MONTHLY WEATHER REVIEW

Editor, ALFRED J. HENRY Assistant Editor, BURTON M. VARNEY

Vol. 53, No. 3
W. B. No. 864

MARCH, 1925

CLOSED MAY 2, 1925
ISSUED MAY 29, 1925

AN ACCOUNT AND ANALYSIS OF THE MEISINGER FREE-BALLOON FLIGHTS

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[Weather Bureau, Washington, March, 1925]

The main purpose of the flights made by the late Dr. C. LeRoy Meisinger can be best expressed by quoting from some of his correspondence on the subject, in which he proposed that the flights be undertaken by him for the Weather Bureau, in cooperation with the Army Air Service. The following is an extract from one of his memoranda:

> We now have at our disposal the machinery for making free-air pressure maps, and the one big problem in connection with them is to learn to interpret them. Can we have confidence in them in deriving the "life history" of free-air currents? The free balloon (manned) furnishes the only means of obtaining an observation upon the path of air moving in response to given pressure gradients. Except for convection induced by thermal inequalities, the air probably has but small vertical component even when being forced aloft by "wedges" of cold air.

It may be opportune here to say that this expedition was the consummation of an enterprise that Doctor Meisinger had advocated and repeatedly striven to undertake for a number of years. The inception of the idea in his mind may be said to date back to the post-war days of his service as lieutenant and meteorological officer in the balloon school of the Army Air Service at Fort Omaha, Nebr. On April 16–17, 1919, while at Fort Omaha, he took part as one of the pilots in a constant-altitude flight made with two balloons taking off at the same time, but flying at different altitudes. This flight was the first experiment at maintaining a balloon at constant altitude in which he participated, and proved very interesting to him from a meteorological standpoint. In his description and analysis of the flight, which appeared in the August, 1919, number of the MONTHLY WEATHER REVIEW, **47:** 535–538, he concludes with the following paragraph:

> It is obvious that the data obtained in a single attempt of this kind are too meager to be the foundation of any theoretical work. Nevertheless, a large number of such observations, where an attempt to maintain a constant elevation is strictly adhered to, would certainly contribute to our knowledge of the motion of air about centers of high and low pressure.

As a trained balloon pilot and keen meteorologist, it was natural that after his entry into the Weather Bureau he should have felt the urge to carry on the work suggested to him by his Army experience, as an important aid to meteorology. A further incentive to undertake these flights was his concern over problems connected with practical interpretation of his laborious work on upper-air pressure reduction, the results of which were published in his monograph on "The Preparation and Significance of Free-Air Pressure Maps for Central and Eastern United States" (MONTHLY WEATHER REVIEW SUPPLEMENT No. 21). As already quoted from him, he saw in the proposed flights a means to prove the trustworthiness of his upper-air pressure maps, and thereby to inspire confidence in their use. A comprehensive outline of the history, aims and purposes of the project, and program of work laid out for carrying it through, was given by Doctor Meisinger in an article that appeared in the MONTHLY WEATHER REVIEW for January, 1924, **52:** 27–29, under the caption, "The Balloon Project and What We Hope to Accomplish."

The flights, 10 in all, were made from Scott Field, near St. Louis, Mo., during the period from April 1 to June 2, 1924. In each flight the balloon was manned jointly by Doctor Meisinger and by Lieut. James T. Neely of the Army Air Service, who served in the capacity of co-pilot in all but the first flight. The choice of time for these flights arose from Doctor Meisinger's conviction that spring would be most propitious. In this connection he wrote: "But I am convinced that flights of 18 to 24 hours and even longer could be made at approximately constant elevations under conditions in which ordinary convection currents are not active, and such times are frequent in early spring."

It developed that the character of the weather in the spring of 1924 proved unfavorable for carrying out his project to the degree of fulfillment that he had hoped for. In many respects the weather maps had the characteristics of summer, i. e., ill-defined pressure systems, unsettled weather, thunderstorms, and considerable convectional activity at various times. There were therefore few conditions that were ideal for his purpose, while the very conditions he hoped to avoid in his choice of time of year for the flights were predominant. It is a tribute to his zeal and to the courage of both pilots that, having embarked on the project, it was carried through in spite of difficulties and repeated dangerous conditions.

Under the circumstances the project for the most part fell short of achieving the main results sought. From an interpretation of the logs and records it is apparent that in only a minority of the flights was anything approximating constant altitude for a considerable distance realized. Much of the value of the records was of course lost with his death, for with his competence and absorption in the subject, coupled with his experience in making the flights, he would have made certain interpretations of many features of the records, that are only a matter of conjecture to others. From a general appraisal of the work, it is apparent to the writer, that so far as it has been possible to compare the paths of the flights with appropriate upper-air isobars, the verification of the accuracy of the Meisinger upper-air pressure reduction method was accomplished.

Whether the flights justified Doctor Meisinger's faith in the free-balloon as a means of demonstrating free-air trajectories, is a matter that does not easily lend itself to an unqualified answer, principally because, under the generally unfavorable weather, the possibilities of free-ballooning to that end were not given a fair test. The delineation of upper-air trajectories is an extremely difficult thing to approach from any method of observation. In addition to the well-nigh insurmountable difficulty of maintaining a free-balloon at a constant altitude for any prolonged period, considerations of vertical component of air movement obviously enter into the problem. A possible underestimation of the factor of vertical movement by Doctor Meisinger is apparent in the paragraph from him already quoted that "except for convection

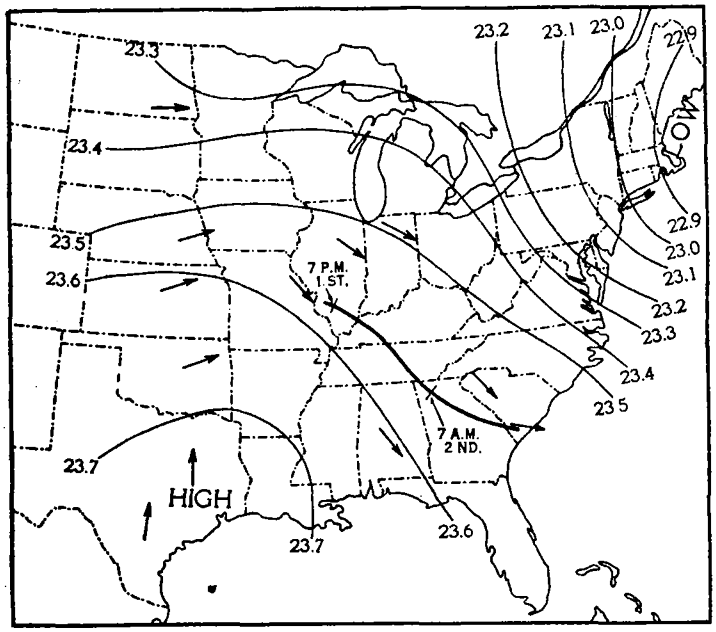

FIG. 1.—Pressure distribution and wind direction at 2 kilometers above sea level, 8 a. m., 75th meridian time, April 2, 1924. Balloon path in heavy line

induced by thermal inequalities the air probably has but small vertical component, etc." Whether or not he underestimated this phase of the problem depends of course on his conception of "small vertical component." However, an instance appears in the first flight, in which, if the conclusions of the writer are correct, the course of the balloon did not represent an air trajectory throughout its length, even though the balloon flew at an approximately constant altitude and closely followed the upper-air isobars. An analysis of this flight is given below, and this is followed in turn by a discussion of all the remaining flights in the order in which they were made.

