Comparisons of Soundings with Radio-Meteorographs, Aerographs and Meteorographs.*

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I. INTRODUCTION

In a previous paper, there was described a radio-meteorograph system developed for use by the Aerological Service of the U. S. Navy Department. During the past year the component parts of the system have been materially improved and the performance of the system has been determined through the medium of comparisons of the radio-meteorograph observations with data obtained by airplane and meteorograph soundings. A description of the improvements effected is given in a separate paper. The present article describes the results of the comparative soundings and presents an estimate of the accuracy of the radio-meteorograph observations on the basis of these results.

A brief review of the method of radio-meteorography employed may be of interest before beginning a discussion of the results. The modulating frequency of the radio wave emitted from the balloon transmitter is controlled by resistors responsive to the temperature and humidity elements and by a fixed calibrating resistor. These resistors are interconnected so that they may be switched in a definite order to produce successive readings of temperature, humidity, and index frequencies. As the balloon rises, the continuously increasing deflection of the pressure-measuring element operates a small switch arm over a set of electrical contacts separated by insulating strips, to accomplish the desired switching operations. The change-overs from the temperature to the humidity and index frequencies occur at predetermined pressure levels. At the ground receiving-station an

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‡Radio-Meteorographs of the type described are manufactured by Julien P. Friez & Sons, Inc., Baltimore, Maryland, who have collaborated with the Radio Section of the National Bureau of Standards in development of suitable instruments to be used with this system.
audio-frequency recorder is connected in the output of the radio receiving set. The record obtained on the recorder chart forms a plot of air temperature and humidity (on the scale of abscissas) against atmospheric pressure (on the ordinate scale).

II. SIMULTANEOUS RADIO-METEOROGRAPH AND AEROGRAPH SOUNDINGS

Fifty radio-meteorograph soundings were made in cooperation with the aerological and radio personnel of the U.S. Navy Department at the Naval Air Station, Anacostia, D.C. The soundings were timed to occur practically simultaneously with the regular early morning aerograph soundings on a Navy airplane. The observations of pressure, temperature and humidity obtained at the radio-meteorograph receiving station for each ascent were plotted on the standard adiabatic chart, with temperatures and humidities as abscissas and pressures as ordinates. The significant points taken from the corresponding aerograph record were then plotted on the same chart for comparison.

A typical plot is given in Fig. 1. (For convenience in plotting, the pressure scale is uniform in this illustration and only the lines essential to the comparison are shown). The plot will illustrate the accuracy of the radio-meteorograph observations. When the balloon reached an altitude of 34,000 ft, a special pressure-operated re-
leasing device opened the string connection between the balloon and a small parachute to which the radio-meteorograph was attached. The parachute then opened and the equipment descended back to the earth's surface. The releasing device, employed in a number of the tests to prevent the equipment from reaching the normal ceiling heights of 65,000 to 75,000 ft, served to provide check radio-meteorograph observations during the descent of the equipment while the batteries were still in good condition and the instrument not too far away from the receiving station. In the plot shown, check readings were obtained down to within 1,200 ft of the ground.

The full lines in Fig. 1 represent the radio-meteorograph observations during the ascent, the circles represent every fifth radio-meteorograph reading during the descent, while the crosses show the simultaneous aerograph observations. The humidity readings corresponding to the descent of the radio-meteorograph are not plotted, since these readings, while indicating changes at the proper altitude levels, did not check the ascending values because of the inherent lag in the hairs after exposure to low temperatures. The close agreement of the three sets of temperature readings testifies not only to the accuracy of the temperature measurements with radio-meteorographs but also to the accuracy of the pressure measurements. The rapidity of the response of the electrolytic thermometer is also indicated, since, during the descent, its rate of motion through the air was approximately double the rate for the ascent and still the same readings were obtained.

A summary of the comparisons of the data for the 50 simultaneous radio-meteorograph and aerograph ascents may best be shown by means of the graphs of Fig. 2. The data for these graphs were obtained as follows. For each comparison test, the deviations of the radio-meteorograph temperature and humidity readings from the significant points taken from the aerograph chart were determined. These data were tabulated in two sets of 25 tests each. The reason for this division was to determine the improvement in performance arising from a number of minor refinements in circuit arrangement and in operating procedure. The full lines in Fig. 2 refer to the first set of tests and the dotted lines to the second set.

