WBAS) (circa 1935). Note modified version of the triple-register at far end of observer's console.

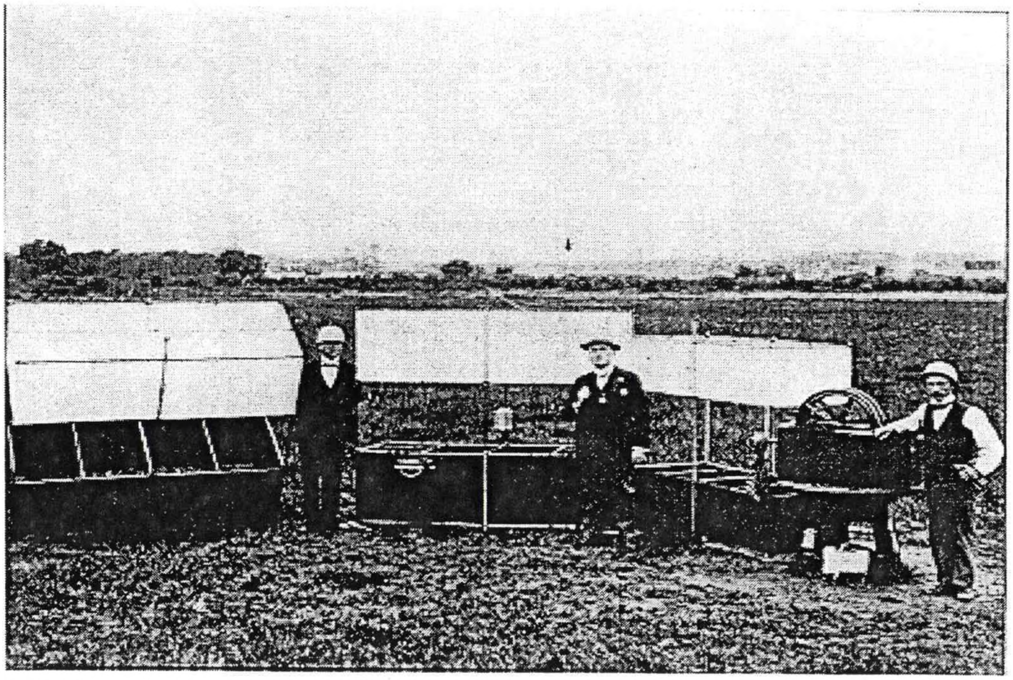

Figure 12. Early kite observers at Dodge city, KS (circa 1900).

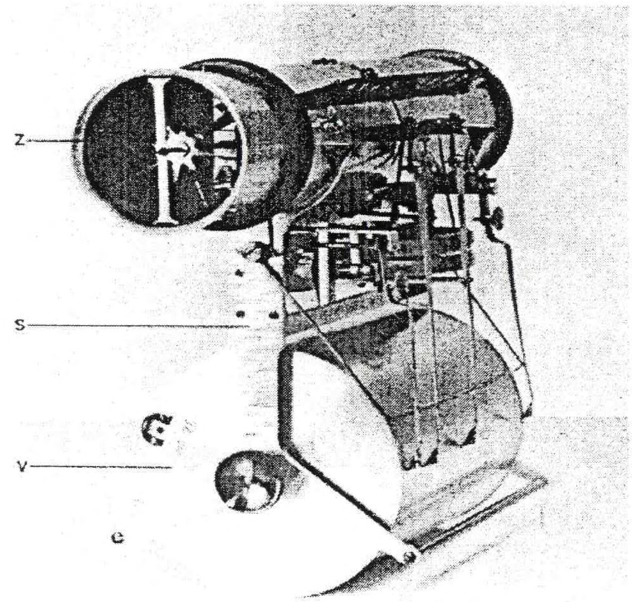

Figure 13. End view of Marvin kite meteorograph. Recording drum (V) is located at bottom of instrument and temperature, humidity, and pressure sensors are located on smaller cylinder (Z). Anemometer located inside of top cylinder.

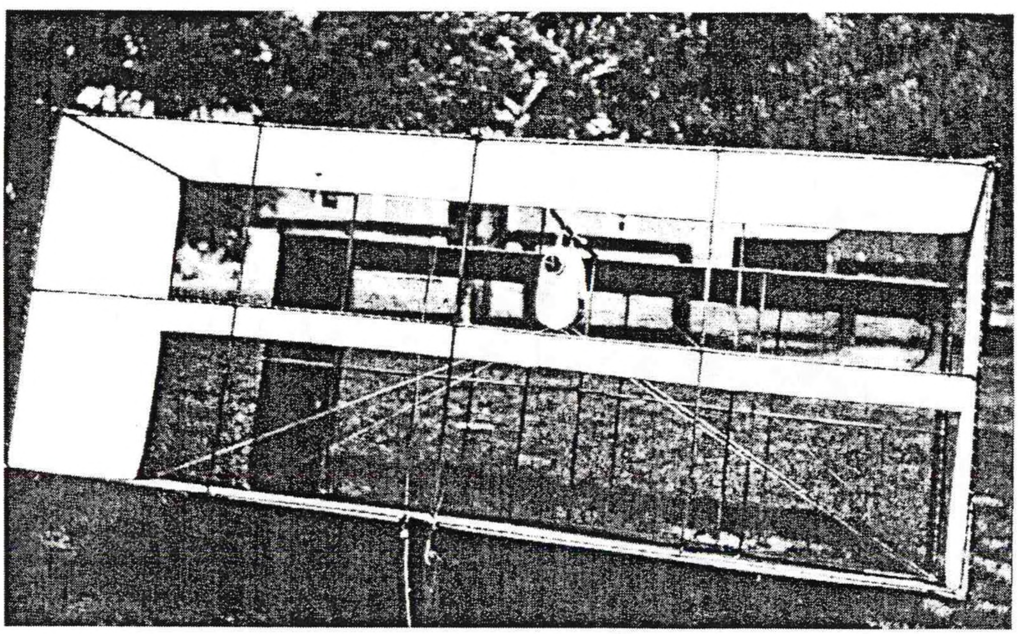

Figure 14. End view of kite showing location of Marvin meteorograph.

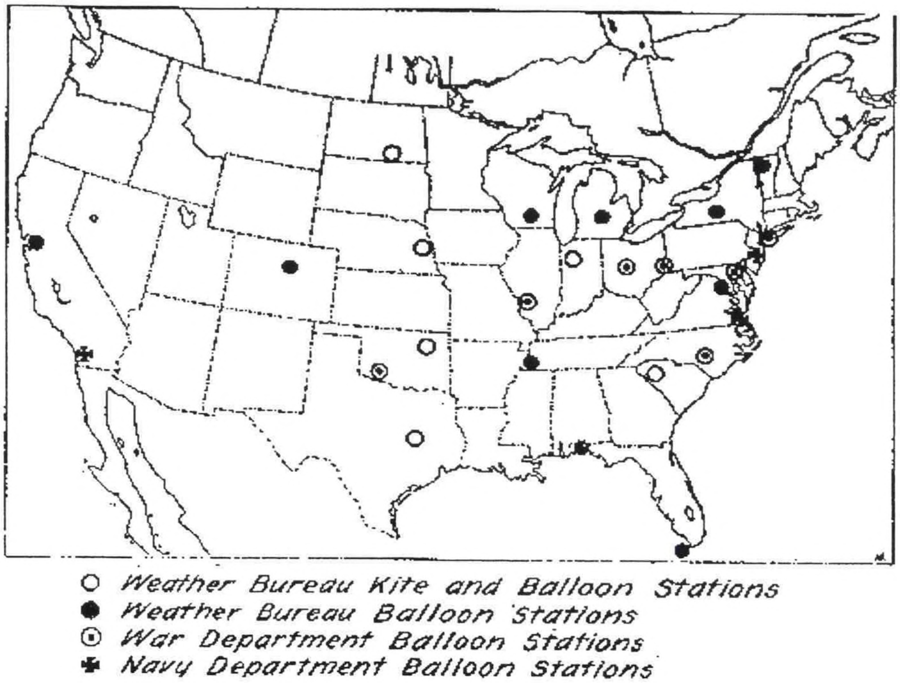

Figure 15. Kite and balloon stations in the United States (circa 1925).

Figure 16. Preparing for a Pilot Balloon ("pibal") observation at Rocksprings, WY (1932).

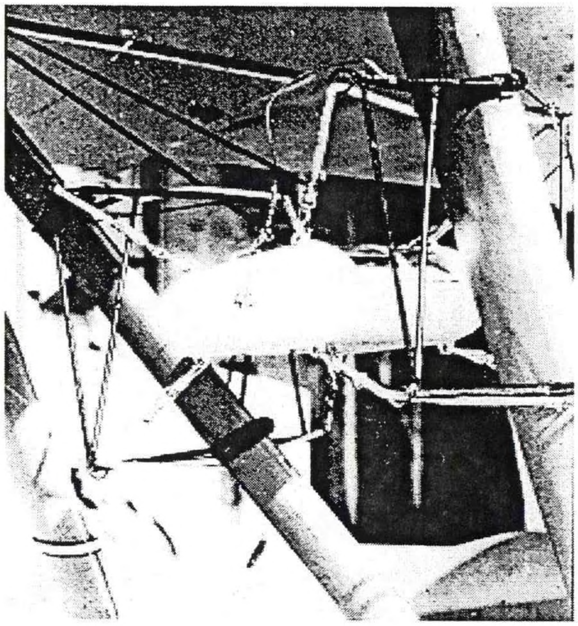

Figure 17. Aero-meteorograph used to obtain Weather Bureau airplane observations.