First flight—April 1, 5:27 p. m., 90th meridian time, to April 2, 5:10 p. m., 75th meridian time. Landing, near Walterboro, S. C., 680 miles from starting point. The balloon's path is plotted on figures 1 and 2, which show the isobars at 2,000 meters, and the surface isotherms and sea level isobars, respectively, for 7 a. m., April 2. The 7 a. m. observation of the 2d has been selected as best representing the accompanying sea level and 2,000-meter pressure distribution, inasmuch as this time falls about midway of the flight, and the upper-air pressure reduction tables are based on the a. m. observations only. Arrows indicate wind directions at 2,000 meters, derived from pilot balloon observations taken on the morning of the 2d.

The close coincidence of the balloon path with the 2,000-meter isobars is at once apparent, although the balloon actually traveled at an altitude somewhat greater than 2,000 meters during a large portion of the time. Attention is next directed to the temperatures observed during the flight, a record of which appears in Table 1. The rise after 1:35 a. m. is noteworthy in view of its bearing on the problem of air trajectory. Possibly erroneous temperature readings might be assumed from the circumstance of approaching dawn and effect of sunlight on balloon and instrument. Temperature observations were made by means of a nickeled Assmann psychrometer suspended by a cord about 15 feet below the basket. However, the rise is already apparent in the readings at 1:35 a. m. and 4:20 a. m., by comparing them with interpolated readings at corresponding altitudes in the early part of the flight. Moreover, an original note appears on the meteorogram at 2 a. m. reading, "Temperature rise about 1.3° C," in explanation of a sudden short rise in the altitude of the balloon. (See fig. 3.) It should also be noted that the low temperatures recorded in the first few hours of the flight were likewise observed while the sun was above the horizon. It must therefore be concluded that at least the greater part of the observed rise in temperature was

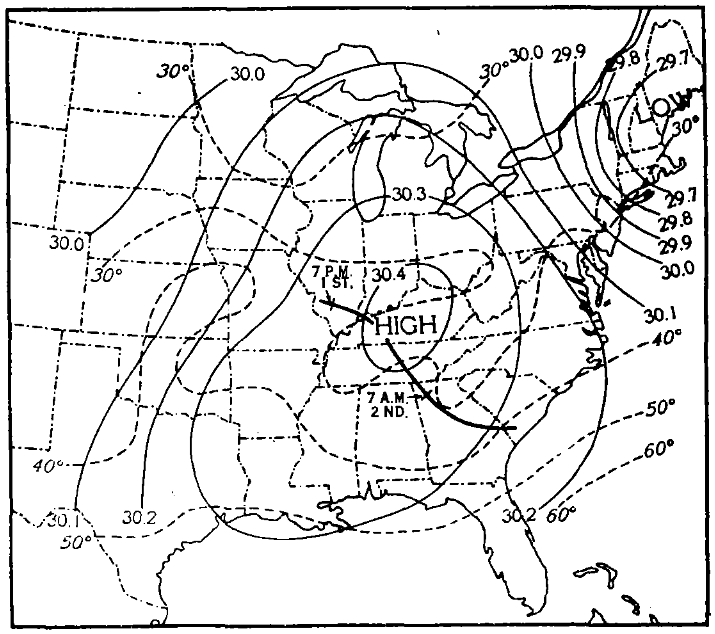

FIG. 2.—Pressure distribution at sea level and surface isotherms, 8 a. m., 75th meridian time, April 2, 1924. Balloon path in heavy line

real. This implies a state of stable equilibrium of the air, or a small lapse rate within the HIGH that was overlying the southeastern states on the morning of the 2d. By noting the displacement of the HIGH toward the west at 2,000 meters, as compared with its position on the surface map, it is apparent that comparatively low temperatures in the lower levels over the eastern states contributed largely toward determining the position of the HIGH on the surface, and that temperatures aloft over the southeastern states were probably not much lower than at the surface. It is evident then that a warmer region was encountered by the balloon at the altitudes in which it flew while passing from the Missouri Valley to South Carolina.

TABLE 1.—*Temperatures observed in the balloon flight of April 1–2, 1924*

Time, 90th meridian	Altitude		Temperature	
	Feet	Meters	°C.	°F.
Apr. 1				
5:27 p. m. (surface)	471	143	4.0	39.2
6:27 p. m.	2,000	610	−4.8	23.4
8:00 p. m.	4,000	1,219	−10.0	14.0
9:06 p. m.	6,000	1,829	−10.0	14.0
9:39 p. m.	7,100	2,164	−10.0	14.0
12:00 midnight	7,100	2,164	−10.0	14.0
Apr. 2				
1:35 a. m.	6,400	1,951	−8.7	16.3
4:20 a. m.	5,600	1,707	−6.5	20.3
5:27 a. m.	5,200	1,585	−4.3	24.3
6:25 a. m.	7,300	2,225	1.2	34.2
8:50 a. m.	8,700	2,652	3.4	38.1
11:47 a. m.	7,600	2,316	5.0	41.0
1:30 p. m.	6,000	1,829	10.0	50.0
4:10 p. m.	Sea level		[1] 15.0	59.0

[1] Interpolated from diurnal maximum temperature readings at Charleston and Savannah.

The air in which the balloon flew after leaving Scott Field evidently had a downward component. Further evidence of this appears in the record of the kite observation; while on April 1–2 the cold air aloft moved in a path that was more or less transverse to the isobars in the lower levels, and therefore undoubtedly had a downward component as it drifted southeastward.

Second flight.—April 11, 2:40 p. m., to April 12, 2:35 p. m., 90th meridian time. Landing, at Palmyra, Ontario, 470 miles from starting point. The flight was made at various altitudes ranging from a few hundred feet to about 4,500 feet, or an average of from 2,500 to 3,000 feet. The meteorogram shows that a constant altitude was maintained only in the comparatively short period from 2 a. m. to 5 a. m. on the 12th, when the balloon was kept at equilibrium very close to 2,100 feet. The path of the balloon was in the form of an arc, the drift being successively toward the NNE., NE., and ENE., at an average speed of about 18 miles per hour. The chief point of interest in this flight is that notwithstanding the staggered record of altitude shown by the meteorogram, the path of the balloon coincides very closely with the isobars drawn for the 1,000 meter pressures at 7 a. m., of the 12th, computed by the Meisinger method. This coincidence is all the more remarkable in view of the fact that, as in the flight of April 1–2 the upper-air map with which comparison is made represents the pressure distribution only for a moment about midway of the time elapsed during the flight, during which period the surface pressure underwent noticeable changes. The p. m. map of the 11th in particular shows a marked divergence of the sea-level isobars from those representing the 1,000 meter pressures at 7 a. m., on the 12th. This flight as well as that of April 1–2, seems to give evidence that a certain stability of upper-air pressure conditions, compared with changes on the ground, prevails during periods when surface pressure gradients are not very pronounced. The surface and 1,000-meter isobars at 7 a. m. of the 12th, together with the path of the balloon, are reproduced in figure 4.

