METHODS OF OBTAINING UPPER-AIR DATA[1]

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Meteorologists have long recognized the need for more complete information about the air currents and the atmospheric changes in the upper strata. A close network of observation stations on the ground makes possible a fairly accurate picture of air movement and weather changes at the surface, but what of the vast sea of air above and the developments that are taking place there? The study of clouds—their numerous forms and changes, their direction and velocity of movement, the kinds of precipitation produced by them—has brought about a partial understanding of the structure of the atmosphere above the surface and has supplied the weather forecaster with information of practical value, but this is far from sufficient if he is to understand fully the changes immediately in prospect both at the surface and in the regions above.

Comparatively little has heretofore been reported regarding the air temperature, the moisture content, and the air pressure at the various elevations. Actual observations have been made from time to time by one means or another as new kinds of apparatus have been developed and as funds have permitted, but only very recently have such observations been attempted on a scale large enough to be of much value in forecasting.

From the early beginnings of atmospheric research use has been made of weather observatories on mountain summits, and our knowledge of the upper air has been materially increased by their records. Such observatories, however, in the United States, at least, have usually been far apart and too few in number to furnish a survey of the upper air masses over any considerable area. They were, moreover, limited to comparatively small heights above the surface stations. Because of their inaccessibility, their heavy cost of upkeep, and their small value for practical forecast purposes, our Government has not deemed it wise to maintain the few mountain-top observatories established in the early days of the weather service. One of these was on Pike's Peak, Colorado, and another on Mount Washington, New Hampshire. It may be interesting to know that the Mount Washington observatory was restored about two years ago and is now being operated by the Massachusetts Institute of Technology.

Other methods of learning the secrets of the upper air have been followed, with splendid results. Important among these was the use of box kites. Usually several kites were attached to a single wire and to one of the kites was fastened a self-recording instrument known

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as a meteorograph. This consists of a revolving drum covered with a sheet of paper or tinfoil, on which delicate pens trace the records of the various weather elements. Many valuable records of temperature, humidity, atmospheric pressure, and wind velocity have been thus obtained, the kites enabling the instruments to remain aloft for hours at a time. These kites usually reached heights of two or three miles, and sometimes four. The Blue Hill Observatory, Harvard College, used kites for meteorological purposes as early as 1894, and in the year 1897 this institution began a series of observations which lasted for five years, the results being published in 1904. The Weather Bureau began the use of kites on a considerable scale in the year 1898, when a series of kite observations was made at 16 stations in the Mississippi and Ohio valleys. The campaign continued for six months and the results were published as Bulletin F of the Weather Bureau. The Weather Bureau later established aerological stations at several points over the country, at which kites were used regularly for many years.

The use of kites was dependent, of course, upon favorable weather conditions. All too often the wind was not sufficiently strong to lift the apparatus off the ground, and irregular records were the result. Occasionally in high winds the kites were blown away. On one such occasion two runaway kites were found 260 miles northeast of the aerological station at Ellendale, North Dakota. On another occasion seven kites, with 6 miles of wire, broke away from the aerological station at Royal Center, Indiana, and landed at a distance of 190 miles, north by east, from that station. Such long journeys were made possible by the stabilizing effect of the trailing wire. Within recent years this apparatus lost favor because of its hazard to airplane flying and because of the superiority of the airplane itself as a means of securing upper air observations. The last kite station of the Weather Bureau was closed in June, 1933.

The balloon has been and still is an important factor in upper air research. Doubtless the earliest adventures of man into the upper regions added materially to his knowledge of temperature, air movement, etc., above the surface, and periodically through the last half century much knowledge of the atmosphere has been gained by this means. However, it must be admitted that this is a crude, rather slow, and expensive method of studying the upper strata. The most serious and probably the most ambitious attempt to acquire first-hand information concerning the free air by ballooning was undertaken in the year 1924 by Dr. C. LeRoy Meisinger, of the U. S. Weather Bureau, and Lieut. James T. Neeley, of the U. S. Army. Dr. Meisinger had engaged in two such flights five years previously while stationed at Fort Omaha, Nebraska, as Signal Corps meteorologist. The 1924 flights were made from Scott Field, Belleville, Illinois. The plan was to make approximately 15 of these flights, the first to be undertaken about April 1. The purpose of the flights is given in the following words of Dr. Meisinger as published in the *Monthly Weather Review* of January, 1924:

> This series of free-balloon flights will be given over primarily to the determination of trajectories of air at levels above the earth's surface. A balloon maintaining a constant elevation will describe a path over the earth's surface which will constitute the best possible approximation to the trajectory of an air particle at that level. While it is clearly recognized that difficulties will be encountered in maintaining a constant elevation under all conditions, it is believed that results of a high order of accuracy may be obtained.