The graphs represent the total percentages of the radio-meteorograph readings falling within specified deviations from the aerograph readings. For the second set of tests, it will be seen that 94 percent of the temperature readings agreed with the aerograph readings within 2°C and 79 percent of the humidity readings agreed with the aerograph observations within 10% relative humidity.* An estimate of the probable absolute accuracy of the radio-meteorograph observations may be had from a further breakdown of the data shown for

*These percentages involve a slight adjustment of data which will appear later in this Section.
the second set of tests. Of the radio-
meteorograph temperature observa-
tions, 68 percent deviated by only 1
C° or less from the aerograph read-
ings, 26 percent by from 1 to 2°, 5
percent by from 2 to 3°, and 1 percent
by from 3 to 4°. Similarly, 51 percent
of the radio-meteorograph humidity
observations deviated by only 5%
relative humidity or less from the
aerograph readings, 28 percent by
from 5 to 10% R. H., 15 percent by
from 10 to 15% R. H., and 5 percent
of the readings deviated by from 15
to 20% R. H. Thus, it is seen that
a majority of the radio-meteorograph
observations agreed with the corres-
dponding aerograph readings within
1 C° and 5% relative humidity; an
agreement considered acceptable be-
tween two separate aerograph instru-
ments in most laboratory practice.

So far in our discussion little has
been said about the accuracy of the
pressure measurements as determined
from the comparison tests. Since the
temperature and humidity observa-
tions of both types of instrument were
plotted against their indicated pres-
sure readings, the agreement of the
temperature and humidity data testi-
fies to the agreement of the pressure
measurements. A further check lies
in the observed agreement of the
pressure levels at which marked tem-
perature inversions and humidity
changes were indicated to occur by
the radio-meteorograph and aerograph
records. However, as the tests pro-
gressed, increasing evidence was accu-
mulated that the latter check could
not be applied indiscriminately, since
the practically simultaneous radio-me-
teorograph and aerograph flights may
actually have travelled in sub-
stantially different adjacent air masses, or
in differently constituted parts of the
same air current.

It appeared that on days when the
air mass was laterally homogeneous
and the balloon was not carried by the
winds to an appreciable distance from
the airplane, very good agreement
was obtained. On other days, when
the weather map showed unstable con-
ditions to obtain, the two instruments
would show inversions to occur at sub-
stantially different pressure levels.
Tests in the laboratory in a controlled
chamber showed that the pressure
measurements of the radio-meteoro-
graph could not possibly be held ac-
countable for such marked differences
in the indicated levels. The only
likely conclusion was, that the two in-
struments were actually measuring
different air mass conditions.

In the graphs of Fig. 2, some ac-
count was taken of the possibility that
the two instruments may travel in
somewhat different air masses by
making a conservative adjustment of
the readings corresponding to the
most pronounced inversion points.
This adjustment consisted of assuming
that the radio-meteorograph and aero-
graph readings corresponding to these
inversion points occurred at the same
pressure levels; no changes were made
in the actual values of the tempera-
ture and humidity readings. In all,
some 5 percent of the readings were
thus adjusted. It is of interest to
present the results of the comparisons
without making these adjustments.
Under these conditions, for the second
set of tests, 87 percent of the tem-
perature readings agreed with the
aerograph observations within 2 C°,
and 77 percent of the humidity read-
ings agreed within 10% relative
humidity.

A marked example wherein the two
instruments were undoubtedly in dif-
ferent air masses occurred on Nov. 9,
when a front passed over the receiving
station practically at the time of re-
lease of the radio-meteorograph. The
plot at the left in Fig. 3 shows the radio-meteorograph and aerograph temperature variations obtained.* Here the curve with the solid line represents the radio-meteorograph data and the dotted curve with triangle symbols represents the aerograph observations at Anacostia. Note the marked inversion (beginning at about 850 mb) shown by the radio-meteorograph record and not indicated by the aerograph data. The conclusion drawn was that the radio-meteorograph was carried away with the outgoing air mass, while the aerograph sounding was in the incoming air mass. The basis for this conclusion resided in independent knowledge of the movement of the front. Also, partial corroboration was had from the fact that a temperature inversion (of considerably smaller magnitude) was indicated at approximately the same pressure level by an aerograph sound-}

*This comparison was not included in the data summarized by the graphs of Fig. 2.
computed data are plotted in Fig. 4 along with the radio-meteorograph temperature observations. The dotted line represents the average rate of ascent of the balloon. Departures from this average may be attributed to irregularities in the vertical air density gradient, to variations in the balloon's free-lift produced by temperature lag of the gas in the balloon with respect to the surrounding air, to vertical components of air movements, and to errors in the point-to-point pressure measurements. An opposite error of, say, 1 mb in successive pressure measurements will account for point-to-point irregularities in the rate of ascent of the order of 150 ft/min. However, where several successive points show the same direction of variation of the rate of ascent, irregular changes in density, balloon gas temperature, and vertical air currents must be involved. The major decrease in rate of ascent, occurring in the altitude range of from approximately 3,000 to 8,000 feet (910 to 2438 m), was observed in the altitude range of from approximately 3,000 to 8,000 feet (910 to 2438 m).