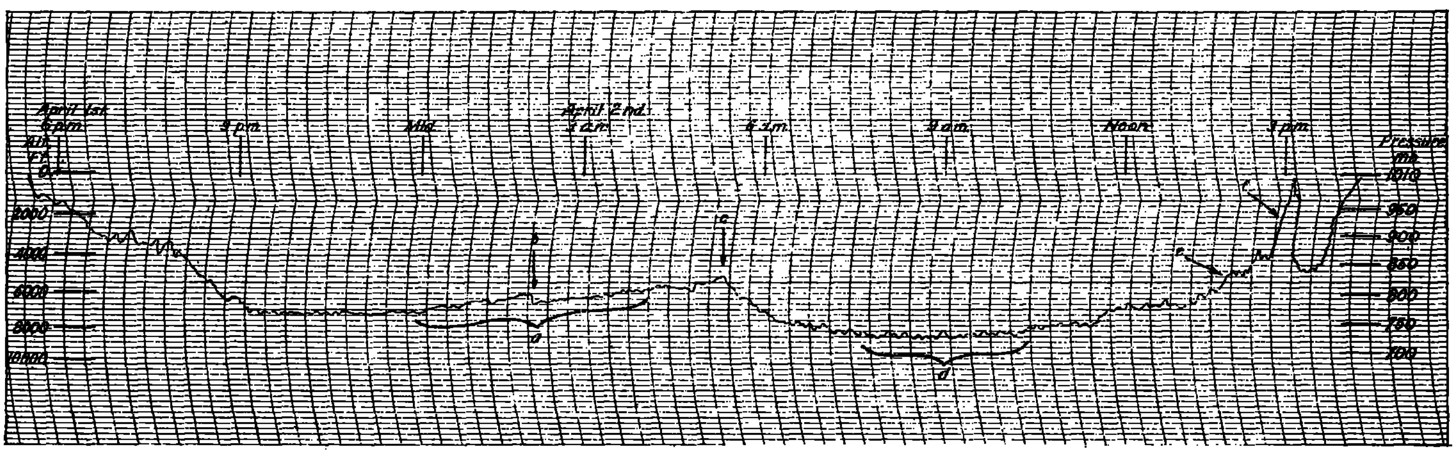

FIG. 3.—Meteorogram of balloon flight of April 1-2, 1924

NOTE.—Key to references to original notes appearing on meteorogram: *a* "Settling owing to nocturnal cooling (no ballast thrown)"; *b* "Temperature rise about 1.3° C."; *c* "Sunrise"; *d* "Equilibrium maintained without valving during day"; *e* "Estimated top of haze layer"; *f* Descent suddenly accelerated, apparently because of cooling after passing below top of haze layer."

tion at Due West on the 1st, which shows a falling temperature at 1,500 meters; also in note of the fact that the temperature over Scott Field, 14° F., at 4,000 meters on the 1st, was potentially very nearly the same as the surface temperature, 42° F., at Savannah at the a. m. observation of the 2d. The inference is strong that a representation of the trajectory of air aloft from Scott Field to South Carolina on the 1st–2d, would be a three-dimensional one, and therefore impossible of deduction from direct observation.

In this connection it may be noted that under certain conditions a mass of cold air aloft may be transported considerable distances southward without material increase in temperature resulting. As a matter of comparison, citation is made of the records of Due West on March 10, 1924 (see Free-Air Summary, MONTHLY WEATHER REVIEW, March, 1924, **52:** 173), wherein such a transport of cold air over a long north-south route is shown. The difference is to be found in the fact that on March 10 cold air simply displaced the warmer air in front of it to a considerable height above the ground in the rear of an intense LOW, where presumably the same configuration of isobars prevailed within the vertical limits of observation.

Third flight.—April 18, 7:35 p. m. to April 19, 5:50 a. m., 90th meridian time. Landing, at Lebanon, Tenn. In a few hours' steady rise after the take-off, an altitude of about 8,000 feet was attained, at which point it was discovered that the balloon was leaking. Descent was then made to 1,500 feet and effort made to maintain that altitude for the remaining few hours of the flight. Owing to the nature of the record, due to the behavior of the balloon, it has not been thought of sufficient value for further discussion.

Fourth flight.—April 23, 5 p. m., to April 24, 2:50 p. m., 90th meridian time. Landing made at Navarino, Wis., 426 miles from starting point. A brief account of this flight is given in the MONTHLY WEATHER REVIEW for April, 1924, **52**:214–216, in connection with a description of the National Balloon Race from San Antonio, Tex. During that portion of the flight extending in an arc from Scott Field to the point on Lake Michigan where, at about 8 a. m., the balloon turned to the west, a fairly constant altitude averaging 1,600 feet above ground was maintained, after which variable winds with

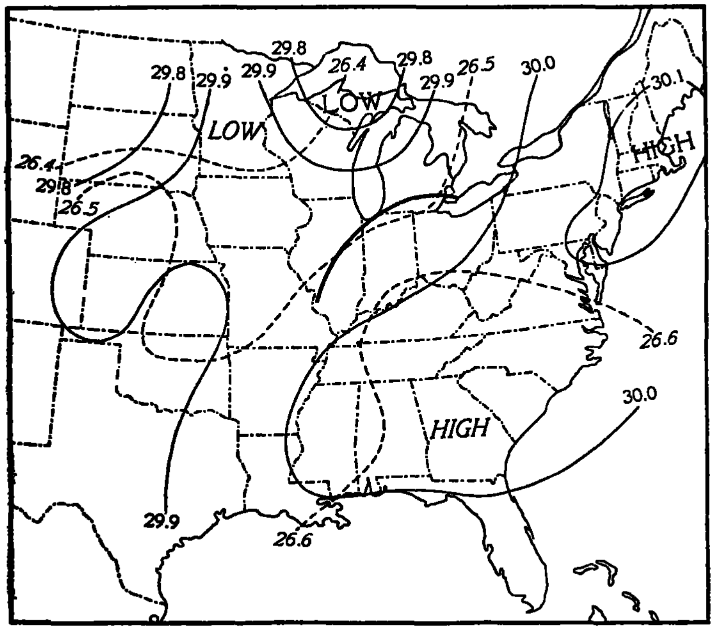

FIG. 4.—Pressure distribution at sea level and 1 kilometer above sea level, 8 a. m., 75th meridian time, April 12, 1924. Solid lines are sea level isobars; dashed lines are 1 kilometer isobars; and heavy line balloon path

threatening weather were encountered, and to maintain a constant altitude was no longer possible. This moderate altitude is that at which ordinarily "gradient winds" occur—i. e., winds paralleling the surface isobars. However, the first part of the arc shows a well-defined outflow from the HIGH situated to the east, and the latter portion a pronounced inflow toward a northern extension or reinforcement of the HIGH, where surface temperatures were lower. While pilot-balloon observations showed the same arrangement of wind directions, the free-balloon flight proves as an actual trajectory what the pilot-balloon observations show merely as an instantaneous line of flow. A further verification of this trajectory is given in the record of temperatures, which shows a quite constant temperature of about 15° C. throughout the constant altitude portion of the flight where the balloon was traveling northward. A later record of temperature made at about the same altitude, when the balloon was traveling westward, showed a much lower reading, indicating that at the point along Green Bay where the balloon was compelled to make an abrupt change in its altitude and course the trajectory changed to one having a pronounced ascending component. Figures 5 and 6 show in detail the path of the balloon and the surrounding sea level pressure for 7 p. m., 23d, and 7 a. m., 24th, respectively, the path of the balloon being reproduced on both charts. The 1,000-meter pressure map for 7 a. m., 24th (not reproduced), shows a close correspondence with the surface isobars at the same time.

