the forecasting problem

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Mr. Chairman, Members of the American Meteorological Society, Ladies and Gentlemen:

I am very happy to be with you tonight. As I look around the room, I see many of the faces I knew so well when I was in the Weather Service, so I feel very much at home.

Mr. Pruett invited me several months ago to be your banquet speaker. I'm afraid that long advance notice gave me a false sense of security, but the intervening weeks have passed rapidly. I'm reminded of an epitaph on a stone in an old graveyard which said, "I expected this, but not so soon." Also, Mr. Pruett gave me complete freedom in my choice of topic. That may have been a polite way of indicating that he had considered what I might talk about, but found it difficult to propose an area for consideration on recalling that I have been out of the field of meteorology for some nine years. However, I appreciated the invitation, and when I noted the theme of the conference—weather forecasting—I gladly accepted. I was concerned with the short-range forecasting problem in a very direct way for twenty years, and as an Air Force officer, I have retained a personal as well as a Commander's interest in meteorology and have tried to keep current with some of the new developments.

Forecasting: a service and a science

I am very pleased to see the AMS devoting one of its national meetings to the weather forecasting problem, because weather forecasting remains the showcase for meteorology. I believe that there are those who make a clear distinction between the *science* of meteorology and the *services* of meteorology and express the fear that attention to the services, with emphasis on operational problems, reduces the scientific vigor of meteorology. Perhaps this condition has existed in the past, but I think the situation may be somewhat reversed today. If we agree that the task of meteorology is to describe, to understand, to predict, and perhaps to modify the atmosphere, it seems to me that the solid advances of the last several years in *describing* and *understanding* atmospheric processes now logically require the application of that understanding to forecast problems. I

think we are even more today in the position expressed by my friend, Joe George some fifteen years ago, when he likened the forecasting problems to a shelf containing a lot of sponges. None of these sponges had been squeezed dry because there were so many of them; instead, we had tried to give each a good squeeze and get a reasonable forecast ability from a first effort. He suggested that the time had come to go back and squeeze the old ones again. I suggest that the sponges may have picked up considerably more moisture from the advances of the science of meteorology in the recent past, and more squeezing may be in order now.

I am also pleased to see that the American Meteorological Society now has its Award for Outstanding Service by a Weather Forecaster, recognizing the great importance of weather forecasting to the public safety and well-being, and the valuable professional services provided by AMS members who are engaged in forecasting activities. I feel very strongly that we need to emphasize to the practicing forecaster the importance of his work, and that it is not necessary to be involved with more exotic areas to make important contributions. Returning again to the distinction we make between science and services, I have long wondered why meteorologists apparently have been reluctant to accord weather forecasters the status the medical profession assigns to its practitioners. In my mind, the positions of these two groups are quite comparable.

I certainly do not feel that the service aspect of meteorology is overemphasized today. The JOURNAL OF APPLIED METEOROLOGY of this Society is intended as "a medium for the publication of research concerned with the application of the atmospheric sciences to operational and practical goals." A rough check of the first five years of articles in that Journal revealed that something less than twenty per cent were related directly to analysis and forecasting. As another indicator, the Fiscal Year 1968 Federal Plan for Meteorological Services and Supporting Research shows that agencies of the Federal Government are spending approximately \$85,000,000 for research, of which a little over \$3,000,000 is for direct research on forecasts. Now I am not implying that these efforts are inadequate, but I do feel that the figures would tend to reject claims of over-emphasis on forecast problems.

¹ Remarks to the Conference on Weather Forecasting, Ft. Worth, Tex., 7 November 1967.

We've come a long way since then

We are approaching the centennial anniversary of a national weather service in this country. As a military officer, I look back with pride on the contributions made by military personnel and military organizations to the formation and achievements of that service. I would like to trace, briefly, some of that history, and particularly to contrast the status of meteorology early in my career with that of today.

Credit for the first official observations of weather in this country belongs to the Army Medical Department. An order in May, 1814, made it a duty of hospital surgeons to keep a diary of the weather. Noting that "the influences of weather and climate upon diseases, especially epidemics, is perfectly well known, "the first Surgeon General of the Army, in indorsing the order, stated that "every surgeon should be furnished with a good thermometer and, in addition to a diary of the weather, should note everything relative to the topography of his station, the climate, complaints prevalent in the vicinity, etc., that may tend to describe the causes of diseases, to the promotion of health and the improvement of medical science."