These two intrepid fliers successfully completed several of the flights planned and were well along on a flight around the center of a low pressure area, when lightning suddenly brought their noteworthy effort to a tragic close, both lives being lost in the crash. Theirs was a genuine contribution to the science of atmospheric research.

Before leaving the subject of manned balloon flights, mention must be made of the recent explorations into the stratosphere by heroes of the air in this and in foreign countries. Such flights have thrilled the entire world, and while they were not made primarily for meteorological purposes the gaining of knowledge of the atmosphere at great elevations and its influence on our surface weather constituted an important feature of the observations.

But manned balloons do not compare in importance with the smaller gas-filled rubber balloons that have been in use for many years by the Weather Bureau and that are being released by the thousands over this and other countries to secure upper-air data. Some of these balloons are attached to cords or wires and are known as captive balloons, the meteorographs being attached to them and the records brought back to the ground station. Other such balloons carrying meteorographs are released to travel where they will, and these have penetrated to enormous heights, at times as great as 15 miles, and have traveled long distances, occasionally across several states. These are known as sounding balloons. When one of these balloons finally bursts the meteorograph becomes the burden of an attendant parachute and usually floats to earth unharmed. A liberal reward secures the return of most of these valuable instruments to the points from which they were released. One instance is cited in which a sounding balloon meteorograph released from Montgomery, Ala., on December 31, 1927, was found near Athens, Ga., on February 28, 1929. After 14 months' exposure the smoked record sheet was found to be in good condition and indicated that the balloon had penetrated the stratosphere. The balloon observation made from Montgomery was one of a series undertaken that winter by the Weather Bureau from twelve selected stations, supplemented by kite flights at a number of other points and airplane flights at several Navy Department flying fields. A study of free-air convection was made at that time and favorable types of pressure distribution were awaited before the balloons were released. Two years later, or in the winter of 1929-30, another series of observations by sounding balloons was made, involving ten Weather Bureau stations. The Nashville station participated in both series.

Of the eight meteorographs released with sounding balloons at Nashville in the second series, four were found in Kentucky, one each in Tennessee, Virginia, and West Virginia, and one was not returned. The elevations reached by them ranged from five miles to eleven miles, and the lowest temperature recorded was —72° F. Considering this series over the entire country, a temperature of —94° F. was recorded by an instrument released from Vicksburg, and —102° by one from St. Louis. The highest elevation attained was fourteen miles. The temperature records in these flights showed the base of the stratosphere to vary considerably in height above sea level, the amount ranging from about five to about eight miles. Likewise there was a wide variation in temperance at the base in different parts of the country; but, with one or two exceptions, the records showed almost constant temperature from the base up to the highest points reached by the instruments. This constancy of temperature is characteristic of that region and has given rise to the term "isothermal layer," often employed in speaking of the stratosphere.

A smaller free-air balloon, known as the pilot balloon, to which no instrument is attached, has come into extensive use within recent years, particularly as an aid to aviation. Released at numerous points over the country at regular intervals, usually six hours apart, and followed by theodolite, with angular readings at one-minute intervals, their course is charted and the velocity and direction of air movement obtained at varying heights to considerable elevations. Data from these flights are immediately transmitted to the forecast centers. About eighty stations in the United States are using pilot balloons. A great mass of useful information about cloud heights and air currents is being obtained through this type of investigation.

A still further use of the balloon is being made to obtain ceilings for aviation purposes. In this case, a toy balloon of known rate of ascent is released and watched until it disappears in the cloud, and the time required in the ascent enables the observer to determine the elevation of the cloud base, otherwise known as the ceiling, which is an important part of an airway weather observation. At night the ceiling is determined by means of an apparatus that projects a spot of light onto the cloud base.

The increasing demand for accuracy in forecasting and for complete information in regard to the structure of the entire air masses has brought about a recent important advance in upper air research, made possible through the daily use of the airplane. For several years the Weather Bureau has used this means of obtaining a survey of the upper air at a few widely scattered points. The more extensive use of the airplane for this purpose came largely as a result of recommendations made by the Special Committee on the Weather Bureau of the Science Advisory Board, appointed by President Roosevelt in July, 1933. In its report the committee said:

During the last decade there has been very rapid progress in Europe in the development and general use of air-mass analysis methods. These require a knowledge of temperatures, humidities, and pressures aloft as well as on the surface, but thus far no systematic attempt has been made to obtain at a given time upper air measurements of these aerological conditions at a considerable number of stations scattered systematically throughout the country so as to make possible the drawing of a daily upper air map of the whole country similar to the surface maps now provided by the Weather Bureau. Hence, as a first step toward the general adoption of air-mass methods of weather analysis in the United States a network of aerological stations must be established at advantageous points throughout the country.