FIG. 4. BALLOON RATE OF ASCENT CORRESPONDING TO THE RADIO-METEOROGRAPH SOUNDING AT THE LEFT OF FIG. 3. (Note the marked decrease in rate while the balloon was in the warm air stratum of the inversion and the marked increase in rate as the balloon emerged from the warm air into colder air above.)

FIG. 5. TYPICAL SIMULTANEOUS RADIO-METEOROGRAPH AND AEROGRAPH OBSERVATIONS IN AN AIR MASS WHICH IS NOT LATERALLY HOMOGENEOUS.
FIG. 6. PLOT OF SIMULTANEOUS OBSERVATIONS FROM A RADIO-METEOROGRAPH AND TWO AEROGRAPHS, ONE CARRIED UPWIND AND THE OTHER DOWNWIND.

765 mb) coincides with the portion of the inversion below the level at which the super-adiabatic lapse rate begins. This decrease may be accounted for in part by appreciable temperature lag of the gas in the balloon. Here, the gas would be colder than the surrounding air, resulting in a decrease in the free lift of the balloon. Between 8,000 and 9,000 ft (765 to 735 mb) the rate of ascent increases sharply. This region practically coincides with the portion of the inversion showing the super-adiabatic lapse rate. In this case, temperature lag would cause the gas in the balloon to be warmer than the surrounding air, thereby increasing the free lift. The variation in rate of ascent of the balloon is thus consistent with the observed temperatures and hence indirectly checks the temperature observations.

Marked differences in temperature indications such as illustrated by Fig. 3 were encountered only twice during the series of 50 simultaneous radio-meteorograph and aerograph soundings. However, evidence that the two instruments sometimes traveled in substantially different air masses was had in quite a few of the tests. The usual case was more like that represented by the graphs of Fig. 5. Here the temperature readings of the two instruments agreed quite well at levels from about 1,020 to 925 mb, from 750 to 720 mb, and for levels below 640 mb. At pressure levels intermediate to these values, the temperature readings disagreed by amounts up to 6°C. It is obvious that the adjustments made in the summary graphs of Fig. 2, consisting of the assumption that corresponding significant points of the radio-meteorograph and aerograph records occur at the same pressure levels, do not actually compensate or the temperature differences.
encountered by the two instruments traveling in somewhat different air masses. It would therefore appear that the absolute accuracy of the radio-meteorograph observations may be appreciably greater than as indicated by the graphs of Fig. 2.

Considerable thought was given to means for proving this hypothesis. Fig. 6 shows the results of one comparison test in which two airplanes carrying carefully calibrated aero-graphs were employed. One of the airplanes traveled downwind (i.e., in the same direction as the radio-mete-

III. SIMULTANEOUS RADIO-METEOROGRAPH, AEROGRAPH, AND METEOROGRAPH SOUNDINGS

In order to determine conclusively whether or not the difference in temperature measurement indicated by the radio-meteorograph and aerograph in some of the comparison tests were due to actual differences existing in the portions of the air mass traversed by the two instruments, a series of six special tests were made during the period Dec. 15 to Dec. 23 inclusive, 1937. This series of tests was made in cooperation with the U. S. Weather Bureau. In each of the tests, a Fergusson-type meteorograph (furnished and calibrated by the Weather Bureau) was attached to the balloon carrying the radio-meteorograph. The release of the balloon was timed to occur practically simultaneously with the regular early-morning Navy aero-graph ascent. The conditions of the air mass under which the tests were made as observed by comparisons of the aerograph and radio-meteorograph observations, were sufficiently variable to make the tests well worth while. The hypothesis as to differences existing in the character of the portions of the air mass in which the balloon and the airplane traveled would be proved if, upon recovery of the meteorographs, their records would show the same differences from the aerograph observations as obtained from the radio-meteorograph records.