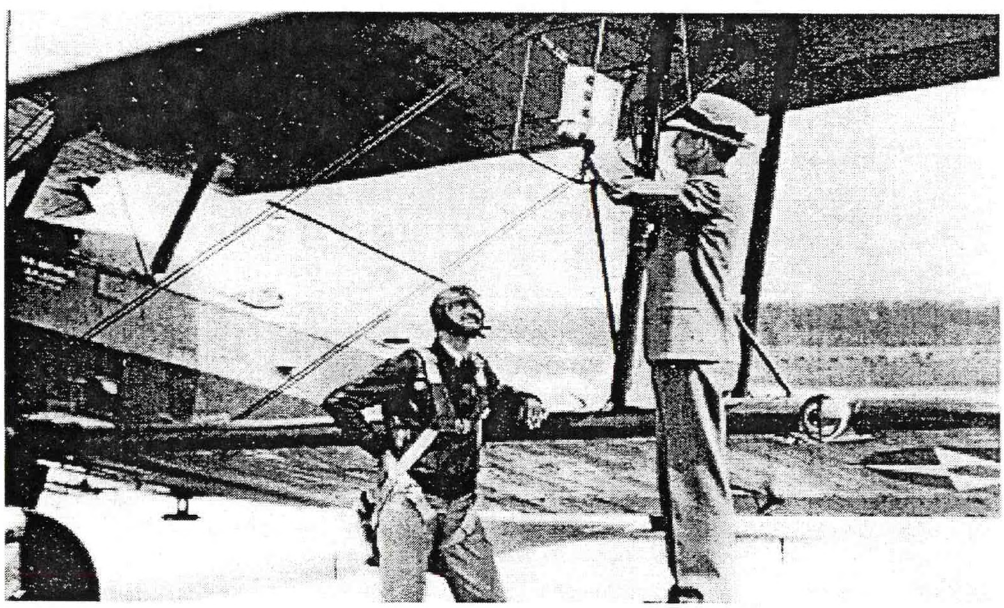

Figure 18. Meteorograph being placed on an airplane for an upper-air sounding (or "apob"). The pilot was subsequently killed while flying a sounding flight.

The Army terminated its apobs program in July 1938, but the Weather Bureau and Navy continued their programs for another 12 months. By the outbreak of WWII, the apob had been discontinued in favor of other, superior data sources.

The radio meteorograph, developed and tested during the mid 1930s, was possibly the single most important breakthrough in weather analysis and forecasting up to that time. Similar to the meteorograph used earlier on kites and airplanes, this version sent back electrical pulses to a receiver on the ground which gave the observer a continuous record of temperature, pressure, humidity, wind speed and direction. Carried aloft by a balloon much like a pilot balloon, the instrument package was equipped with a parachute that allowed it to float back to earth after the balloon had burst. The recovery and refit of the instrument package helped reduce the overall cost of the program.

The radio meteorograph, despite some glitches, proved superior to anything that had been used before and, by 1940, was the primary source of upper air data. Even in early experiments, the balloons reached an average height of 50,000 feet, far higher than most airplane obs. In late 1938, the term "radio meteorograph" was dropped in favor of "radiosonde", which was soon shortened to "raob" by Bureau meteorologists. By 1941, thirty-four radiosonde stations were taking daily upper air observations at noon. Shortly thereafter, this was increased to twice-daily obs at 12:30 pm and 11:00 pm EST (Whitnah, 1961).

Probably the second most important technological advance was the development of the teletype. During the late '20s, more and more weather data was becoming available as the Bureau added new stations. It was evident early on that the telegraph was too cumbersome for the increasing volume of data. And although the Bureau did rely on the telephone to a certain extent, it too was not well-suited for routine transmission of data. Radio was used fairly heavily by the WB, but mainly for broadcast of forecast information; even so, the broadcasts often suffered from interference of one form or another.

The inauguration of teletype circuits in the Northeast in 1928 relieved the Bureau's dependence on telephone and telegraph for relay of basic weather data. The system of circuits paralleled the major air routes and carried all kinds of aviation information, not just Surface Airway Observations (SAOs) (e.g., Notices to Airmen, or NOTAMS, that contained information about field conditions, equipment outages, etc.) (Cartwright & Sprinkle, 1996) (Fig. 19). This was a cooperative effort between the WB and the CAA to ensure that essential weather information was available to all facilities in both agencies, a relationship that continues today between the NWS and the FAA.

Within two years, the teletype circuits covered 8,000 miles of airways; by 1937, this had been extended to 13,000 miles or about 40% of the total airway mileage. Also in 1937, the speed of transmission was increased from 40 to 60 words-per-minute (wpm), and to 100 wpm in the years following WWII. In 1939, the switch was made from the old coded-word format to a new, more efficient number code which could relay the same weather information with

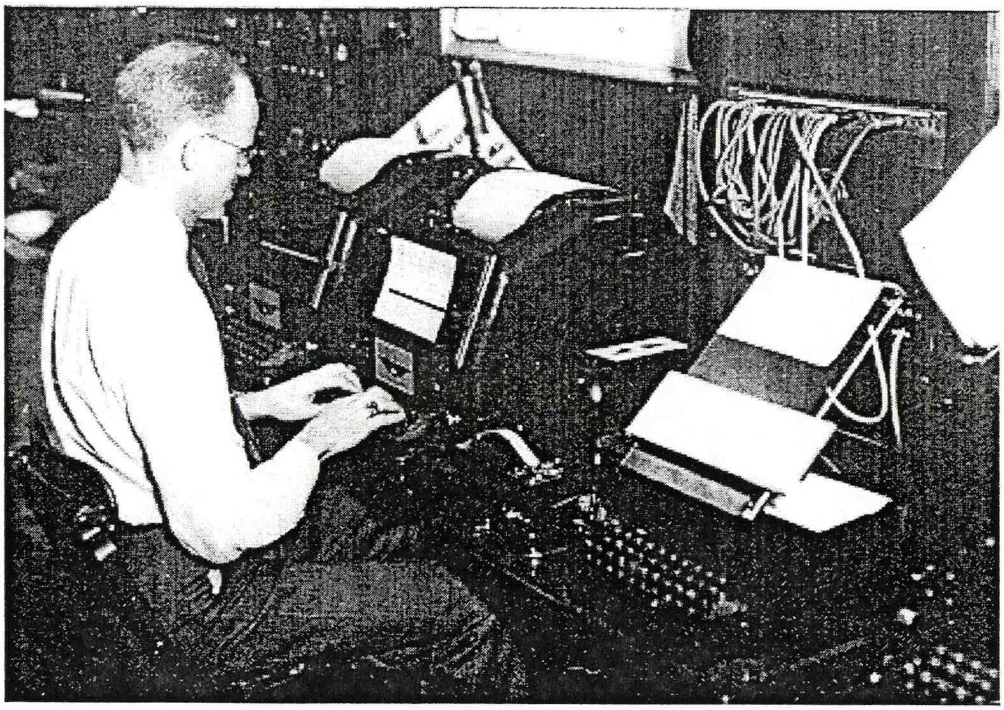

Figure 19. Sending weather information over the teletype at the Nashville, TN office (1938).

a third less characters.

Other technological developments, such as the ceilometer for measuring cloud heights and the transmissometer for measuring runway visual range, helped improve the quality of weather observations. And the post-WWII developments of weather radar, computers, and weather satellites have led to a tremendous improvement in the quality and accuracy of weather forecasts in general. But it was the pre-WWII developments of around-the-clock operations (a result of the passage of the Air Commerce Act of 1926), high-speed teletype communications, two-way ground-to-air radio communications and most of all, the advent of the radiosonde that set the stage for the advances in aviation weather services in the decades to come.

2. Growth of Aviation Weather Forecasting: A Kansas City Perspective (1939-1982)

Roy P. Darrah

The first weather office in the Kansas City area was established on July 1, 1888. Although relocated a number of times, it remained in the downtown area for the next 9 decades (Parvin & Galway, 1989).

Kansas City's role in aviation weather was solidified in the late 1920s when it became one of 14 district offices nationwide (Figs. 20a and 20b). The duties of a typical WB District Office included issuing aviation forecasts every 6-12 hours as well as providing weather information to pilots. At this time, the Bureau was the sole provider of aviation weather data. The FAA had not yet come into existence and it's predecessor, the CAA, provided no pilot weather briefings.

Especially during the past 60 years, the Weather Bureau Airport Station in Kansas City played an important part in providing forecast services to aviation. The WBAS always maintained good relations with the FAA and the U.S. Air Force's Air Weather Service, to the benefit of all involved.

Starting in 1939, the Weather Bureau began to expand the Aviation Forecast Services. A large number of high school science teachers were hired into civil service jobs after completing some short college courses in meteorology. New forecasters also came from the Army cadet program and various other college programs.

The aviation forecasts for Iowa, Nebraska, Kansas, and Missouri were issued by the meteorologists at Kansas City's Municipal Airport. An area forecast (FA) for clouds, weather, and wind was the first product. By the late 1940s, about 30 terminal forecasts were being issued. Flash Advisories (FL) for icing, turbulence, and convective activity were also added.

In 1944, the Weather Bureau established Flight Advisory Weather Service (FAWS) Units[4] at the 26 Air Route Traffic Control Centers (ARTCCs) around the nation. The Kansas City facility was located on the top floor of City Hall (Fig. 21). The FAWS Unit, separate from the aviation forecast unit at Municipal Airport, was co-located with a military flight advisory unit. Aircraft arrivals and departures were handled by controllers in an office next door (Fig. 22). A conveyor belt delivered messages back and forth between the two rooms.

The FAWS Unit plotted and analyzed their own charts, briefed the controllers and military flight

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4 The FAWS Units were the precursor to today's Center Weather Service Units (CWSUs).