This recommendation of the committee was put into effect on July 1, this year, when daily airplane observations were begun at the following places: Billings, Mont.; Cheyenne, Wyo.; Fargo, N. Dak.; Nashville, Tenn.; Oklahoma City, Okla.; Omaha, Nebr.; Galveston, Tex.; San Antonio, Tex.; Spokane, Wash.; Montgomery, Ala.; Hempstead, L. I.; Belleville, Ill.; Detroit, Mich.; Dayton, Ohio; Pearl Harbor, Hawaii; Norfolk, Va.; Pensacola, Fla.; San Diego and Sunnyvale, Calif.; Seattle, Wash.; Washington, D. C.; Lakehurst, N. J.; and Philadelphia, Pa. Six of these are under contract with commercial airplane operators, eight are obtained by army pilots at the various army fields, and nine by navy pilots.

The pilot is required to begin the ascent about 5:00 a. m. (E. S. T.) (except near the Pacific coast, where the flights are made several hours later), but his flight is dependent upon favorable weather conditions. An effort is made to reach a height of 17,000 feet. In the case of the commercial pilot the full contract price is paid if he attains that height, but only partial payments for lesser heights. During the five months of airplane observations at the Sky Harbor airport, near Nashville, a flight has been made every day and the pilot has failed to reach the maximum height required only four times. It is hardly to be expected that this almost perfect record can be attained throughout the winter. The following incident is related to show the hazard connected with the work. On the morning of August 22 a dense ground fog developed while the pilot was in the air and his view of the field was completely shut off. As he returned for the landing his plane could be heard in the vicinity of the field. The two weather observers on duty, realizing the danger of the situation, undertook to direct the landing. One stood out of doors and called to the other, who was stationed at a telephone, informing him of the apparent position of the plane and its direction of movement with relation to the field. The observer at the telephone gave the information to the Department of Commerce radio operator at Donelson, twenty miles away, who in turn relayed it to the pilot. The result was that the plane was landed safely through the dense fog and the weather observation was transmitted at the usual time.

An airplane weather observation is made in the following manner: The aerometeorograph is attached to the plane in such way as to minimize the effect of vibration and in such location as not to be influenced by the heat from the engine or the cabin. "The rate of climb during the airplane's ascent must not exceed 1,500 feet for any five-minute period. The airplane must level off during the ascent for at least one minute at approximately 1,500 feet above the ground and at each approximate 3,000-foot interval thereafter; also at the maximum altitude reached in each flight. After reaching the maximum altitude the airplane is brought to the ground as rapidly as practicable, the descent portion of the record not being used. The entire flight is made as nearly as practicable directly over the airport from which the take-off is regularly made." At the same time that an automatic record is being made of the temperature, pressure, and humidity, the pilot is making notes of the types of clouds observed and their elevations, of fog, haze and smoke layers, of the various kinds of precipitation encountered, the formation of ice on the plane, of excessive turbulence, etc. After the completion of the flight the pilot must promptly submit a written statement of the various phenomena observed. The weather observer hastily interprets the entire record made, prepares a message in code, and transmits it to the several forecast centers in time to be used along with the numerous surface observations that are coming in at the same time.

A still further improvement in method is promised through Radiometeorography, or the transmission of signals from pilot or sounding balloons to a receiving station on the ground, these signals indicating the position of the balloon or the air characteristics being encountered, or both. A description of this method, yet in the experimental stage, appears in the July, 1934, issue of the *Monthly Weather Review.*

Thus, rapid progress is being made in upper air investigations, and the detailed up-to-the-minute observations now being obtained and those in prospect will inevitably lead to weather forecasts of greater accuracy and for longer periods than are now being made.

CORRECTIONS

Through some error, the January number of the *Journal* was printed on cover 1 as Volume IX, Number 1. This should have been Volume X, Number 1. Will every library and member of the Academy at once look up their January number and correct the number in ink? On the same cover of this same number of the *Journal*, J. H. Robertson was wrongly printed "J. R. Robertson." The group of photographs on page 5 (The Birds of Late Summer on Reelfoot Lake, by Compton Crook) was erroneously labeled *"Photographed by Jesse M. Shaver."* These photographs were the work of the author. This phrase, *"Photographed by Jesse M. Shaver,"* really belongs to figure 3 on page 7.