In order to increase the probability of recovering the Fergusson meteorographs, the pressure-operated releasing device mentioned in connection with Fig. 1 was adjusted to provide for the return of the equipment to the ground from an altitude of approximately 30,000 ft. A pilot balloon was attached to the equipment to render it more conspicuous upon return to the ground. Four of the six meteorographs were recovered, corresponding to the tests of Dec. 16, 21, 22, and 23. All were found in Delaware and, had it not been for the special releasing devices used, would have been carried far out over the Atlantic Ocean. Table I summarizes some points of interest in connection with the ascents, descents and recovery of the instruments.

Of the four meteorographs recovered, the clock had stopped in one (Dec. 23) just after the release of the balloon, and the pressure pointer had locked in position in another (Dec. 21). The latter failure did not
FIG. 7. PLOT OF SIMULTANEOUS OBSERVATIONS FROM A RADIO-METEOROGRAPH, AN AEROGRAPH AND A METEOROGRAPH, DECEMBER, 16, 1937.

TABLE I

<table>
<thead>
<tr>
<th>Date of test</th>
<th>Balloon released</th>
<th>Balloon at top reached</th>
<th>Equipment height in to ground (estimated)</th>
<th>Reported time of recovery</th>
<th>Place of recovery</th>
<th>Airline distance from Anacostia, Delaware D. C., in miles</th>
<th>Airline distance from Bay, in miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec. 16</td>
<td>7:18 AM</td>
<td>8:00 AM</td>
<td>27,000</td>
<td>9:00 AM</td>
<td>Searf, Del.</td>
<td>76</td>
<td>25</td>
</tr>
<tr>
<td>Dec. 21</td>
<td>7:32 AM</td>
<td>8:28 AM</td>
<td>29,700</td>
<td>9:00 AM</td>
<td>Lincoln, Del.</td>
<td>86</td>
<td>7</td>
</tr>
<tr>
<td>Dec. 22</td>
<td>7:45 AM</td>
<td>8:47 AM</td>
<td>30,500</td>
<td>9:18 AM</td>
<td>Lewes, Del.</td>
<td>101</td>
<td>2</td>
</tr>
<tr>
<td>Dec. 23</td>
<td>7:12 AM</td>
<td>8:07 AM</td>
<td>28,000</td>
<td>9:00 AM</td>
<td>Greenwood, Del.</td>
<td>76</td>
<td>17</td>
</tr>
</tbody>
</table>

affect the comparison of temperature and humidity observations, which could be accomplished quite accurately on a time basis. Three complete comparisons were thus available. In all three comparisons, the meteorograph observations showed practically all of the differences from the airplane-aerograph charts also exhibited by the radio-meteorograph records. Conclu-
sive proof was thus had that the differences between the airplane and balloon observations were actually caused by their geographic separation in the air mass.

The results of the three comparison radio-meteorograph, aerograph and meteorograph soundings are shown in Figs. 7, 8 and 9. It is of interest to note that for these comparisons, the radio-meteorograph data were evaluated by the writers, the meteorograph data by personnel of the Weather Bureau, and the aerograph data by personnel of the Navy Department. The detailed agreement of the radio-meteorograph and meteorograph temperature observations may be seen from a study of these figures. Note particularly the agreement of the two balloon-carried instruments and their disagreement with the aerograph at the following pressure levels: Fig. 7, 800 to 600 mb; Fig. 8, 790, 720, 655 and 635 mb; Fig. 9, 1,000 to 850 mb, and 730 mb.

The agreement of the humidity observations from the three types of instruments is not as satisfactory as for the temperature readings. This is probably due to the different treatment of the hair elements in the three instruments prior to the ascents and also to their different exposure. Because of the somewhat greater indicated variations in humidity at the
higher altitudes exhibited by the meteorograph records, it is likely that the meteorograph humidity element was probably the most accurate of the three. There is some evidence that the radio-meteorograph humidity readings could be improved by providing a better air flow through the enclosure around its hair element.

For convenience in study, a summary of the results of the comparisons for the three records is given by the graphs of Fig. 10. In this illustration, comparisons of the performance of the three types of instrument are shown in the following combinations: (a) between the radio-meteorograph and the meteorograph (represented by the graphs with open-circle symbols), (b) between the radio-meteorograph and the aerograph observations (see the graphs with solid-circle symbols), and (c) between the meteorograph and the aerograph observations (represented by the graphs with triangle symbols). The graphs show the percentages of readings (of the observations compared) falling within the indicated deviations in degrees Centigrade or in percent relative humidity.
For convenience in computing the data on which the graphs are based, the comparisons were made for the pressure levels corresponding to the significant points taken from the aerograph charts.