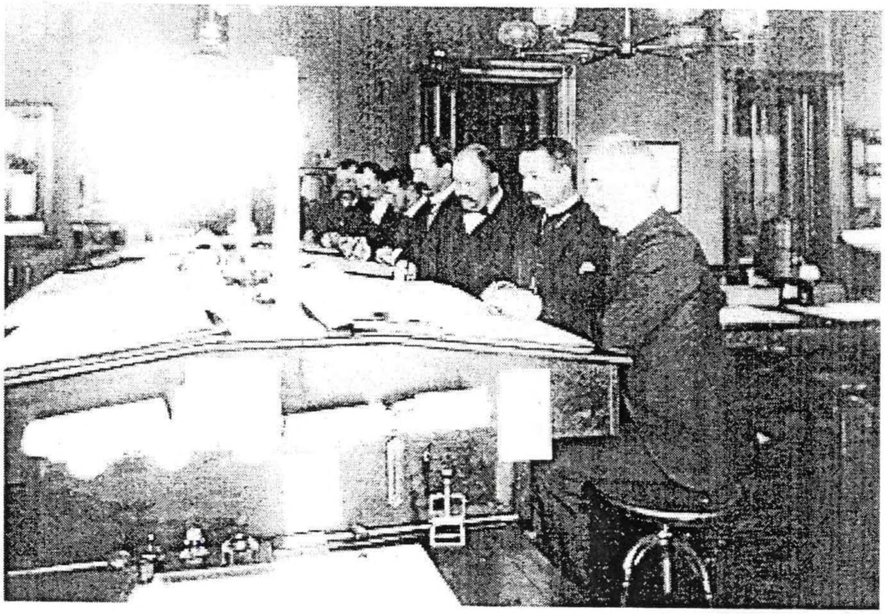

Figure 20a. District Forecast Office (location unknown), not unlike the Kansas City office, about 1920.

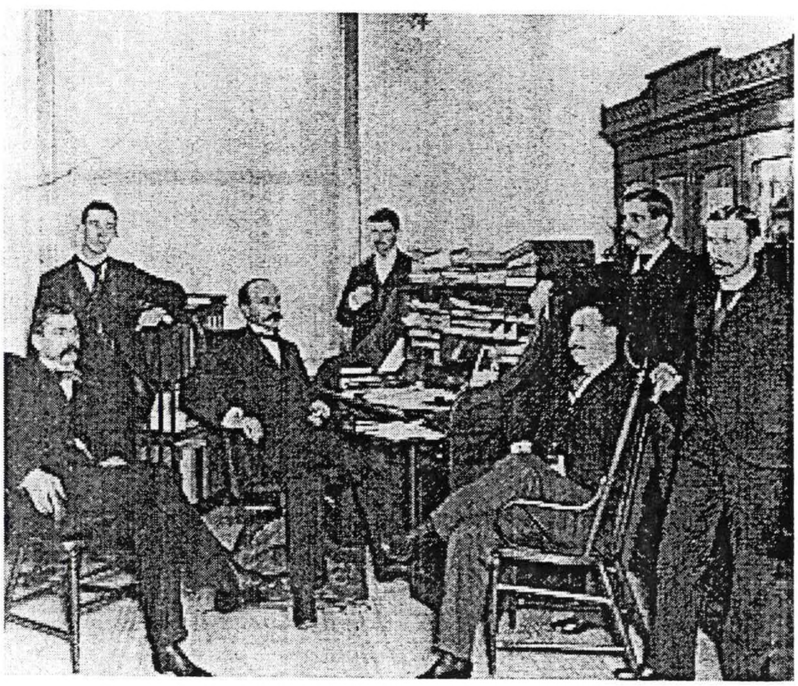

Figure 20b. District Forecast Office during the 1920s (location unknown). Roll-top desks were used by Meteorologists-In-Charge in most Weather Bureau offices into the 1940s.

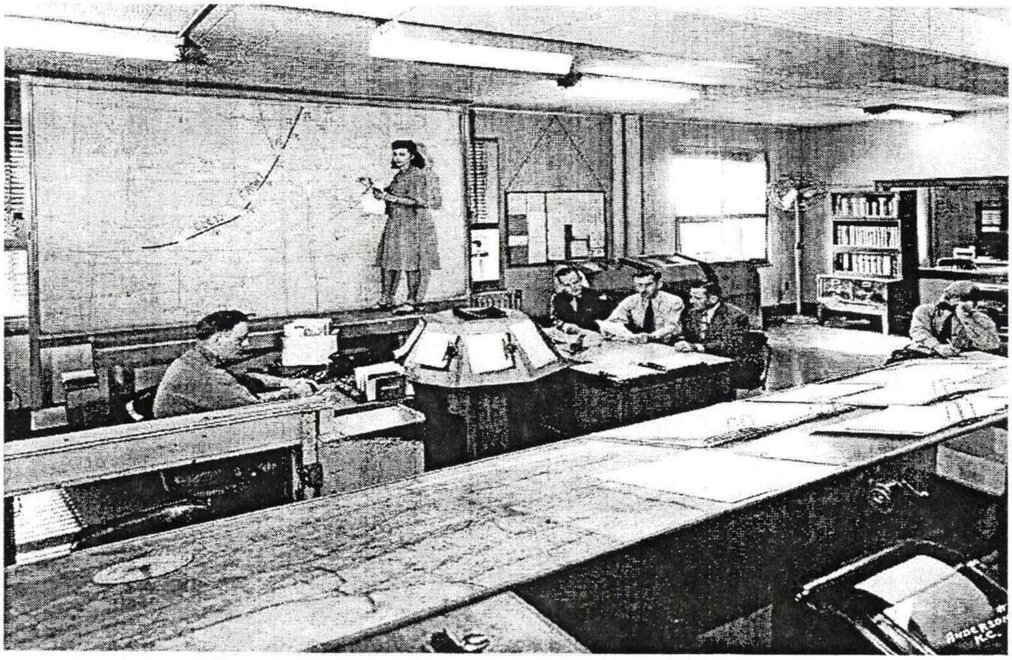

Figure 21. Weather Bureau Flight Advisory Weather Services (FAWS) Unit in Kansas City, MO, 1946.

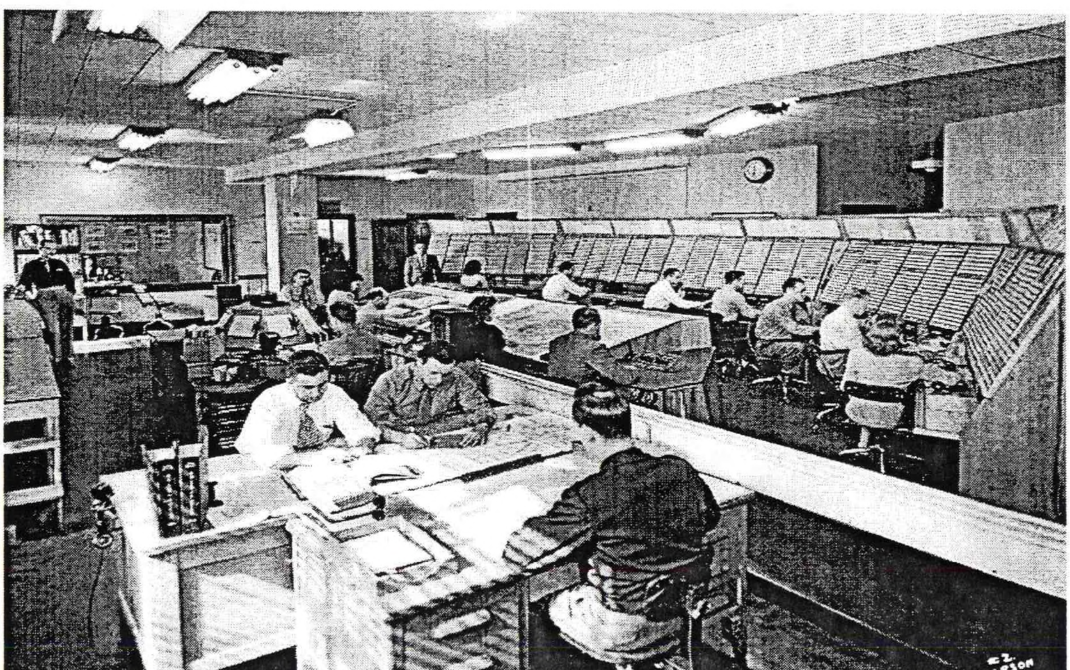

Figure 22. Kansas City Air Route Traffic Control Center (ARTCC), 1946, located on the top floor of City Hall adjacent to the WB FAWS Unit.

service people, and maintained a big "current weather" board. There was also a hot line to the WBAS office for consultation with the aviation forecasters at Municipal Airport.

In the late 1940s, the FAWS Unit moved to Municipal Airport. By this time, the office also briefed pilots over the phone and in person, and issued winds aloft forecasts (FDs) for the Iowa, Nebraska, Kansas, and northwest Missouri area. Local warnings for the airports in the KC area were also made. The CAA did not provide pilot weather briefings in those days.

In 1955, the forecast office was moved to the Federal Office Building at 911 Walnut Street (Fig. 23), and only an Observer/Briefer Unit remained at the airport. An hourly radar chart, plotted by the Radar Analysis and Development Unit (RADU) (Fig. 24), was used by both the Severe Local Storms Forecast Unit and the aviation unit. This product was summarized by teletype and transmitted throughout the weather service.

By the late '50s, the FAWS and Area Forecast (FA) Units were consolidated. There were now 9 centers in the 48 contiguous states, with Alaska and Hawaii having 4 additional offices. All aviation products were now issued from each FAWS Center. These included Significant Meteorological (SIGMET) advisories and Airman's Meteorological (AIRMET) advisories which replaced the earlier Flash (FL) advisories. The FAs, terminal forecasts (FTs), Route Forecasts, and pilot weather briefings were all done at these centers.