Another military man who made significant contributions toward a weather service was Lt. Mathew Fontaine Maury, a naval officer who later was the first Superintendent of the U. S. Naval Observatory and Hydrographical Office. Maury spent years of intensive study of the ocean and the winds above it, giving the first reliable knowledge of oceanic climates and firmly establishing marine meteorology. He was the U. S. representative and the leader in a pioneer scientific conference held in Brussels in 1853, called to secure international cooperation in a world-wide system of meteorology. Later, he developed a plan for a national weather organization which was introduced in a bill to Congress, but the impending Civil War prevented the adoption of his plan.

Lt. Maury is of interest to me in another way. His crusading articles, written while he was recovering from a serious accident, played a significant role in the establishment of the U. S. Naval Academy.

In 1850, under an act of Congress, the Chief Signal Officer of the Army was made responsible for conducting weather observations and for establishing the first national forecasting service in this country. Generals Myer, Hagen, and Greely developed the service from 1870 until, in 1891, the meteorological duties were shifted from the Signal Service and assigned to a civilian bureau under the Department of Agriculture.

Prior to the beginning of the First World War, no provision had been made for systematic meteorological activities to support the activities of war. However, in 1917, the renowned scientist, Robert A. Millikan, then in service as a Lt. Colonel and Chief of the Science and Research Directorate of the Signal Corps, was directed to supervise a meteorological service organization within the Signal Corps, working in close coopera-

tion with the Weather Bureau. Several of the outstanding forecasters of the Weather Bureau were commissioned in the Signal Corps, and over 550 men were trained for service in Weather Bureau stations and in a Signal Corps School of Meteorology at Texas A and M College.

After the war, the responsibility for meteorological activity in the Army remained with the Signal Corps until July 1, 1937, when the Air Corps was charged with the responsibility.

When I entered flying school in the early 30's, the requirements for meteorological service were not very great. The first aircraft I flew was a PT-3, open cockpit, no brakes; it looked much like the World War I Jenny. We received no instrument training to speak of, and initially it was strictly fair weather pilotage using that well-known iron compass, the railroad, for navigation. The capability of the aircraft, its power plant, and its pilot were all limited. Consequently, the demands placed on the forecaster were few. In fact, we were taught meteorology at the ground school by a lieutenant who also taught maintenance, aircraft structure, and, later in the year, the duties of a judge advocate. There were no schools for meteorology; most forecasters were given on-the-job training. What little meteorology taught in schools and universities was taught in conjunction with geography and climatology. Although the classical papers of the Norwegian School had been in existence for some time, their application to forecasting received little attention in the United States.

In my first assignment after flying school, my squadron received the Martin B-10. With these aircraft, it became evident that an improved forecasting service would be required. Rossby had arrived in the States in the late 20's, and he made several overtures to get meteorology "off the ground" and on the way to importance in the scientific community. Later, he organized the Department of Meteorology at MIT. Petterssen arrived in the 30's, and he too, had much to do with improving the quality of meteorological instruction and of meteorology in general.

After completing advanced flying training, I was assigned as a recon pilot in Hawaii. In addition, I was communications and armament officer, assistant supply officer, and periodically, assistant mess officer. One day, a notice appeared on the bulletin board which stated that all those officers wishing to volunteer for graduate training in meteorology should sign below. Although I had difficulty pronouncing meteorology, much less defining it, someone told me what it meant and it sounded interesting. Besides, I was tired of being a supply officer. So I signed up and a year and a half later I received orders sending me to Cal Tech for weather training.

My career as a meteorologist began in 1938 at Randolph Field, Texas, then the basic flying training field for the Army Air Corps, famed as the "West Point of the Air."

Less than two years before my arrival at Randolph, the weather office had consisted of two operations clerks and one Signal Corps man who copied weather over the radio. Once daily, the reports were plotted on a blackboard, and isobars were drawn. When I arrived at Randolph with my year's training at the California Institute of Technology behind me, our task was to provide weather service to the pilots and to instruct in the flying school, using the "new" techniques of air mass and frontal analysis. Our upper air observations consisted of daily aircraft flights with meteorographs, made by pilots at a number of airfields to elevations around 15,000 feet, and increasingly supplemented by a revolutionary new instrument, the radio meteorograph. Although many new forecast problems have developed in recent years, most of the problems we faced then continue to this day; we were concerned with route and area winds, icing and enroute weather, and terminal conditions of ceiling, visibility, winds, and precipitation. I remember that one of our most difficult terminal forecast problems was the time of onset and duration of fog and low stratus at the field, and I'm sure this problem of Texas weather continues to plague forecasters.