A study of Fig. 10 clearly shows that much better agreement is obtained between the radio-meteorograph and meteorograph observations than between the aerograph readings and either the radio-meteorograph or the meteorograph observations. The quantitative order of agreement should not be given too much weight, since only three tests are here summarized. However, it will be seen that a majority of the radio-meteorograph and meteorograph observations agreed within 1°C and 5% relative humidity. This is the same result as obtained for the second set of 25 radio-meteorograph observations summarized in Fig. 2. For the sake of comparison, several points from the graphs of Fig. 2, relating to the second set of 25 tests, are plotted as crosses in Fig. 10. The order of agreement is not materially different.

**IV. Conclusions**

The following conclusions may be drawn from the summaries presented in Fig. 10:—

1. Because of the possible lack of lateral homogeneity of an air mass, comparison soundings using two instruments on the same balloon give more reliable results than comparisons of a balloon instrument with an aerograph.

2. Nevertheless, when the air mass is laterally homogeneous or when the geographic separation between the balloon and airplane instruments is not too great, the latter type of comparison becomes quite reliable.

3. Furthermore, when a sufficiently large number of radio-meteorograph and aerograph comparisons are summarized, and pronounced inversions indicated by the two types of instruments are taken as occurring at the same pressure levels, the results may be considered reliable.
(4) Finally, an estimate of the probable absolute accuracy of the radio-meteorograph in its present form may be made. On the basis of the tests it appears reasonable to assign equal probable errors to the three types of instruments used. In comparison of the radio-meteorograph with the other two types of instruments, agreement was obtained of some 90 percent of the temperature readings and 75 percent of the humidity readings within 2°C and 10% relative humidity, respectively. Hence, recognizing the fact that some errors in the pressure measurements by the different instruments were present, an absolute accuracy for the radio-meteorograph of ±1°C and ±5 to 8% relative humidity does not appear unreasonable.

V. ACKNOWLEDGMENT

The writers wish to express their appreciation to Commanders W. M. Lockhart, T. J. Raftery, and Mr. R. J. Brown of the Bureau of Aeronautics, U.S. Navy Department, and to Commander G. B. Hall and Mr. Malcolm T. Hanson of the Bureau of Engineering, U.S. Navy Department, for their cooperation and interest in the performance tests of the radio-meteorograph. Acknowledgment is also due Messrs. L. T. Samuels, A. H. Mears, and J. C. Ballard of the U.S. Weather Bureau for cooperation in the simultaneous radio-meteorograph, aerograph and meteorograph tests.

Weather and Health

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THERE ARE ESSENTIALLY TWO MAJOR WEATHER CHARACTERISTICS DIRECTLY AFFECTING HUMAN FUNCTIONS AND MAN'S PHYSICAL WELFARE. FIRST, AND MOST IMPORTANT, COMES THE MEAN TEMPERATURE LEVEL WITH ITS CONTROL OVER THE RATE OF HEAT LOSS FROM THE BODY; AND SECOND IS THE STORMINESS OR ATMOSPHERIC [MACRO-]TURBULENCE TO WHICH MAN MUST BE CONSTANTLY ADAPTING HIS BODY FUNCTIONS. THESE TWO PHASES OF WEATHER EFFECTS EXERT PROFOUND INFLUENCES OVER MAN'S EXISTENCE, BUT DIFFER WIDELY IN THE MECHANISM BY WHICH THE EFFECTS ARE PRODUCED. THEY MUST BE CONSIDERED SEPARATELY IN ANY ATTEMPT TO ANALYSE AND UNDERSTAND THE PART WEATHER PLAYS IN OUR LIVES.

CONTROL OF BODY HEAT LOSS AND METABOLIC ACTIVITY BY MEAN TEMPERATURE LEVEL

Most fundamental of all body processes is that of combustion. Practically all types of functional activity that go on in the body are accompanied by heat production from the oxidation of foodstuffs. This is especially true in warm-blooded animals and man, where a large part of this internal heat production is needed to maintain a body temperature at a constant level considerably above that of the surrounding environment. As outside temperatures drop and heat loss from the body is increased, internal combustion is stepped up to meet the more rapid heat loss and prevent a lowering of body temperature. Careful studies have shown that the level of body heat production

*An expansion of Prof. Mills' talk at the Indianapolis Meeting, and a review of his philosophy of the subject. A list of his many publications on weather effects appears at the end of this article, and anyone interested in further details should consult the original papers.—Ed.