In the 1960s, many more changes were made. RADU began transmission of 3-hourly Radar Summary Charts on the facsimile (fax) network. Transcribed Weather Broadcasts (TWEBs) were made from a prepared script containing aviation weather information for a radius of 250 miles. These were broadcast over low and medium frequency navigation aids.

The dual weather office format continued, with one unit in downtown KC and a second in the old tower at Municipal Airport. Most of the forecasts were made at the downtown office, but surface observations and pilot briefings were all done at the airport (Fig. 25). The CAA, now re-named the FAA, was also at the airport (they now did some briefings) as was the headquarters for Trans World Airways (TWA). We always had good dealings with both of them. The pilots from TWA, Delta, and Continental Airlines along with other airlines would come up to the WB office for the latest weather. Many pilots of small aircraft would also come in for the latest briefing, and the phone stayed busy from 5 am to 8 pm.

In 1961, an experimental Pilot-To-Forecaster (PTF) Unit was established, funded by the FAA, here in Kansas City (Fig. 26), and at two other sites on the east coast. They talked directly to pilots en route. Aircraft flying at 30,000 feet could be reached from near Chicago IL to Russell KS, and from Sioux Falls SD to Tulsa OK. Radar charts were used in these briefings, plus the latest forecasts and observations. The PTF unit lasted until 1964.

In the late '60s, the FAA Flight Service Station (FSS) and the WBAS at Municipal Airport moved from the tower to a small building across the field. Along with taking observations and briefing

Figure 23. Kansas City Weather Bureau Forecast Office moved to the Federal Office Building at 911 Walnut in 1955. Note the radar tower on the roof.

Figure 24. Radar Analyst Don Thomas using a light table to hand-plot WSR-57 radar data on a national chart for use by the aviation unit.

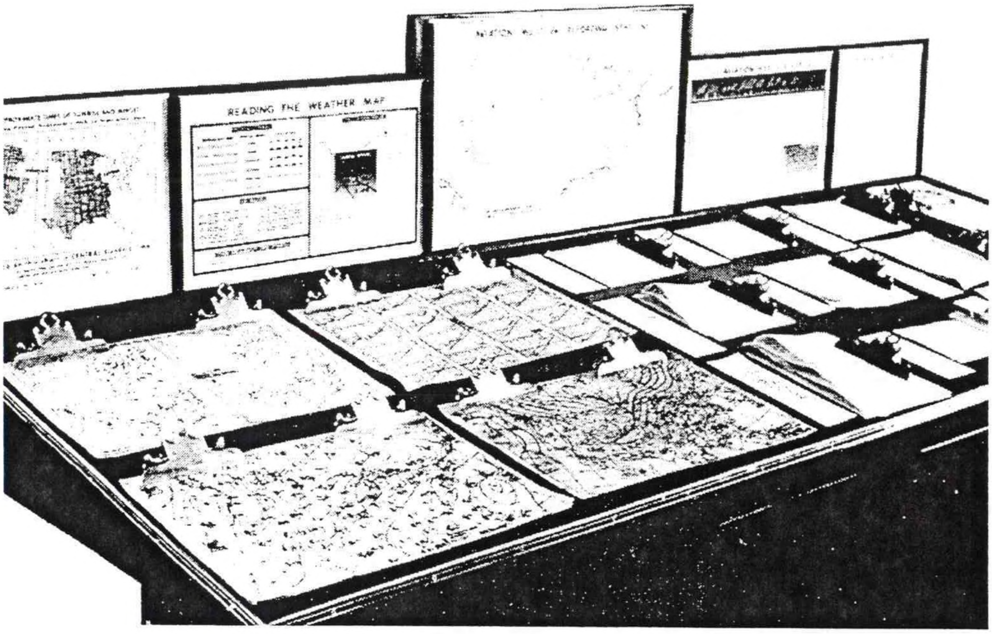

Figure 25. Typical layout of weather maps and teletype data at pilot weather briefing desk in a typical WBAS.

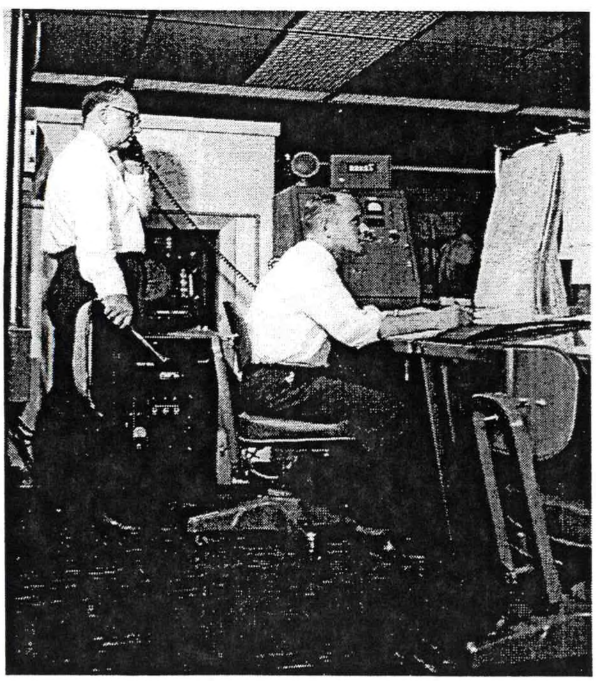

Figure 26. Experimental Pilot-To-Forecaster Unit in Kansas City, early 1960s. WB Forecaster Bob Baskin talks with a pilot by phone while Meteorologist Bud Schaffer analyzes weather data.

pilots, we meteorologists would update products (FTs, FDs, AIRMETs, FAs, etc.)as needed.

In 1970, the Weather Bureau, which had resided within the Environmental Science Services Administration (ESSA) since 1965, experienced yet another identity change. Re-christened the National Weather Service (NWS), it was placed under the newly-created National Oceanic and Atmospheric Administration (NOAA) within the Department of Commerce. A number of policy changes accompanied this bureaucratic shuffling. Meteorologists were no longer at the airport office. Meteorologist Technicians now took the surface observations and did a few pilot briefings.

The FAWS unit in Kansas City continued until the late '70s issuing FTs for about 30 cities, TWEBs, FAs, AIRMETs, SIGMETs, and preparing pilot report collectives for transmission to other parts of the country. However, the responsibility for issuing TWEBs and FTs was soon shifted over to the Weather Service Forecast Offices (WSFOs) at the state level.

Recommendations by the National Transportation Safety Board (NTSB) in the wake of a thunderstorm-related airline crash led to the formation of the Convective SIGMET Unit in 1978. The purpose of the unit was to provide hourly forecasts of thunderstorms that pose a hazard to in-flight aircraft across the contiguous United States (Fig. 27). In addition to the convective SIGMETs for the entire nation, FAs, AIRMETs, and non-convective SIGMETs were issued for Colorado, Wyoming, North Dakota, South Dakota, Nebraska, and Kansas.

With the formation of the National Aviation Weather Advisory Unit (NAWAU) in late 1982, the 9 previous FAWS offices were consolidated at Kansas City. All AIRMETs, SIGMETs, and FAs for the entire country were now done from one location. And what had been the job of 27 meteorologists was now to be done by only 15. Alaska and Hawaii continued issuing the forecasts for their own respective areas.

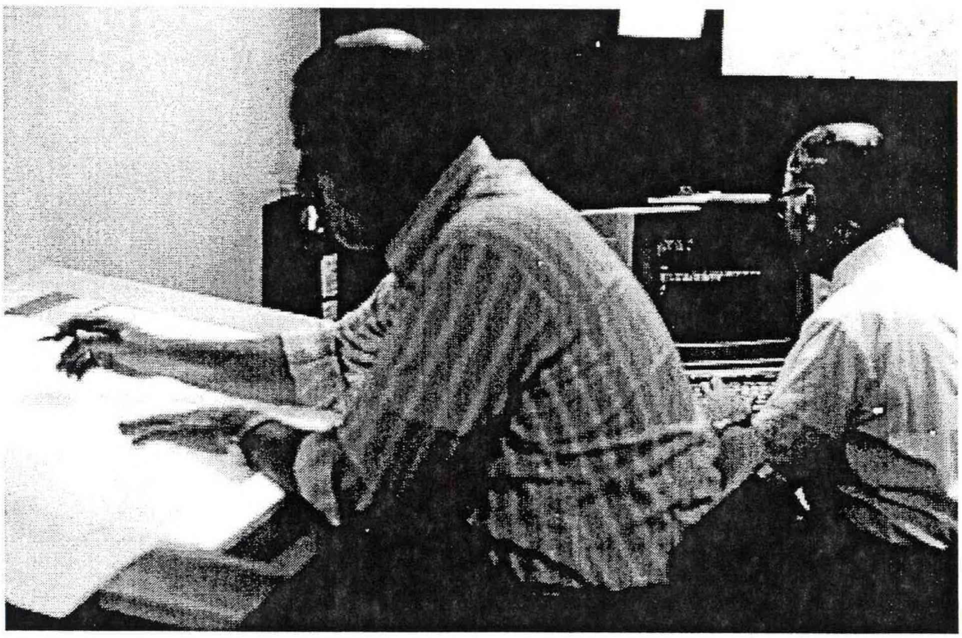

Figure 27. Radar Analyst Gary Mounsey plots hourly radar data while Forecaster John Michener types up the actual Convective SIGMET bulletin on the "bee hive" computer.

3. Expanding horizons: National Consolidation in Kansas City (1982 - 1997)

Richard J. Williams

3.1 Establishment of a National Aviation Center

The National Weather Service's Regional Aviation program was built around nine Area Forecast Centers. Each center produced the Area Forecast (FA) for their region of the country along with AIRMETs and SIGMETs. In a move to reduce the number of forecaster positions, a plan was drafted to consolidate the nine FA centers into one "national" center. In view of Kansas City's successful experience in producing the hourly Convective SIGMET product on a national scale, and with much of the computer and communication infrastructure already in place, the choice of Kansas City as the home for the new center was a natural one.