Fifth flight.—April 29, 3 to 10 p. m., 90th meridian time. Landing, at Hartsburg, Mo., 130 miles nearly due west of starting point. A LOW was centered over Arkansas, and when the balloon took off, the surface wind was southwest at Scott Field and northeast at Columbia, Mo., 1[illegible]0 miles to the west. The flight was therefore made close to—and apparently ended directly at—the wind-shift line. A constant altitude of about 4,700 feet was maintained from 4 p. m. to 8 p. m. in an east-southeast wind. Owing to cloudy weather and precipitation, making the locating of the balloon's position difficult to the pilots, the course of the last two hours of the flight is uncertain, except that it is clearly evident that the descent from 9 to 10 p. m. was made in a northerly wind.

As the LOW was vigorous and moving, and as the flight was of short duration and length and near the time of the p. m. observation, it is obvious that no

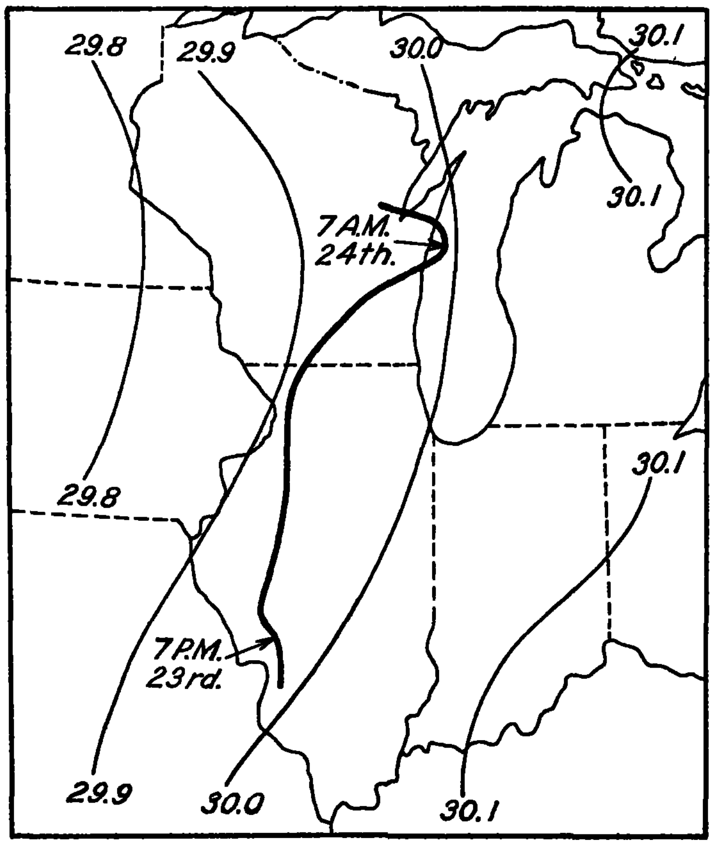

FIG. 5.—Pressure distribution at sea level, 8 p. m., 75th meridian time, April 23, 1924. Balloon path in heavy line

useful comparison is possible with upper-air maps, inasmuch as they apply to a. m. observations only. Interest in this flight is centered in the records of weather, temperature, and wind direction, and comparison of them with corresponding surface weather elements and changes therein. Making allowance for possible inaccuracy in outlining the path of the balloon, it is apparent from Figure 7 that the course lay either along the direction of the sea-level isobars, or deviated somewhat from them in the direction of higher pressure. General precipitation attended the LOW, and rain and snow were encountered at intervals during the flight, the snow being observed in the occasional short ascents into higher altitudes where near-freezing temperatures prevailed. Rain became increasingly frequent as the balloon progressed westward, until at the western terminus of the flight steady rain compelled the decision to descend.

The temperature recorded was generally about 6° C. at the constant altitude of 4,700 feet, which compared with 13.3° C. on the ground at St. Louis at 7 p. m., shows

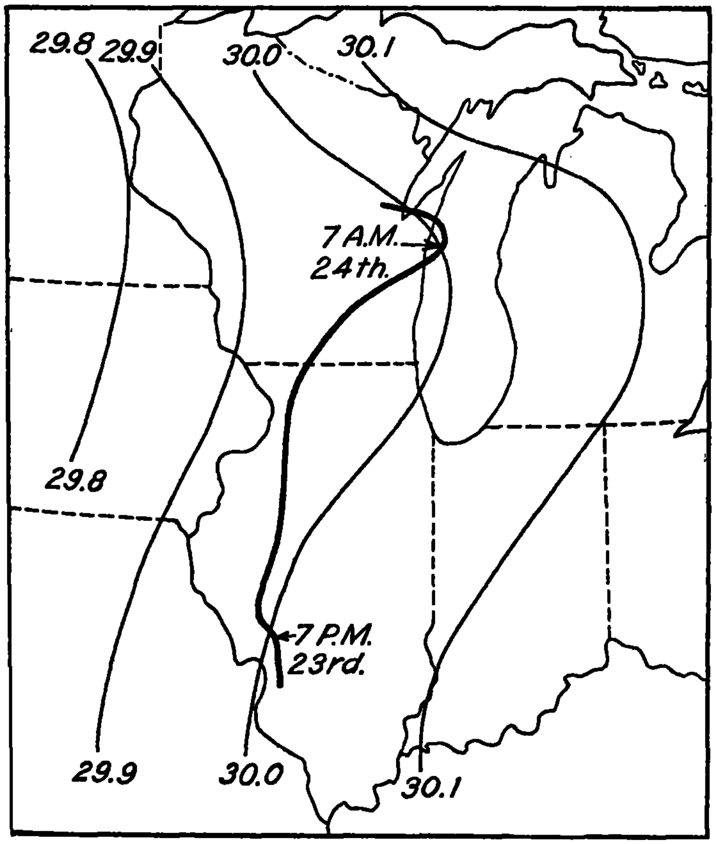

FIG. 6.—Pressure distribution at sea level, 8 a. m., 75th meridian time, April 24, 1924. Balloon path in heavy line

a lapse rate practically equal to the moist adiabatic for the given temperatures. This evidently represents the state of the air over that part of Missouri traversed by the balloon up to the time the wind shift occurred. From the fact that the surface wind became northerly at Columbia at 9 a. m., and at St. Louis soon after 8 p. m., it is clear that the last portion of the flight was made in an easterly wind underrun by one of increasing depth from a northerly direction, to which circumstance the precipitation in this portion of the LOW may be ascribed. The horizontal trajectory of air toward the west-northwest, represented by the constant altitude portion of the flight, unquestionably underwent a radical change at the point where the balloon was compelled to descend. It seems an inevitable conclusion that to whatever horizontal direction the trajectory continued, a strong vertical component applied.

