at a time and calculating the probability of rain for the various combinations possible for these two elements, one would attain to greater accuracy.

One can conceive, for example, that the coincidence of a low pressure and a wind from the northeast, which is usually accompanied by a high pressure, would be susceptible of furnishing a much better forecast than that which one could deduce from a low pressure and a wind from the northeast, taken separately.

The elements considered in this work can be combined two by two in 15 different manners. Among these 15 different combinations, I have studied 9 which appeared the most interesting: Pressure and variation of pressure, direction of the wind and pressure, direction of the wind and variation of pressure, direction and velocity of the wind, direction of the wind and temperature, and, finally, cloudiness combined with pressure, with direction of the wind, with the variation of pressure, and with temperature.

For each of the first five groups, the numerical results furnished by statistics have been reduced to graphic representations of three coordinates, representing the curves of equal probability of rain, traced for each 10 per cent. For each of the groups where cloudiness is concerned four curves of two coordinates have been drawn, relative to the four degrees of cloudiness previously specified.

Contrary to what one might hope, they do not present a great advantage over the curves representing one element. Certain of them give less satisfactory results than the one element. For instance, the curve representing pressure and direction of the wind combined furnished only 69 correct forecasts out of 100. Now, we have seen that in taking the mean of the probabilities, deduced separately, of pressure and of direction of the wind, we will be correct 70 times out of 100. The inferiority of the curve of two elements results from the fact that there are so few cases of areas of very high and very low pressure occurring with each direction of the wind that it is impossible to deduce any rule to govern these conditions. One is thus obliged to consider the probability of rain in such cases as equal to $\frac{50}{100}$. Now, with the probability $\frac{50}{100}$, in only one case out of two could rain be safely predicted.

As to the curves representing only one element, they may be extended to the most extreme variations of the element, and the cases that escape their application are very rare. In the field of general utility the two processes give equivalent results; in fact, if we take the proportion of correct to incorrect forecasts, we find that the proportion is the same for both.

In spite of the slight inferiority which the graphics of two elements offer, taken separately, they constitute, when we combine them, a better means of forecasting than the curves of only one element. After having attempted nearly all the combinations possible, I recognized the fact that in order to attain the maximum proportion of success it is best to use all the graphics of two elements enumerated above, excepting that combining the direction of the wind and the temperature, the addition of which is detrimental. We take simply the arithmetical mean of the eight figures of probability, and according to whether this mean is more than 50 we forecast or do not forecast rain. This method gives 73 per cent of correct forecasts.

It happens quite frequently that among the eight figures of probability there is one higher than 73 or lower than 27; in this case, it would seem that one should base the forecast on this number rather than on the mean of the eight numbers. I am convinced that in reality one gains nothing in proceeding thus, no doubt because 73 per cent is only a mean value, systematically of too little weight in this particular case.

I thought it interesting to apply this method to last winter, which is not included in the data upon which these curves are based.

In the course of the winter it rained or snowed 17 times at 9 o'clock. There remained seventy-four days, for which the forecast was correct 57 times and incorrect 16 times; besides, the probability, 50 per cent, was obtained once. The proportion is 78 per cent. The variation between this result and the average result, 73 per cent, deduced from a long series of observations, shows that one should expect to see the proportion of success attained vary from year to year, which is not surprising in considering a question into which chance enters to a certain extent.

The average success of 73 per cent could be considered as fairly satisfactory, but it should be observed that the question, as it is stated, admits of great difficulty, in spite of the short period covered by the forecast. To avoid all arbitrariness, we have considered as rain the least fall of water or of snow, even when reduced to fine drops of drizzling rain. Now, we frequently observe in winter, according to the temperature, drizzling rain or small flakes of snow, even when the general condition is that of dry weather. By treating in the same manner the question as to whether an appreciable amount of rain will fall—for example, 1 millimeter—we will certainly attain a higher proportion of success.