In the summer and fall of 1982, plans were finalized for the establishment of the National Aviation Weather Advisory Unit (NAWAU) within the National Severe Storms Forecast Center (NSSFC). The Convective SIGMET unit's five meteorologists and five technician/analysts would be joined by fifteen additional forecasters - at the GS-13 grade level. Doug Mathews, from the Kansas City Satellite Field Services Station (SFSS), was chosen to be the GS-14 supervisor in charge of the new unit; he continued in that role until his retirement in July 1997.

Ultimately, the closing of the nine Area Forecast centers was a money-saving move in the face of the NWS's continuing austere budget climate. Twenty-seven field positions would be replaced by fifteen NAWAU slots. Terminal forecasts (FTs, which became TAFs after July 1996) and route forecasts (TWEBs) remained Forecast Office products as they are today. But the Area Forecasts (FAs), AIRMETs, and SIGMETs for the lower 48 states plus coastal waters were to become centralized products issued by NAWAU.

The Kansas City office provided a natural home for the nascent center from several standpoints. From the days of the Radar Analysis and Development Unit's (RADU's) national radar summary chart, initiated after completion of the WSR-57 weather radar network in the late 1950s, to the Convective SIGMET unit's national-scale products, the Kansas City office had already demonstrated the ability to assemble the human, computer, and communications resources needed to reliably meet important deadlines. In the words of then-NSSFC Director Alan Pearson, "Our office always had a 'can-do' reputation within the Weather Service."

Some key decisions had to be made even before the unit was established. First, how many forecasters would be needed to duplicate the work done at nine offices? This was purely a judgment call. Without any real precedent, it was decided that the country would be divided into six areas with each forecaster handling two of the six areas - a division of labor that continues even today.

Next...would the staffing be five forecasters for the three areas or something even more austere? The local branch of the National Weather Service Employees Organization (NWSEO) played an important role in these discussions. In the end, it was decided that five forecasters would be needed in each of the three forecast regions (East, Central, and West) in addition to the Convective SIGMET staff of five meteorologists and five meteorological technicians.

The new NAWAU staff members began assembling in Kansas City about a month prior to the scheduled November 10th launch date. The five Convective SIGMET meteorologists were all Kansas City personnel with thunderstorm forecasting experience gained primarily from working in the nearby SEvere Local Storms (SELS) unit (Fig. 28). Of the fifteen FA forecasters selected for the new unit, nine were already on- station, with six coming from other offices and backgrounds. Several arrived from Center Weather Service Units (CWSUs) in the FAA ARTCC system, two came from the discontinued Area Forecast unit in Fort Worth, and one from the Alaskan aviation unit. Thus, considerable aviation forecasting experience was on hand from the very beginning. Still, no one had ever attempted to write FAs for the extensive areas required under the new alignment.

The NWS Training Center set up a one-time course for the Area Forecast staff. The class ran from October 18th to November 5th, and in that two-and-a-half week period, experienced aviation forecasters from each NWS Region were brought in to impart both the techniques of writing FAs, AIRMETs, and SIGMETs as well as providing a short dose of regional aviation climatology. No one regarded the mission as easy, and the visiting instructors along with the students acknowledged the challenge of having three people per shift duplicate the work formerly done by nine at the different FA Centers.

A new format was developed for the Area Forecast to coincide with the start-up of the new unit. The FA became a five-part message with the AIRMET-criteria conditions for moderate turbulence, moderate icing, IFR weather, and mountain obscuration all incorporated into the FA. AIRMETs would then be issued only when conditions warranted between FA issuances.

3.2 Opening Day

A start-up in relatively benign, late summer weather would have been ideal however, the start date was set for November 10th, 1982. And as the vagaries of climate would dictate, NAWAU openers Carl Aldridge, Ron Olson, and Gene Hafele jumped feet first into an El Niño-influenced regime of widespread, rapidly changing weather conditions, especially across the western U.S. The first FAs were issued on the midnight shift, accompanied by some of the inevitable kinks and delays associated with a complex new venture. But...the Unit was at last underway (Fig.29).

Were the new products received with wide acceptance from the outset? Not entirely. Any time a program changes, especially when it changes from a local or regional program to national, it is inevitable that there will be qualms on the part of the users. This certainly proved to be the case

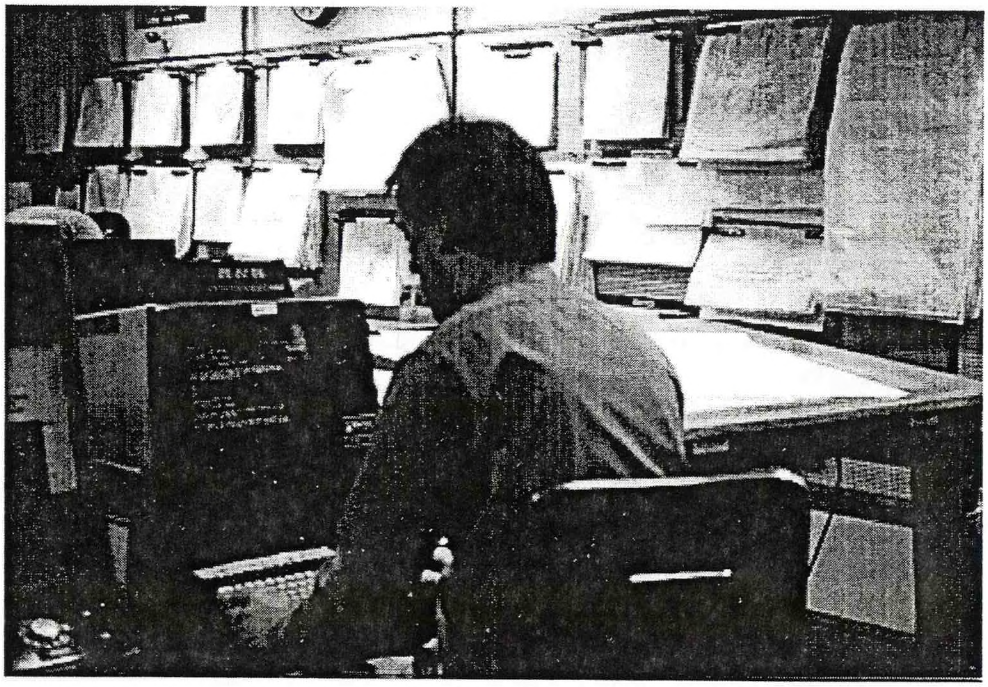

Figure 28. Convective SIGMET Forecaster Bill Carle, a former SELS Assistant, types advisories into the Delta word processor prior to transmitting the product (circa 1985).

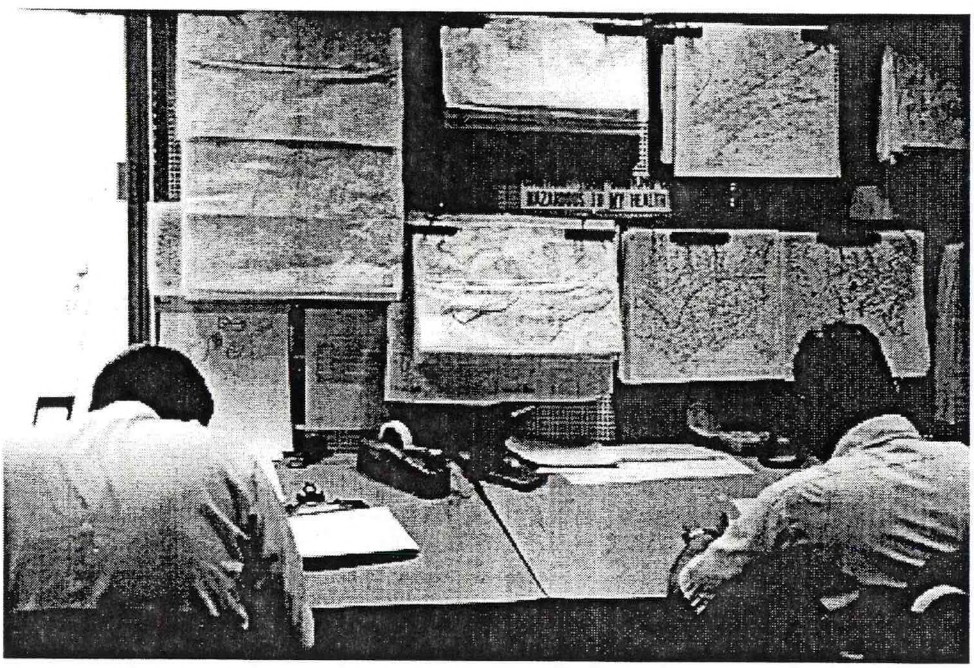

Figure 29. Forecasters Carl Aldridge (left) and Hugh Jones in the new National Aviation Weather Advisory Unit (NAWAU) (circa 1983).

with the centralization of the FAs, AIRMETS, and SIGMETS. The volume of calls and comments indicated that the NAWAU products were widely used and were being actively monitored for timeliness and accuracy. Flight Service Stations as well as NWS offices kept a watchful eye on the Kansas City-based products. The feedback was useful in calling attention to several meteorological "hot spots" such as coastal California and the Pacific northwest. Both areas have complex terrain resulting in wide variations in weather conditions over time and distance.