Sixth flight.—May 7, 5 p. m., to May 8, 2 a. m., 90th meridian time. Landing made at Henderson, Ky., 140 miles to the east-southeast of starting point. The meteorogram shows that in a gradual ascent of two hours an altitude of about 7,000 feet was attained, which with some variations of a few hundred feet, was maintained for about three hours. Following this brief period at constant altitude, the records show a more or less irregular descent lasting four hours. The flight was made in the rear of a low-pressure area that covered most of the eastern half of the country and caused general precipitation within its confines. As in the flight immediately preceding this one, rain and snow, tending to become continuous, compelled the descent. As nearly as can be ascertained from the log, the balloon drifted in a direction that varied from northwest-southeast in the lower levels to approximately west-east at the 7,000-foot altitude, the speed being somewhat greater aloft than near the ground. The nearest maps in point of time and altitude to which this flight can be referred are the sea level and 2,000-meter maps for 7 p. m., May 7, and 7 a. m., May 8, respectively. These show close agreement between the isobars and the path of the balloon at corresponding altitudes. Owing to the short distance (60 to 70 miles) at which a constant altitude was possible, neither the path of the balloon nor the maps applicable to it are reproduced.

The value of this flight, apart from what can be derived bearing on the main purpose of the project, lies in the somewhat unique upper-air data it furnishes. It represents an observation that, under similar conditions

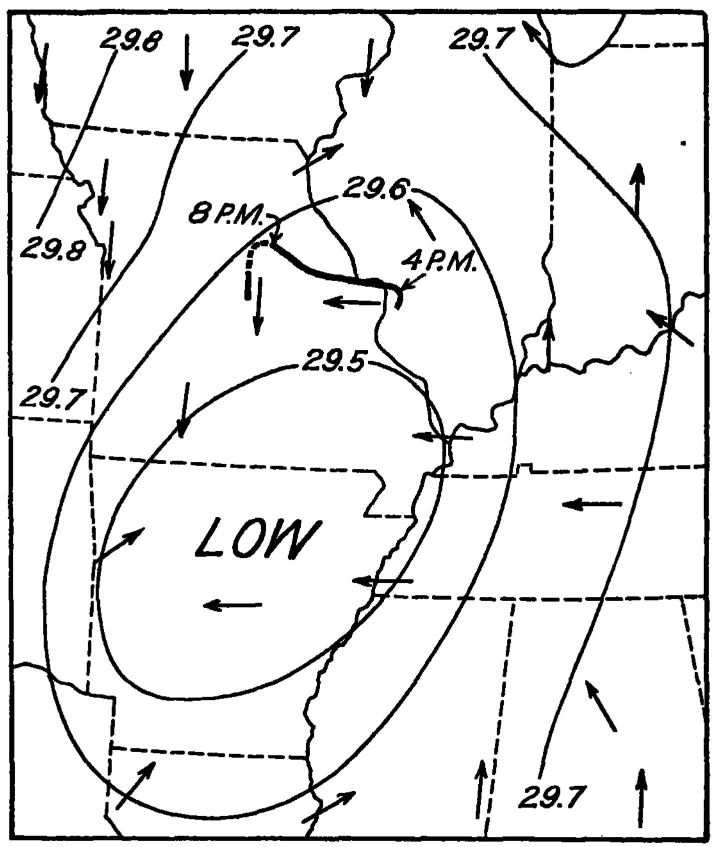

FIG. 7.—Pressure distribution at sea level and surface winds, 8 p. m., 75th meridian time, April 29, 1924. Balloon path in heavy line

of weather can not be wholly duplicated by ordinary methods of aerology, due to the limitations of kite and pilot-balloon observations during the prevalence of precipitation. An examination of the log shows that the balloon was repeatedly in and out of cloud banks that were encountered in various strata from about 2,500 feet altitude to as high as 8,000 feet. A rather complete record of temperature was taken during the ascent, and at frequent intervals while drifting at high altitude, the main features of which appear to be a continuous fall in temperature with height. The reading of temperatures was terminated with loss of the recording instrument shortly before descent was begun.

The temperature at 7,000 feet at 7 p. m. was definitely 1.0° C., as it was substantiated by repeating readings at about the same altitude. At this time the balloon was only a short distance from Scott Field; therefore referring this reading to the simultaneous temperature at St. Louis, 14.4° C., a lapse rate more than the saturated adiabatic, and consequently active convection, is indicated. There is available for comparison a diurnal series of kite flights at Broken Arrow, 400 miles to the southwest, made on the 7th–8th. These observations show a gradually-increasing lapse rate on the 7th, due to falling temperature aloft in a northwesterly wind, until at 7 p. m. the temperature in a vertical direction was very nearly the same as that recorded by the balloon in the same range of altitude. The fall in temperature over Broken Arrow was attended by rising humidity, but not to any degree approaching saturation as was the case over the region near St. Louis. From the records of the sequence of events over Ellendale, Drexel, and Broken Arrow on the 6th–8th, and at the surface at St. Louis and contiguous territory on the 7th–8th, it is plausible that the temperature over the latter region underwent the same changes as noted over Broken Arrow on the 7th. In lieu of more detailed discussion, the observation is made that the similarity of records made at Broken Arrow and in the balloon, suggests an explanation of the lack of precipitation on the one hand and its occurrence on the other, over the respective regions. The key to the situation appears to be the relative amounts of moisture present and the distribution of pressure, as in the vicinity of St. Louis the pressure was lower and the humidity higher than at Broken Arrow.

Seventh flight.—May 15, 1:30 p. m. to 2:45 p. m., 90th meridian time. Owing to threatening weather and proximity of thunderstorms it was found necessary to descend almost immediately after having risen to 3,400 feet. Landing was made 25 miles to the southeast, a little over an hour after taking off, giving a record too brief to merit any discussion.

Eighth flight.—May 16, 5:35 p. m. to May 17, 7:05 a. m., 90th meridian time. Landing near Carey, Ohio, 390 miles east-northeast of starting point. The meteorogram shows a rapid ascent to about 7,000 feet in the first two hours following take-off, after which there is an undulatory record of gradually diminishing ordinate to the end, indicating a slow descent through a series of rises and falls. Owing to the serrated nature of the meteorogram record, and the fact that the log was lost overboard shortly before landing, and only the last five hours of it recovered (no other diary of the flight was found in Doctor Meisinger's effects), it has not been found possible to make any satisfactory comparison with accompanying weather conditions, nor to plot the entire course of the balloon with any precision.

The irregular nature of the altitude record can most plausibly be explained as due to difficulty in control of the balloon, possibly on account of a leak in the fabric, although no comment on the condition of the balloon appears in the log. In this connection, however, reference is made to an apparently similar situation in the early part of the next flight, in which note is made in the log that behavior of the balloon compelled descent to a lower altitude.

The flight was made in the region between a high pressure area over the southeastern States and a LOW centered in Ontario. By plotting the path of the balloon from the salvaged portion of the log, and assuming a straight line flight thence from starting point, it is apparent that the balloon flew in a moderate west wind at high altitudes in the evening and night of the 16th, and in very strong southwest winds at low altitudes in the morning hours of the 17th. This is in agreement with pilot-balloon observations, which, furthermore, show that the upper-air winds, particularly in the lower levels, increased in force from the 16th to 17th in connection with falling pressure and increasing pressure gradient over the zone of flight. The only dependable conclusion to be arrived at from this flight is that it supports the evidence given by the pilot-balloon observations, to the effect that there was an outflow from the LOW in the upper altitudes, a flow parallel to the surface isobars at lower levels, and an inflow near the ground.