Incidentally, we were also concerned in those days with the representativeness of our observations. One of my first tasks was to explain the fact that the wind speeds recorded at Randolph seemed to be consistently higher than those reported at neighboring stations. No scientific breakthrough was required to find the explanation; our anemometer, instead of being installed at the standard six meters above the surface, was located on top of the Administration Building, some 200 feet above the ground. After a series of checks with a hand anemometer at six meters, we applied correction, and the reduced wind speed agreed nicely with surrounding reports.

Later, in 1940, I was sent to MIT to study and become a long-range weather forecaster under Namias. Research, begun in 1935, led to the popular five-day forecasts first issued to the public in 1940. Upon the completion of this course, both Namias and I returned to Washington where I became a long-range forecaster for the Air Corps under Namias at the Weather Bureau. It wasn't long after my assignment to Washington that we were in the war.

In spite of the role played by meteorologists in World War I, the requirements for meteorological service to military aviation were grossly underestimated and a vast training program for meteorologists had to be undertaken at the outbreak of World War II. Before the war, the service consisted of some 200 enlisted men and less than 50 officers. At the end of the war, the number had grown to nearly 20,000 officers and enlisted personnel. Today, over twenty years later, I'm sure it would be interesting to note how many in this audience can trace their initial association with the field of meteorology to this war-time program. The Service established about 325 new stations in the United States and nearly 550

overseas. I am sure that the global ramifications of this wartime weather network had, and continues to have, a marked influence on the progress of meteorology. Aerial weather reconnaissance, weather radars, and centralized analysis facilities utilizing facsimile networks were among the contributions of that period.

Some steps ahead

After the war, in 1948, another milestone was achieved by military forecasters. Fawbush and Miller had for some time been developing techniques for forecasting tornadoes and other severe storms. At that time, tornado forecasts were frowned upon if not outright prohibited. Before they were given permission to issue these forecasts, a tornado struck Tinker AFB, Oklahoma, where they were stationed. Just five days later, a similar weather situation developed and Fawbush and Miller issued a pinpoint tornado forecast for Tinker AFB. Fortunately for them and unfortunately for Tinker, another destructive tornado did hit the base, but everyone was expecting it and the Air Weather Service severe weather forecasting team was off to an auspicious start. Today, of course, we realize that such pinpoint forecasts of tornadoes are not within the state of the art, but the fortuitous circumstances launched a very worth-while effort.

In the early fifties, the development of the electronic computer allowed meteorologists to realize Richardson's goal of the numerical simulation of the atmosphere. Again, military meteorologists are proud of their contributions to the Joint Numerical Weather Prediction Unit which was established in 1954. Former Air Weather Service people still represent a sizeable nucleus in today's National Meteorological Center.

Since I left the Air Weather Service in 1958, the weather satellite has revolutionized the field. A Solar Forecasting Center has come into existence. Computer methods have been developed to solve a wide variety of operational problems. Many new geophysical parameters are being observed and utilized in forecasting. The Air Weather Service now relays data and returns forecast information on a new high speed network operating at 3000 words per minute. Just recently, the Air Weather Service has increased its effort to develop an operational capability to provide weather modification support.

I mentioned earlier that many of the forecast problems of thirty years ago still face today's forecaster. We would hope that there has been progress in solving the forecast problems, and it would be fine if we could cite verification data to demonstrate that progress.

In this connection, I made an effort to obtain verification data, but data over long periods of time are very difficult to find. Perhaps this problem of verification has been slighted, but I think the basic reason for the lack of long verification records lies in the changing nature of the forecasts to meet changing operational requirements, the increasing number of parameters pre-

dicted, and the larger range of activities for which useful predictions are now made. These changes in themselves represent significant increases in forecast skill, but quantitative answers of the degree of increase are not generally available.