3.3 Co-location of NAWAU and SELS

One of the very important advantages to the centralization of the Area Forecast program was the collocation of NAWAU with the SELS unit. Computer resources were on hand at the NSSFC that would not have been available at any of the former FA centers. From the beginning, the McIDAS[5] system was used to display weather data of several types, from satellite imagery to model data to surface and upper air observations. Only one McIDAS terminal was initially available for the three FA writers on duty (Fig. 30), and it was more or less piggybacked on the SELS-oriented system. But it proved functional for met-watching surface and en route conditions. AFOS[6] was the primary source for meteorological data initially (Fig. 31), but it played a reduced role as the McIDAS hardware and software evolved.

The staff within NSSFC's Techniques Development Unit (TDU) provided technical support for both SELS and NAWAU. A 24-hour computer room staff kept the Data General midi-computers, IBM mainframes, and AFOS computers in operation which freed the forecasters from such functions throughout the '80s and early "90s. Additional McIDAS terminals were acquired over the years, allowing each FA forecaster to have a complete workstation. Software and hardware upgrades eventually provided each of the four workstations (including Convective SIGMET) with full roam-and-zoom capabilities on PC OS/2 Warp-based equipment.

Forecasters within NAWAU rose to the task of developing stand-alone software to support the unit's mission. A pilot report decoder was written which produced AFOS graphics of turbulence and icing. This augmented the text display of the individual state-by-state PIREP bulletins. Meteorologists Bill Carle and Dick Kerr wrote this and other decoders and product-checking

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5 McIDAS is the Man-computer Interactive Data Access System developed by the University of Wisconsin Space Science and Engineering Center as an interactive system for displaying meteorological data.

6 AFOS stands for Automation of Field Operations and Services, and is the National Weather Service's primary computer network dating back to about 1980. Although the communications network remains essentially in place for data relay, AFOS itself is gradually being replaced by AWIPS (Advanced Weather Interactive Processing System).

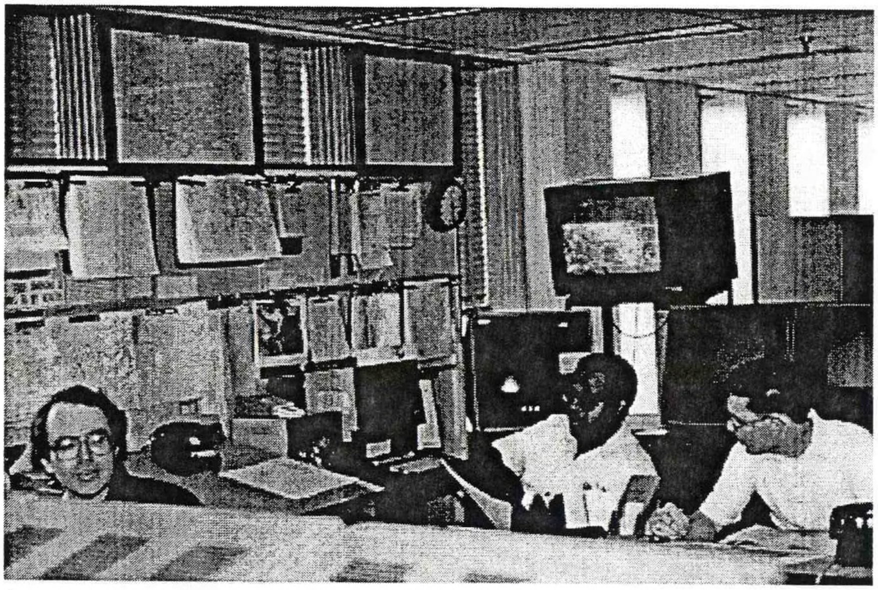

Figure 30. (left to right) Original NAWAU forecasters Dick Williams, Frank Woods, and Paul smith surrounded by a ring of equipment. Note single McIDAS workstation just behind Frank Woods.

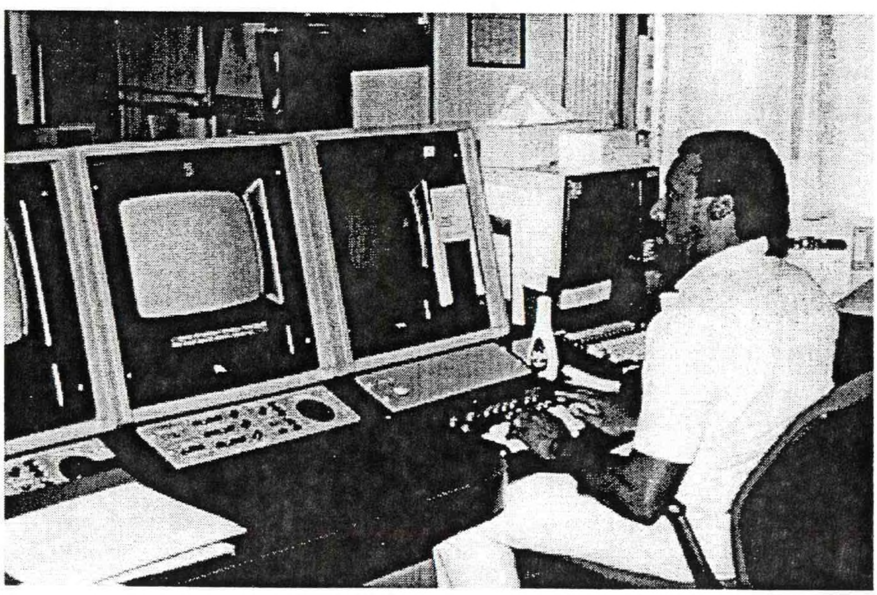

Figure 31. NAWAU forecaster Henry Fields calls up products on AFOS. To his right is a Delta word processor used for generating.

routines. Kerr's FACHECK program greatly assisted forecasters and strengthened the usability of all FA-side products.

Technology changes within the unit were sometimes subtle, sometimes major. One major change occurred in late 1987 when the hand-plotting of radar data gave way to on-screen plots via the McIDAS terminal. The manually-plotted radar chart, a Kansas City institution since 1956, was used for years in the production of the National Radar Summary chart - a mainstay of facsimile circuits and airport briefing counters nationwide.

In 1978, the hand-drawn and analyzed chart was superseded by a computer-produced chart, again with attendant user reaction as to the change in appearance and content. The hand-plotted chart, based on radar VIP levels[7] from the WSR-57 radars with manually-assigned tops and movements, continued to be used in the Convective SIGMET program until 1987 when the staff of five radar analysts was disbanded.

New sensors and technologies were quickly exploited at NSSFC, sometimes in roles unforeseen when the data first came online. Lightning data, available on an experimental basis since 1988, proved to be of tremendous value to the Convective SIGMET forecasters, providing an important adjunct to the satellite and radar data. NAWAU and SELS were both heavy users of the new technologies and each benefitted from the development work done by TDU, although most of the development was in support of the SELS mission.

3.4 Changing Programs and Lessons Learned

The rules of the road for the FA side of NAWAU are set down in Weather Service Operations Manual (WSOM) Chapters D-20 and D-22. A lengthy process of rewriting these two chapters stretched from mid 1988 until final implementation in mid 1991. Since NAWAU's inception, there existed a two-part system for AIRMETs. AIRMET criteria conditions, generally moderate icing, moderate turbulence, and the occurrence of widespread IFR and mountain obscuration, was covered within the three-a-day Area Forecasts. Then, as conditions changed between FA issuances, an AIRMET series was started to amend the previous FA. This dual system had been the source of long-standing confusion among product users.

The chapter rewrite addressed this, providing for scheduled AIRMET bulletins issued every six hours and valid for six hours. Thus, pilots and briefers would always have a set of valid AIRMETS to refer to, regardless of the state of the weather. AIRMET TANGO provided turbulence information, AIRMET ZULU covered icing, and AIRMET SIERRA IFR and Mountain Obscuration conditions (Fig. 32).

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7 A VIP level is one of 6 Video Integrator Processor levels representing echo intensity in radar reflectivity data.

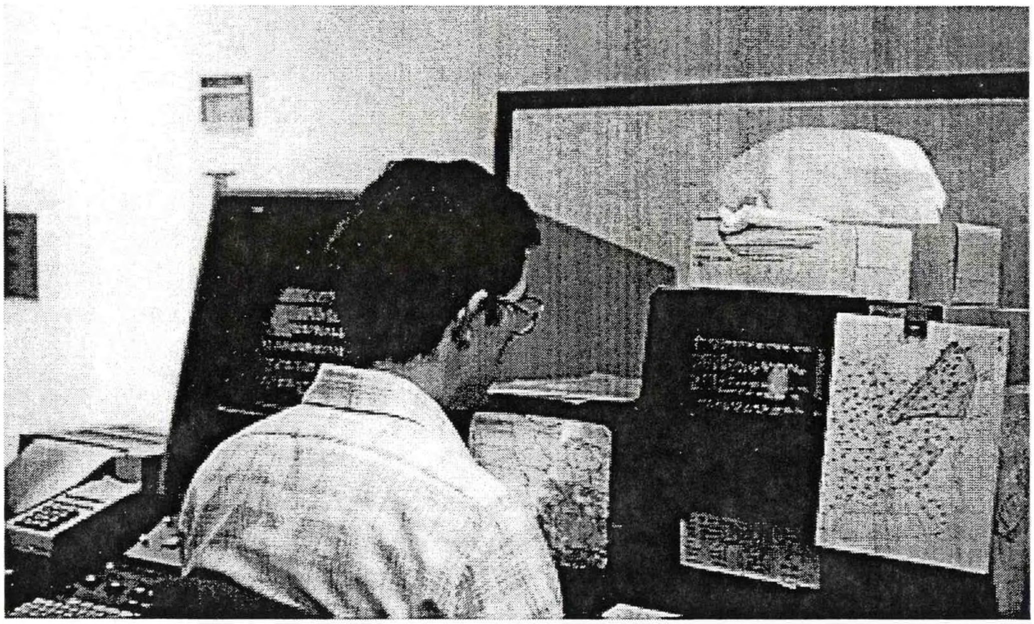

Figure 32. East FA Forecaster Paul Smith types up AIRMETs on the Delta word processor . Note the map to his right showing the areas of concern in the BOS and MIA FA areas for which he has responsibility.