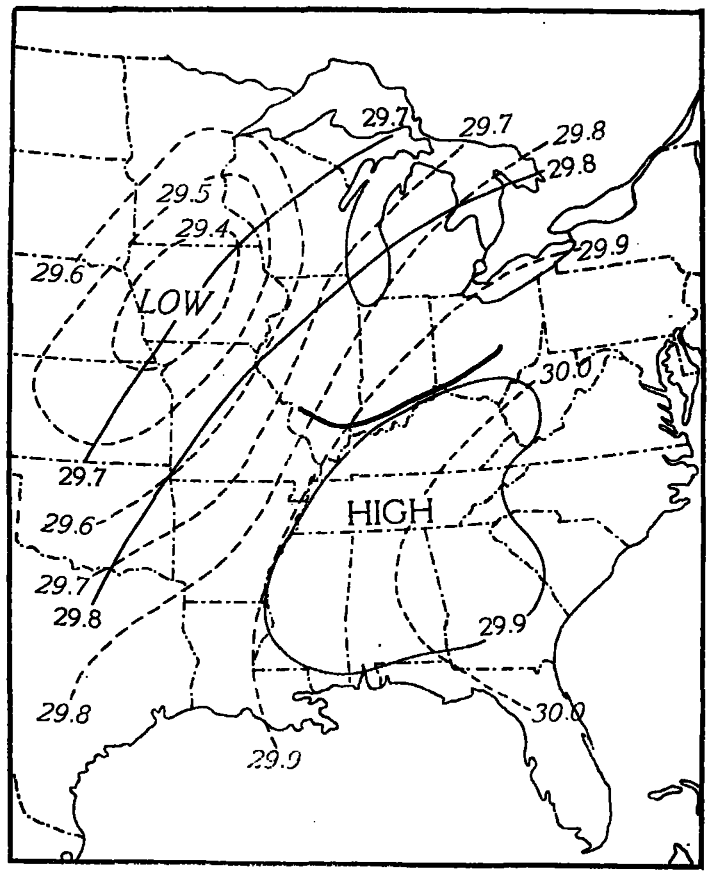

FIG. 8.—Pressure distribution at sea level, 8 p. m., 75th meridian time, May 22, 1924, and 8 a. m., 75th meridian time, May 23, 1924. Solid lines, p. m., 22d; dashed lines, a. m., 23d. Balloon path in heavy line.

Ninth flight.—May 22, 3:14 p. m., to May 23, 9:21 a. m., 90th meridian time. Landing, at Roseville, Ohio, 410 miles east-northeast of starting point. An altitude of about 6,000 feet was attained in a steady ascent from take-off, but was abandoned a few hours later for reason given in the following excerpt from the log: "Balloon behaving as it has before, so we conclude to come low and try for equilibrium." Descent was made at 8:30 p. m., and thereafter for the remainder of the flight an approximately constant altitude of about 1,300 feet was maintained. Threatening weather was encountered in the first few hours of the flight, notes of showers about and in the vicinity of the balloon and thunder in the distance being occasionally entered in the log. The balloon outran this threatening weather by nightfall, as no further entries of that nature appear in the log after late afternoon.

The balloon took a course about east-southeast in the short distance it traveled at a high altitude during the early part of the flight; and thereafter, at the low altitude in which the flight was completed, the course was about east-northeast, approximately conforming to the isobars in the rear of a HIGH that overlay the southeastern States. Figure 8 shows the sea-level isobaric lines at 7 p. m., 22d, and 7 a. m., 23d, and the path of the balloon. On account of the low altitude at which the balloon flew from about Evansville, Ind., to the landing place, this portion of the flight is directly comparable with the pressure gradients and changes therein at the surface. The comparison shows that the direction of flight changed to conform with the changing configuration of the isobars; also that the balloon moved from a region of falling pressure to one where the pressure was rising, as is shown in the following record of sea-level pressures near the beginning and end of the flight: 7 p. m., 22d, St. Louis 29.82, Roseville, Ohio, 29.84; 7. a. m., 23d, St. Louis 29.70, Roseville, Ohio, 29.96.

The evidence of this and the preceding flight is that at those levels near the ground where winds indicated by the surface pressure gradients are fully expressed, the trajectory of air particles is defined by the trend of the surface isobars, irrespective of changes in pressure, such changes in pressure by corollary being imposed by changes aloft. It may seem that this conclusion must be qualified as not having universal application, after considering some case, as, for example, the flight of April 23–24, in which the course of the balloon showed an outflow from the rear of a HIGH, changing later to an inflow. The matter hinges largely on horizontal and vertical temperature gradients, and therefore the flight of April 23–24 probably does not invalidate the conclusions derived from this one, inasmuch as in the former flight the balloon was approaching a region of great diversity of temperature within narrow limits in all directions.

Tenth flight.—June 2, 4:10 p. m. to about 11 p. m. 90th meridian time. This flight was made in the southeast portion of a rather ill-defined area of low pressure, centered near the upper Mississippi Valley. (See fig. 9.) The trajectory of the flight determined from the log shows a somewhat irregular course toward the north and northeast, but averaging about north-northeast, as shown by a line drawn from Scott Field to Monticello, Ill., 125 miles distant, near which town the balloon fell. The course was apparently directed more toward the east in the higher altitudes, in agreement with pilot-balloon observations made a few hours earlier. The balloon did not adhere to any certain altitude for more than a few minutes at a time, as the meteorogram shows that it rose and fell in a series of ascents to sucessively higher altitudes. (See fig. 10.) In each case the descent was made to almost exactly 600 feet above ground. This procedure in manipulating the balloon can hardly be attributed to threatening weather conditions on the assumption that each descent was made as a precaution against recurrent dangerous conditions. The only mention found in the log of threatening or dangerous weather is at 9:10 p. m., where the following entry appears: "Occasional lightning flashes in distance." That this observation gave the pilots no concern as to its possible portent is indicated by the fact that immediately following this entry, which was made at low altitude, the balloon was allowed to rise again to a high altitude.

The regularity with which a certain altitude was reached on each descent suggests that the balloon was under control at all times until the end, and that the

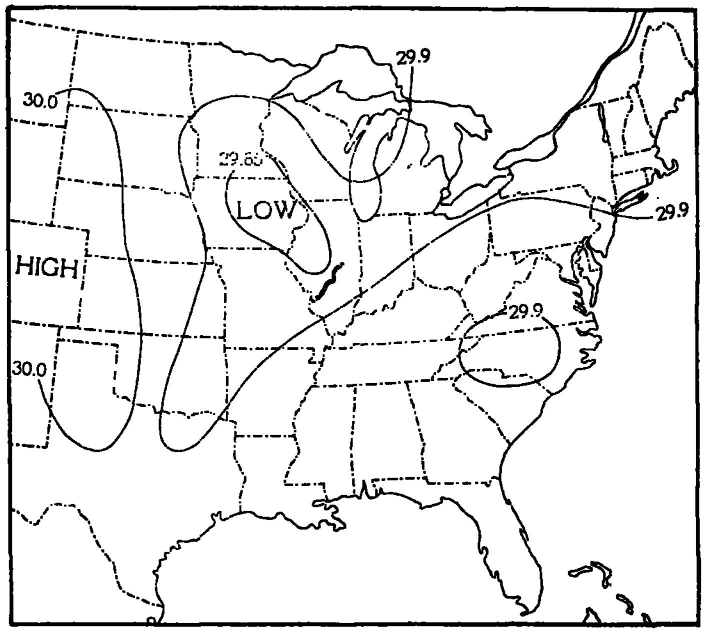

FIG. 9.—Pressure distribution at sea level, 8 p. m., 75th meridian time, June 2, 1924. Balloon path in heavy line

alternate ascents and descents were probably deliberately made with a purpose in mind. A clue to what this purpose might have been is given in the following extract from the writings of Doctor Meisinger, already referred to:

> Flights at varying elevations: * * * to begin a flight in the southerly current in front of a cyclone, proceed northward in it until one is above the easterly surface wind, and allow the balloon alternately to ascend and descend through the cloud layer from one stream to the other. By coming below the cloud layer for, say, a half hour, one could pick up his location, then ascend through the cloud and remain above it for another half hour, after which another descent could be made, position obtained, indefinitely so long as the ballast and gas permitted. This would give the direction of both streams.

Opposed to this idea of purposeful manipulation of the altitude of the balloon, is the fact that no altitude was maintained long enough to determine the direction of stream flow. It is therefore possible after all that the peculiar record of altitude was due to difficulty in controlling the balloon, as was inferred to be the case in the previous two flights. Intimation of such difficulty of control is conveyed by the frequent entries of ballast released while the balloon was descending, of which an instance is shown in the excerpted last four lines of the log given below.

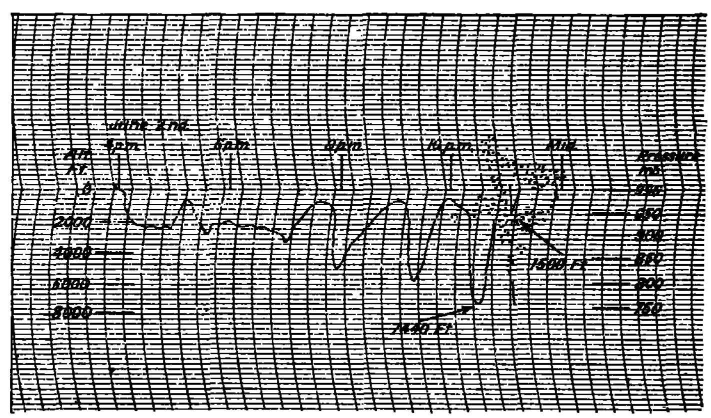

FIG. 10.—Meteorogram of balloon flight of June 2, 1924

At the time the balloon took off, weather was unsettled and threatening over a considerable area surrounding Scott Field, especially to the northwest. A fairly well-defined but somewhat distorted wind-shift line extending from Oklahoma to the Upper Lakes and passing to the west and northwest of Scott Field, appears on the p. m. map of June 2. By 7 a. m. June 3 the wind-shift line had advanced southeastward, and rains with scattered thunderstorms were reported from a large portion of the region east of the Mississippi River. It seems probable that the advance of the wind-shift line over the path of flight of the balloon was responsible for the development of weather conditions that caused the destruction of the balloon. In this connection the wind record over central Illinois in the late hours of June 2 is significant, inasmuch as the time of wind shift shown by the anemographs is very close to the approximate time of the disaster. At Peoria, 66 miles northwest of Monticello, the wind shifted abruptly from south to northwest at 10:15 p. m. At Springfield, 55 miles to the west-southwest of Monticello, the wind shifted abruptly from southwest to west at 10:47 p. m.; while at St. Louis, 125 miles to the south-southwest the wind remained south from 9:25 p. m. to midnight, after which it became southwest, and later northwest.

Conditions probably did not appear dangerous to the pilots until after the last entry in the log, which was made at 10:48 p. m., when the balloon had reached the highest point of any ascent, and just before it began the rapid descent that was soon to be followed by the death of both pilots. The first mention in the log of the balloon being in clouds appeared at 9:40 p. m., which probably marks the beginning of development of threatening weather in the vicinity of the balloon. The following is a copy of the entries in the last four lines of the log:

Time (p. m.)	Altitude (feet)	Ballast (bags)	Temperature (°F.)	Remarks
9:40	5,900	1	....	Over Macon. In cloud. WOAW.
9:50	3,000	1	....	5 mi. S. Decatur.
10:18	1,400	1	....	KSD weather bulletin rec'd.
10:48	[1] 7,000	1	36	Taking altitude to try to go eastward and avoid LOW.

[1] 7,440 corrected.

The conditions surrounding the line of flight favored the formation of instability showers and thunderstorms. This is indicated both by the temperature record of the balloon and the aerological observations at Royal Center, Ind., about 200 miles away. As the balloon record of temperature agrees quite well with that observed at Royal Center a few hours earlier, the Royal Center aerological record, being more complete, is reproduced, and appears in Table 2. It will be noted that there was a practically dry adiabatic lapse rate from the ground to 2,000 meters, with 100 per cent humidity near the top of the record. The evidence all points to an unstable condition along the path of the balloon, which in connection with the proximity of the wind-shift line, made the position of the balloon a precarious one.

TABLE 2.—*Free-air conditions at Royal Center, Ind., on June 2, 1924*

Time (p. m.)	Altitude, M. S. L. (meters)	Temperature (°C.)	Relative humidity (per cent)	Wind direction	Wind velocity (m. p. s.)
2:09 (surface)	225	21.0	56	sw	3.1
2:15	494	18.0	58	wsw	6.2
3:36	1,370	8.4	100	sw	5.8
4:41	2,045	3.1	100	sw	7.5
5:00	1,464	5.0	73	sw	6.5
5:12	664	12.2	56	sw	8.5
5:19 (surface)	225	20.0	57	sw	2.7

The meteorogram shows a rapid drop taking 12 minutes from the last high point reached at 7,440 feet down to an altitude of 1,700 feet. Below this point the record is blurred, but descent for the remainder of the distance to the ground was probably at the same or even greater rate of speed. After a short interval, corresponding to about 12 minutes on the meteorogram, but undoubtedly due in part at least to jarring of tle instrument caused by landing of the basket, the record shows a rapid rise from the ground to 1,500 feet, followed immediately by an equally or more rapid fall. The total duration of this last ascent and descent was about six or seven minutes.

The descent from 7,440 feet, at about 10:50 p. m., while much more rapid than any of the previous descents, was still apparently too slow to indicate that any accident had befallen the pilots. It is probable that on account of suddenly developing threatening weather, a quick descent was decided upon, and that the last part of the descent was so hastened by valving that a bumpy landing was made. Ascent was again begun, evidently by intention, and when an altitude of 1,500 feet was reached the balloon became ignited, causing its destruction with tragic consequences.

The cause of ignition of the balloon was undoubtedly either a direct stroke of lightning, or a spark, probably from the radio antenna, occurring simultaneously with a discharge of lightning. An example of the severity of the charge possible on the radio antenna during threatening weather is given in the following extract from a letter by Doctor Meisinger referring to the last portion of the flight of April 23–24, when flying close to thunderstorms:

> The bulletin the next day (April 24) at 11 a. m., was not listened to, owing to heavy static which not only prevented our hearing more than WOC's time signals but also caused such violent sparking about the radio set as to cause us to reel in the trailing antenna and attach it to the counterpoise, which operation was not accomplished without the reception of violent shocks by Lieutenant Neely.