Forecasting winds for air operations is one area where we can be sure that significant improvement has been achieved. This improvement is largely due to the improved forecast flow patterns from numerical prediction techniques. The automated forecast wind factors which the Air Weather Service provides for Military Airlift Command flights are a good example. In 1966, forecast wind factors in comparison with actual wind factors fell within the prescribed error limits 94% of the time. These limits are 15 knots for conventional aircraft and 25 knots for jet aircraft. In the earlier days of manual preparation, errors in wind forecasts resulted in about 45 operational hazard reports yearly. Today, the number of such reports has dropped to an average of about 5 per year—nearly a 90% drop.

The severe weather prediction capability is a very significant one. Despite low skill in pinpointing the exact degree of severe weather, when convective phenomena are forecast, some kind of hazardous convective weather occurs 85% of the time. Similarly, for about 80% of the observed cases of severe convective activity, a warning has been issued.

Forecasting terminal weather is one forecast problem which has not progressed proportionately to advances in other areas. Since the late forties, it has been estimated that an average of one million dollars a year has been spent in the United States on research to improve the short-range terminal forecast. Some benefits and aids have resulted, but no major breakthrough has been obtained. Someone has likened the short period to trying to catch small fish with a large mesh net. The forecast techniques have necessarily been based on synoptic scale observations, attempting to describe phenomena on a much smaller scale.

The Air Weather Service's 4th Weather Wing provided some verification data which is probably representative. Considering a very short-range forecast, a two-hour forecast, for 45 locations for the first 6 months of 1967, in which the objective was to forecast one of the three operational weather categories—corresponding to above-instrument conditions, instrument, and below minimum—the overall accuracy was approximately 94%; however, of the forecasts of a change in category, only approximately 40% verified; and of the changes in category which actually occurred, only 40% were forecast.

Some recent improvement in the Air Weather Service has been reported through the use of persistence-probability tables. These are complete climatological tables for the entire history of weather records at the base which show, for any time of day, for any month, the probability that a value of ceiling or visibility will raise, lower, or remain the same for any period up to 24 hours. The tables provide an additional tool for the

forecaster in evaluating the current local weather. Perhaps these procedures will be discussed in one of the sessions of this conference.

Despite the difficulties, progress in solving forecast problems will follow efforts to improve. I think we can take comfort from a couple of statements which were made in the history of our science, which in themselves were terrible forecasts, but which serve to emphasize that optimism is justified. As a first example, the noted French astronomer, Arago, wrote in 1845: "*Never*, no matter what may be the progress of science, will honest scientific men, who have a regard for their reputations, venture to predict the weather." More recently, in 1944, an article in one of the leading professional journals of our science, in discussing various forecast methods, viewed the prospects of numerical weather prediction as follows: "The physical method was employed by L. F. Richardson and when one looks through his monumental work, *Weather Prediction by Numerical Process*, adequate reasons are evident why no attempt has been made to repeat his performance. In brief, it may be *definitely* asserted that the purely physical approach to the problem of weather forecasting is *impracticable* and will remain thus for many years to come." Just a little over a year after these words appeared—in January 1946—we in Air Weather Service met with U. S. Weather Bureau and Navy representatives to discuss the possibility of weather forecasting by numerical process, using the computers being developed by industry and the Institute for Advanced Study at Princeton. Less than a decade after the article appeared, I pushed the button on the computer which inaugurated routine operational numerical forecasts.

The computer gave us a dramatic solution to the problem of predicting the future flow patterns of the atmosphere, but forecasting specific weather elements remains a very serious problem which the researcher and the forecaster must solve. Some of these specific forecast problems may not lend themselves to completely satisfactory solutions, but improvement is possible and should be pursued. I am confident this conference will contribute to that improvement.

Ladies and gentlemen, I hope I haven't placed you in the position in which one of our cadets found himself a few months ago. He was invited back to attend some ceremony at his old high school, and carried off his responsibilities very well. However, the main speaker chose to develop his address around the name of the school, Yuma. He began by saying, "The 'Y' in Yuma stands for Youth, the 'U' for understanding, the 'M' for mastery, and the 'A' for ambition, and I would like to discuss each of these terms briefly." Over two hours later, his speech finally ended. I saw this cadet later and I asked him about his trip home. He explained what had happened, and then in a somewhat pleading voice, said, "Sir, let's never ask that speaker to the *UNITED STATES AIR FORCE ACADEMY!*"