Although coordinated extensively at HQ levels, the change in format was probably not adequately heralded at the working level. Considerable user confusion translated to many phone calls upon initiation of the changes. In the end, the utility of scheduled, full-time AIRMETS was realized as was the lesson that aviation program changes must be explained to users thoroughly and well in advance of implementation.

In 1989, NAWAU received a NOAA Unit Citation in recognition of the important work performed by the national unit since its inception in 1982. All NAWAU personnel who worked in the unit from the beginning through May 1989 were included in the citation. The plaque hangs proudly in the AWC reception area.

3.5 New Areas of Aviation Research and Support

In early 1992, an important step was taken when the Experimental Forecast Facility (EFF) was formed to provide direct support to NAWAU. The EFF received funding from the FAA to develop and evaluate new aviation forecast techniques. Meteorologists Ron Olson and Don McCann were chosen from within NAWAU ranks to fill the two EFF slots. In late 1993, the position of NAWAU Science Officer was established, somewhat paralleling the successful Science and Operations Officer (SOO) position in the NWS Forecast Offices. Ron Olson was selected for the Science Officer slot, and Henry Fields moved into the vacated EFF slot.

The EFF proved immediately useful and productive. As the office transitioned from main-frame hardware to workstation and PC-based systems, the unit began making use of the N-AWIPS (AWIPS for National Centers) and its associated GEMPAK[8] software. These systems allowed workstation-based display of many meteorological fields and the development of many new diagnostic fields. McCann exploited these features and provided the forecasters with new tools such as the Turbulent Kinetic Energy (TKE) and Mountain Wave (MWave) diagnostics.

Icing has become a prime topic of interest, especially after the crash of an ATR-72 near Roselawn IN on 31 October 1994 as a result of ice build-up. Cooperative efforts between researchers at the Forecast Systems Laboratory (FSL) in Boulder CO and the EFF meteorologists has placed other new tools in the hands of forecasters. While not every new tool has stood the test of real-world applicability, the close proximity of research and operational meteorologists has resulted in forthright and speedy feedback.

EFF Meteorologist Henry Fields' area of concentration has been cloud and visibility forecasting,

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8 GEMPAK is a software package originally developed by the National Aeronautics and Space Administration (NASA) that has been adopted for use with AWIPS and N-AWIPS. GEMPAK is the acronym for GEneral Meteorological PAcKage.

and he has authored a number of new display and forecast routines that have enhanced the forecaster's repertoire for met-watching areas of IFR and mountain obscuration. Fields is also working on a computer-generated Area Forecast to serve as a preliminary text for the meteorologist. Forecaster evaluation of that project is now underway.

3.6 Expanding Duties

The expansion of NAWAU duties moved forward in 1992 when the unit assumed a portion of the NWS's International SIGMET duties. These products, previously written by the Washington DC office, were moved to Kansas City in October 1992. Once again, the presence of computer resources, both hardware, software and, most importantly, human resources, provided the key to supporting the program. The McIDAS system, now operating under the VDUC[9] configuration (Fig. 33), provided an excellent means of displaying pilot report information, satellite imagery, and model forecasts for a one-stop look at the new areas of oceanic responsibility that stretch from 40 degrees West longitude in the mid Atlantic to 165 degrees East longitude in the central Pacific.

The IGEN program, written by TDU meteorologist Pete Browning, provides a quick means of composing the International SIGMET message interactively on VDUC. The international duty shifts seasonally between the Convective SIGMET Unit (aka WST unit, for their product identifier) and the FA unit. In the spring and summer, peak-time for the WST unit, the program resides in the FA section. The Pacific is met-watched by the West FA forecaster and the Atlantic by the East FA meteorologist. During the cool season, the program migrates back to the normally quieter WST desk. Kansas City also has backup responsibility for International SIGMETs authored by the Tropical Prediction Center in Miami FL and the NWS Forecast Office in Honolulu HI.

3.7 Separation Anxiety and Benefits Realized

The 1990s have seen major changes in the Kansas City office, foremost being the move of the SELS unit from Kansas City to Norman, OK. That move took place between the fall of 1996 and January, 1997. A key part of the NWS Modernization and Restructuring is the placement of most public forecast and warning responsibility within the local offices, centered around the WSR-88D radars. The slow-to-be-deployed AWIPS computer system and full meteorological and hydrological staffing are other key components of the forecast office modernization. In October 1995, as the former National Meteorological Center (NMC) became the National Center for Environmental Prediction (NCEP), SELS and NAWAU were re-christened the Storm

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9 VDUC stands for VAS Data Utilization Center. VAS is VISSR Atmospheric Sounder. VISSR is the acronym for Visible-Infrared Spin Scan Radiometer, referring to the actual satellite technology.

Figure 33. Convective SIGMET Unit showing the national lightning data display (left) and VDUC interactive workstation. Upper screen shows a regional radar composite over Florida.

Prediction Center (SPC) and the Aviation Weather Center (AWC), respectively.

There was a long-standing desire by Dr. Elbert Friday, then-Director of the National Weather Service, to relocate SELS/SPC to Norman OK to be near the National Severe Storms Laboratory (NSSL), the Operational Support Facility (OSF) for the new radars and the University of Oklahoma's well-respected Meteorology department. In an understanding between the National Weather Service and the office of Missouri Senator John Danforth, it was stipulated that an aviation weather center would remain in "the Kansas City area" once SELS relocated. This language appears in correspondence from Dr. Friday to Missouri and Kansas lawmakers and in the 1992 NOAA appropriations bill .

As a result of the departure of the SPC staff, the computer support staff was also split, with some going to Norman and about half remaining in Kansas City. While this division was disruptive and expensive, it did mean that for the first time, the AWC would be the sole operational unit and thus receive the undivided attention of the newly-designated Aviation Support Branch (ASB) composed of former TDU staff. Likewise, the administrative and electronic staffs would be supporting only the core programs of the aviation center. Thus, the longtime arrangement of the aviation unit having to share resources with a more visible severe weather unit, was instantly reversed in January 1997.

In the realm of technical support, the reduction of allotted personnel continued, a trend that had persisted for years. Locally, the computer room staff was switched from NWS-employed personnel to contract employees. At the same time, the coverage was reduced from 24 hours to 10-hour a day coverage. This change was permitted, in part, by the move from main-frame to workstation and server/client architecture. However, the multitude of servers, data-ingest computers, and networked workstations still required knowledgeable people on duty round the clock. This responsibility was shifted to the duty forecasters.

In late 1996, the AWC received the green light to upgrade five GS-13 meteorologist positions to GS-14 Lead forecaster positions. Four of the 5 were selected from within the Kansas City unit. The fifth position was filled by the supervisor of the Transition Aviation Program (TAP) unit at NCEP in Washington that was destined to move to Kansas City in mid 1997. The Lead positions would have overall responsibility for shift operations with an emphasis on analyzing computer and data flow problems. First the Leads, and later all the Center's meteorologists, were given training in the many systems used by AWC.

3.8 AWC Support of National Programs

The current AWC and earlier NSSFC office have long provided support for NWS programs falling outside the realm of aviation forecasts and advisories. With the extensive satellite-receiving capability and multiple data lines to the FAA, the Kansas City office has always been a major conduit for weather data flowing between the NWS and FAA. In addition, the many satellite receivers used by the AWC to provide independent data sources serve as a back-up for supplying the NWS as a whole with weather data in case of a disruption in the regular communication network. Communications between the NWS and the FAA are essential to ensure the proper distribution of data for all concerned. To safeguard this flow of data, a backup capability, known as "alphanumeric backup", resides at the AWC.

Ingest and decoding of all WSR-88D radar data is performed at the AWC with the resultant fields shipped to NCEP in Camp Springs MD for production of the national radar composite chart. The highly-automated output of the 88Ds lacked several key elements such as radar tops and precipitation character that had been available in the manually-coded radar reports from the old network radars. Innovative work-arounds using model output, infrared satellite imagery, and data from the national lightning detection network were devised by Jan Lewis and Dr. Fred Mosher of the ASB to meet these critical user requirements. The Center also produces an AFOS graphic of lightning strikes across the country.

Dr. Mosher has developed a number of new techniques for utilizing the different sensors on board the GOES spacecraft. His low-cloud enhancements, developed especially for tracking the development and movement of nighttime stratus layers and fog, is used extensively in the AWC and throughout the Weather Service. He has also adopted a split-channel differencing technique for use in detecting volcanic ash that is very useful for the International SIGMET program.

For years, a staff of NWS meteorologists were co-located with the FAA's System Command Center (SCC) in Washington, D.C. to provide weather support for the nationwide flow of air traffic. In early 1996, the FAA made an abrupt decision to terminate the NWS contract effective that April, replacing the NWS personnel with Briefing Specialists from within their own FSS system. Although well-experienced at providing en route briefings to pilots, these specialists did not have the extensive meteorological training possessed by the NWS forecasters. To remedy this short-coming, the AWC was asked to join in a daily conference call between the SCC personnel and airline meteorologists to discuss the day's weather problems. The forecasters working the Convective SIGMET and East FA desks provide this input seven days a week at 4 am Central time.