Another possible source of danger in free ballooning during thunderstorms is mentioned by Mr. Ralph Upson, the noted aeronaut. From the July 1, 1924 number of the National Aeronautic Association Review, the following paragraph from an article by Mr. Upson is quoted:

> During the past few months it has been brought out by authorities on electrostatics that a discharge of gas or ballast from a free balloon in flight seems to break down the dielectric of the air, and provide a path for a charge to pass from cloud to cloud, or to a lesser extent from cloud to ground.

From the testimony of persons living in the vicinity of the place where the disaster occurred, it has been ascertained that the balloon caught fire simultaneously with or soon after the occurrence of a crash of lightning. It is therefore very probable that the balloon was struck directly by a stroke of lightning. Other evidence, such as condition and position of the wreckage and bodies of the pilots, leads strongly to the belief that Doctor Meisinger was instantly killed when the balloon was ignited, and that Lieutenant Neely met his death in the attempt to save himself by parachuting.

CONCLUSIONS

1. The flights of this series add to the testimony of ordinary aerological observations to the effect that free-air pressure maps according to the Meisinger system can always be relied on as being at least approximately correct. The qualification implied by saying "approximately" refers to the crudities inherent in a system based, as it is, on the comparatively meager records of aero-

logical observations available. Now that the long-sought foundation for a reliable system of pressure reduction is laid out, further developments in aerological work and the establishment of truer free-air normals, hold out hopes of future refinements in the system to the point of unreserved acceptance of the results.

2. As brought out in the text of this paper, there are a number of difficulties in the way of representing free-air trajectories by means of the free balloon, or of accepting such representation as valid. The chief of these are the difficulties, in practice, of maintaining constant altitude and determining the location of the balloon, and considerations of vertical component of air movement. The question as to whether further practice of free ballooning might lead to closer approximation to the facts on this particular point, vies with the question as to whether the additional knowledge gained would justify the effort and expense involved.

3. Referring to the general problem of free-ballooning with relation to meteorology, there can be no question as to the reciprocal benefits of one to the other; in fact, the very dependence of ballooning on meteorology compels the belief that meteorology can not help but add to its fund of knowledge from a pursuit to which it is indispensable. There are a number of problems in meteorology peculiarly adaptable to free balloon investigation, some of sufficient importance to make this means of attempt at solution well worth the effort. Suggestions of such problems, that incidentally were accessorial reasons for Meisinger's flights, are contained in the text of this paper, as, for example, in the fifth and sixth flights.

Any program of free-ballooning for meteorological purposes must necessarily contemplate flights in unsettled weather, rains, and snows, as well as in fair weather. To pronounce against flights in any but fair weather would go a long way toward admitting the futility of aeronautics. The great danger lies, of course, in thunderstorms. The tragic denouement of this project, following so soon after the toll of lives exacted by the conditions during the National and International Balloon races of 1923, emphasizes the menace of thunderstorms to inflammably charged balloons. It is a matter of record that in all instances in recent years of disasters to manned balloons attributable to thunderstorms the voyagers were aware beforehand of the risks they were facing. It is sufficient testimonial to the aid rendered by meteorology in this field that it can warn of danger even though it can not prophesy disaster. Safety in free-ballooning will be realized when precaution is no longer made subordinate to loyalty to purpose and when it is conceded that "safety first" is as applicable and justifiable in this line of scientific work as in any other peacetime endeavor.

ON THE MEAN VARIABILITY IN RANDOM SERIES[1]

By EDGAR W. WOOLARD

[U. S. Weather Bureau, Washington, D. C., March 27, 1925]

The human mind is so constituted that, when confronted by an extensive array of numerical data, it is incapable of adequately grasping the significance of the figures or of detecting and comprehending the relations and laws exhibited by the data. To overcome this defect, special methods, known as statistical, have been devised for the scientific treatment of collections of data pertaining to mass phenomena. Statistics accomplishes its object by displaying data in forms such that their significance can be more readily grasped, and by inventing special analytical processes designed to reveal the laws and relations concealed in the figures.

One common statistical procedure for rendering data amenable to our mental faculties is that of replacing the original large body of raw numerical material by a very small and compact set of summary coefficients which concisely, yet adequately and comprehensively, resume in themselves all the essential features of the complete data. Of course such a replacement is necessarily made at the expense of detail—no summary can, by virtue of its very nature, contain *all* the facts—but the effort is made to retain in the summary all the facts and features *essential or relevant to the purposes in hand.*

An extensive body of numerical data may thus be succinctly described or characterized by, and, at least for many purposes of statistical analysis, may be replaced by, a brief set of statistical coefficients or indices, one coefficient for each of the important and relevant features of the data. The comparative analysis of two different sets of data, and of the respective phenomena to which they pertain, in respect to each of their essential characteristics, then becomes largely a matter of the comparison of corresponding statistical indices; two different phenomena may be identical in that aspect characterized by the arithmetic mean of the data, and yet differ widely in respect to the feature characterized by, say, the standard deviation. Obviously, in any given case it is a matter of very great importance to be sure we have included in the set of coefficients an index for each and every important aspect of the phenomena under consideration.

Now, the statistical coefficients pertaining to a single variable to which nearly all the attention of statisticians has thus far been directed/relate entirely to the various characteristics of the frequency distribution.[1] In most cases, perhaps, this is sufficient, but in some problems, including many important meteorological applications, at least one other feature of the data must be taken into consideration, viz, the *order of succession.* If the statistical data in hand relate to, say, biometric measurements, it is immaterial in what order the data are presented; but if the data relate to the successive values taken on by a time-variable, the order in which the values occur may be quite relevant.

The order of succession is, in fact, one of the many peculiar problems encountered[2] when one seeks to apply the Theory of Probability and the ordinary Theory of "Errors" to meteorological data; the meteorological variables frequently do not conform to the conditions under which the mathematical theories are valid. Statistical

[1] In view of the usefulness of the so-called Goutereau ratio in meteorological investigations, Mr. Woolard was asked to examine the question as to whether there could not be developed a generalization of Goutereau's theorem, which as we understand it applies strictly to numbers in a Gaussian distribution. From a very superficial examination on my own part, I am impressed with the fact that this ratio, while not constantly equal to the square root of 2, (1.41), nevertheless has a value differing but little from that value for very widely differing frequency distributions. For example, the U-shaped distribution of a table of sines seems to lead to a ratio of about 1.25.

The problem might be stated as follows:

Given a limited series of numbers, a, b, c, . . . k, of which f_a, f_b . . . f_k represent the relative frequencies of these numbers. Regardless of the order of succession, the mean deviation of these numbers may be expressed as *md*. If the average value of the mean variation of the numbers in a sequence of unrelated numbers is v, what is the ratio of v ÷ *md*?—*C. F. Marvin.*

[1] See G. U. Yule, *Introduction to the Theory of Statistics*, chap. vii. 7 ed., London, 1924.

[2] See, e. g., V. H. Ryd, On Computation of Meteorological Observations. Danske Meteorologiske Institut, *Meddelelser Nr. 5.* Copenhagen, 1917.