Having determined the slight advantage obtained by calculating the probability of rain in function of two elements instead of one, one may question if it would not be advantageous to calculate the probability in terms of three elements or more. This method is altogether impracticable at the present time. In fact, in order to establish statistics of probability based on three elements at the same time, it would be necessary to divide the data into a number of groups about ten times greater than for two elements and consequently ten times more observations would be required to obtain the same precision. Now, our twenty-one years scarcely suffice to calculate the probability in terms of two elements. More than two hundred years of observations would thus be required to calculate the probabilities in terms of three elements.

I will point out, in closing, some particularly interesting facts brought to light by graphics of the two elements.

For all winds, excepting those blowing between the north and the west, rain presents a maximum of probability for a pressure of about 750 millimeters; for winds from the east-northeast this maximum is very marked and corresponds to 755 millimeters.

The increase of the probability of rain with the velocity of the wind is verified for all directions, but it is very slight for winds from the east-northeast and is most marked for those between south and west.

The probability of rain increases with the temperature for all directions, but only reckoning from a minimum which occurs at about —5° for winds from the south, and about —1° for winds from the north. For winds from the north, the temperature presents a maximum at 3° from which it decreases.

When the sky is clear or slightly cloudy, the probability of rain is minimum for a barometric rise of 0.1 millimeter from 6 to 9 o'clock, and *increases notably with the rise.* Thus, for cloudiness comprised between 0 and 4, the probability is only 25 per cent for a barometric rise of 0.1 millimeter and becomes 50 per cent for a rise of 2.25 millimeters.

These remarks have not a great practical importance in weather forecasting, but they present a certain interest from a general meteorological point of view.

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NOTE BY PROF. E. B. GARRIOTT, CHIEF OF FORECAST DIVISION, U. S. WEATHER BUREAU.

The local signs of approaching weather changes, rain for instance, necessarily vary in different countries, and, in many instances, in different parts of a State. The whole proposition, in fact, places local observations in the same relation to the reports of a meteorological service that the reports of a

meteorological service bear to world-wide reports. The reports of a meteorological service enlarge the area of vision and *permit the forecasting of local signs.* The future will undoubtedly provide for a similar treatment of the general weather conditions of a country by the employment of telegraphic reports from a world-wide area.

## AIR RADIATION.

By C. C. HUTCHINS and J. C. PEARSON, Bowdoin College, dated July, 1904.

In 1892 one of the present writers carried out, at the request of Prof. Cleveland Abbe, some experiments for finding the radiation constant of atmospheric air. The radiation was measured from a hot, moving column of air of 1 centimeter depth in the line of sight, and as close as possible, consistent with proper screening, to the heat recording apparatus. Owing doubtless to defective surroundings, the results obtained from day to day showed considerable variation; in fact, more than could be produced artificially by changing the normal constituents of air in a closed room, such as dust and moisture, between wide limits. An average of the best results gave .00000114 small calories per second per square centimeter per degree for a thickness of 1 centimeter of the radiating layer.

In 1900 Professor Very published an extended monograph on the subject, in which very numerous experiments of his own and others are collected and discussed with the utmost skill and patience. Very's result, stated in the terms given above, at 100° excess temperature, was .00000036, or three times smaller than what we had obtained. This large difference led to a reexamination of our figures and methods, without finding anything that could account for it. An entire change of apparatus and method often leads to unexpected results, and may cause us to modify our views as to the probable error of our former consistent figures. In 1902 we constructed an entirely new apparatus, containing nothing that belonged to the old. A radio-micrometer, after Boys, was the heat receiving instrument. We avoided all suspicion of air contamination by taking air from out-of-doors. A box some 6 feet long, 2.5 feet wide, and 3 inches deep, containing a sheet iron bottom about halfway up, and covered with a single sheet of glass, was set at an angle of about 45° outside a south window. The upper end of the box was extended by a wooden chimney that projected through a slit in the window shutter. The box had trunnions at the sides, upon which it could be tilted by pulling a string. The radio-micrometer was mounted inside the shutter so that in the lowest position of the chimney the current of air that streamed up through came opposite the radio-micrometer opening. Sunlight falling upon the exposed glass cover heated the sheet iron bottom, and this in turn heated the air in contact with it, and a current of hot air was delivered through the chimney. The temperature of the hot air was obtained by a thermal junction of two thin copper and iron wires inserted in the stream, the circuit being completed through a calibrated galvanometer.