3.9 Our Expanding International Role

The Weather Service must always conform to budget considerations and political priorities. In the mid '90s, one such goal was the movement of functions out of the Washington, D.C. area. By this time, the only aviation function remaining at NCEP/Camp Springs was the creation of the facsimile charts used by both domestic and international aviation interests. The 24-hour Significant Weather (SIGWX) progs, issued in support of the World Area Forecast System (WAFS), graphically depict areas of turbulence and convection, jet streams and frontal positions. Until the summer of 1997, these charts were generated by members of the TAP unit located in the World Weather Building at Camp Springs MD. The TAP unit, composed of 10 meteorologists plus a supervisor, also created the aviation-related panels of the 12 and 24-hour domestic graphic forecast depicting IFR/MVFR regions, turbulence, and freezing levels over the contiguous U.S. These charts are used by pilots nationwide and by the FAA's Briefing Specialists at all FSSs.

The move of this Washington-based function to Kansas City between July and September of 1997 placed the AWC even more firmly in the international realm. Forecast responsibilities now range from eastern Europe westward across the Atlantic, the United States, and the Pacific to east Asia, and includes airspace well south of the equator. Indeed, two-thirds of the world's airspace now falls under the umbrella of the Aviation Weather Center, in one sense or another.

Further additions are expected as the U.S. assumes its full role under International Civil Aviation Organization (ICAO) treaties. Widening use of twin-engine turbine aircraft on international routes dictates the need for mid-level guidance charts. These charts are already being produced by other world forecast centers. The SIGWX unit within the AWC expects to begin production of mid-level graphics in FY98.

As with other programs that migrated to Kansas City, the SIGWX program has benefitted a great deal from the software support that is now dedicated one-hundred-percent to aviation operations. Based in large part on the global Aviation model, these charts were formerly prepared using acetates and grease pencil (Fig. 34). The meteorologists prepared the forecast data, then handed the acetate version to a met tech who sent the data to the main NCEP computer via the Intergraph system for ultimate outside distribution (Fig. 35). Now, however, newly-written software, running on Hewlett Packard workstations under the N-AWIPS umbrella, allows the forecaster to interactively edit the initial data fields, then send them directly to the computer.

The Aviation model still provides the primary guidance for the 24-hour forecast, but a series of forecast algorithms compute guidance fields for the various elements on the SIGWX chart: convection and high-level turbulence, jet streams, frontal positions, and tropopause depictions. These guidance fields are available to the forecaster who makes exactly the same meteorological judgments as were made previously in the acetate-grease pencil era (Fig. 36). The first AWC-produced SIGWX charts were transmitted in early August , 1997. The KC-generated products for the domestic low-level charts went into production the following month.

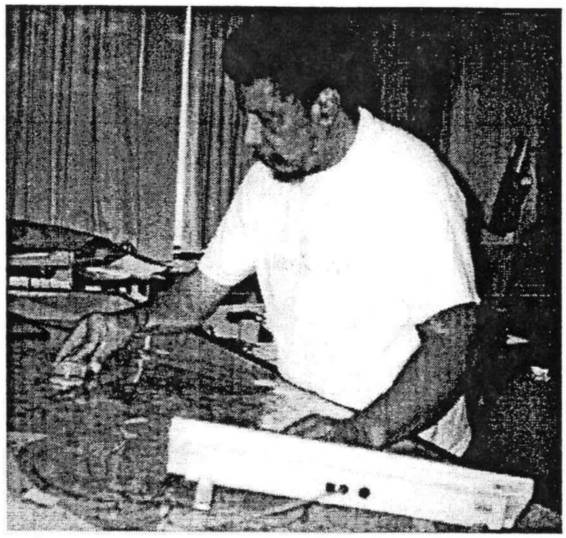
Were there growing pains? Yes; but that's to be expected with any major program change. The forecasters gradually acclimated to the new software. The computer support staff, working alongside the forecasters, was able to make almost immediate changes in the software, sometimes on an hourly basis. But it was the technical support devoted entirely to the new aviation program that permitted this rapid development.

3.10 The Users -- The Reason We're Here

In a field such as aviation weather forecasting, with a very identifiable user community, it's

Figure 34. TAP Meteorologist Randy Schrull prepares an acetate for the high-level SIGWX prog. This method of manually-generating the product prevailed until late summer of 1997 when the process was automated.

Figure 35. Met Tech Davey Myers uses the Intergraph system to input the SIGWX graphics chart into the NMC computer for outside distribution.



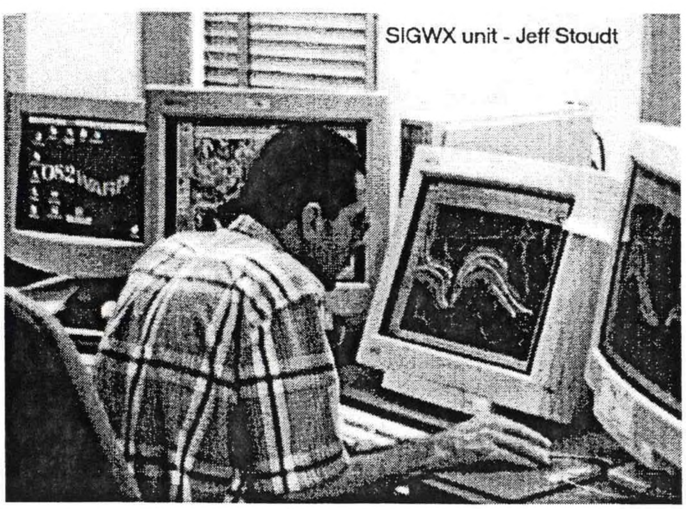


Figure 36. Former TAP Meteorologist Jeff Stoudt uses N-AWIPS workstation to manipulate gridded fields as part of the now-computerized process of generating the high and low-level SIGWX progs at AWC.

important to maintain contact with those users. Throughout most of the NAWAU/AWC era, meteorologists within AWC were encouraged to meet with users via personal visits, familiarization flights, and attendance at professional conferences; however, agency-to-agency contacts were mainly reserved for Headquarters personnel.

With its increasing prominence and visibility during the past two years, the AWC has instituted a range of outreach, educational and feedback efforts. The AWC has a strong presence on the World Wide Web (http://www.awc-kc.noaa.gov) under Webmaster Bill Hirt. Although the Web is not an official means of product distribution, its almost universal availability to the user is unprecedented. On average, the AWC website is accessed over 300,000 monthly, a reflection of its success and popularity among the user community.

Another web-based dissemination vehicle is the Aviation Digital Data Service (ADDS), a collaborative effort between the AWC, FAA, and FSL. The ADDS site provides access to gridded model data for users world-wide. The user can download the gridded data and manipulate it for their specific needs or download any number of pre-computed fields that are also available on the site.

As part of its efforts to increase contacts within the aviation world, the AWC hosted a meeting of the Air Line Pilots Association Safety Committee in the spring of 1997. A recently-instituted newsletter, edited by meteorologist Rick Cundy, will provide FSS personnel, pilots, and other AWC customers with information on our products and a mechanism for offering feedback about those products. Members of the Center have joined Regional and Headquarters personnel in representing the NWS at the Experimental Aircraft Association's annual Fly-In at Oshkosh WI for many years, providing demonstrations, briefings, and seminars to thousands of pilots from all over the world.

For decades, the KC office has had ties with the military, particularly the U.S. Air Force. In the 1940s, the FAWS unit was co-located with a military flight advisory unit in the KC ARTCC. Beginning in the mid '50s, the civilian and military severe weather units worked side-by-side to monitor and forecast the occurrence of tornadoes and other forms of hazardous weather. This collaboration continues today in the cooperative relationship between the AWC and the Air Force Weather Agency (formerly Global Weather Central) at Offutt AFB, Omaha NE. This relationship is being further strengthened by the development of a two-way backup plan to minimize the disruption of products and services in the event of a power failure or other emergency. Both agencies should benefit from this arrangement.

4. Concluding Remarks

From the preceding narrative, it should be evident that Kansas City's Aviation Weather Center has a very rich heritage in aviation. The scope of its contributions has grown from a strictly local role to one that is global in reach. From the first weather office in 1888 through the explosive growth of aviation in the 1930s, the KC office was primarily a local player. With the prototype aviation units of the 1940s, the Radar Analysis and Development Unit of the late '50s, and the regional aviation functions of the 1960s, its role expanded to encompass ever larger areas of responsibility. The establishment of the Convective SIGMET unit in the late '70s and NAWAU in the early 1980s cemented the Center's presence on a national level. The decade of the '90s brought international responsibilities which have culminated in the Aviation Weather Center of the present day.

Many programs have changed throughout the past century; a few outdated ones have disappeared while others were modified and updated based on changing user needs and/or emerging technology. In some cases, entirely new programs have evolved and been incorporated into daily operations while others were abandoned after a trial run. But in all cases, it was the convergence of significant communications resources, skilled personnel, and ever more powerful and flexible computing resources that allowed this evolution to progress to its present level.

The personnel of the Center and all it's predecessors have been able to develop innovative solutions to the challenges placed before them, which has led to their expanded forecast role decade after decade. Today, the Aviation Weather Center (AWC) in Kansas City is the nation's leader in providing aviation weather data for the domestic airspace. During the past decade, the role of the Kansas City office has become more global in scope. The AWC is one of only two World Area Forecast System (WAFS) offices in the world (the other being at Bracknell, England).

The dominant theme over the more than 100 years of weather forecasting in Kansas City has been **growth** in the face of uncertain budgets and changing economic priorities. During this period, the continuing evolution of technology has been successfully applied by the AWC and its predecessors to meet our responsibilities over a wider area with fewer resources. The recent consolidation, necessitated by budget constraints and made possible by improvements in communications, has allowed Kansas City to assume the role of a **national leader** in aviation weather forecasting.

Coming attractions…

Groundbreaking for new home of Aviation Weather Center - March 4, 1997. KCI

- Shared with NWS Training Center
- Southeast of Kansas City International Airport
- Features:
    - 140 seat auditorium
    - 90,000 square feet
    - NOAA training facility
- Anticipate Occupancy January 1999

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