On clear, still days, excess temperatures of 50° to 60° of the hot air stream were obtained, and from the deflections produced, as compared with those produced by a lampblacked surface, at known temperature, we got values of the radiation constant that lay on both sides of the mean result of 1892. Great difficulty was experienced in getting a steady flow of hot air, and the behavior of the radio-micrometer was far from satisfactory. The experiments were discontinued when it was found that nothing new was to be learned by this method. We could at least conclude that the difference between pure air and that contained in an ordinary room with respect to radiating power was inappreciable.

The winter of 1902–3 was spent in improving the radio-micrometer, and an instrument of remarkable sensitiveness and accuracy was produced.[1]

This season we have taken up the problem anew with much improved apparatus and in very much improved surroundings. The investigation was carried out in the constant temperature room of the Searles Physical Laboratory, and the extreme range of temperature during the weeks of experiment has been less than 2°.

Finding our knowledge of the absorption of air for its own radiation in a very imperfect state, we turned our attention first to that problem.

### DESCRIPTION OF APPARATUS.

The radio-micrometer was mounted upon a massive stone table, and screened from external sources of radiation. In line with the opening of the radio-micrometer was placed a truncated cone of sheet tin, 45 centimeters long, having an opening 1.5 centimeters in diameter, corresponding to the opening of the instrument, and enlarging to 5.5 centimeters at the other end. The cone is extended by a cold-drawn seamless brass tube, polished within, 280 centimeters long, and 5 centimeters internal diameter. Over the end of the brass tube is slipped a tin tube 8 centimeters in diameter, held in place by wooden rings and projecting 70 centimeters beyond the brass tube. These 70 centimeters are thickly set with diaphragms, having 5-centimeter openings, and the tube and diaphragms are carefully blackened. The legitimacy of using reflecting tubes for passing along a radiation from a distant source has often been called in question. All doubt should, however, be set at rest by recent experiments made upon the reflecting power of metals bathed in air, for long waves. Hagen and Rubens show[2] that all metals are practically perfect reflectors for radiations of great wave length, and it is certain that any difference between the reflecting power for air radiation, which is known to be of very great wave length, and the radiation from a lampblacked surface at slight temperature excess would be inoperative so far as our present purposes are concerned. Opposite the tin tube is placed the device for heating and delivering an air column. A box of wood, 100 centimeters by 35 centimeters by 14 centimeters, is mounted upon trunnions, so as to be tilted by pulling an attached string. In its vertical position, the column of hot air is delivered centrally past the opening of the long tube, but upon releasing the string the box tilts back out of the way. Beyond the air column stands a large blackened copper cube filled with water at the room temperature, and to this all temperatures are referred.

The box is filled with coils of iron wire, which are heated by a current taken from the lighting circuit, and the air flowing up through them is heated in turn. The temperature of the hot air is given by a thermometer having a very small bulb held in the stream at the height of the opening in the long tube.

### EXPERIMENT TO DETERMINE THE ABSORPTION IN THE LONG TUBE FOR LAMPBLACK RADIATION.

As our values of air radiation were to be obtained in terms of radiation from a lampblacked surface, it became necessary to inquire whether the column of air in the long tube exerts any appreciable absorption upon the lampblack radiation. Langley, in his work on the temperature of the moon, has shown that a column of air 110 meters deep absorbs about 20 per cent of the rays from a blackened surface at 100° C. If the absorption follow Lambert's law, it would, in a column of air 245 centimeters deep, the depth used in the following experiment, be about 0.5 of 1 per cent, and may be neglected. The object of the following was to ascertain if the absorption changes with temperature excess.

A second blackened tank at a higher temperature than the standard tank was thrust in front of the tube and the deflection of the radio-micrometer noted. The following table gives the results:

[1] Am. Jour. Sci., Vol. XV, April, 1903.

[2] Drude's Annalen, Vol. II, 1903, p. 873.