SPECIAL CONTRIBUTIONS.

MONTHLY STATEMENT OF AVERAGE WEATHER CONDITIONS FOR NOVEMBER.

By Prof. E. B. GARRIOTT.

The following statements are based on average weather conditions for November, as determined by long series of observations. As the weather of any given November does not conform strictly to the average conditions the statements can not be considered as forecasts:

In its general character November weather forms a mean between the heat of late summer and early fall and the cold of winter, and, in marked contrast to the severe storms of August, September, and October, the weather in the tropical and subtropical regions of the Atlantic Ocean is usually settled and fine. In the Pacific Ocean and on the southeastern coasts of Asia the typhoon season is nearing its end. In the middle latitudes of the oceans the winds become stronger and blow more steadily from the northwest, shifting to west, southwest, and south, as a given parallel is followed from their western to their eastern shores. The storms encountered in the middle latitudes are not as strong as the tropical bred storms of the preceding month, nor the storms which occur during the winter season. The southward flow of arctic ice in the Atlantic has ceased, and but little fog is encountered in the transatlantic steamship routes near Newfoundland.

In the United States the Pacific coast wet season begins in October, and the rainfall increases until December. Over the middle and northern Plateau regions there is an increase in rainfall as compared with the summer and early fall months, except in Utah, where the rainfall is less than in October. In Arizona and New Mexico November is dry as compared with the summer months. In Montana November is one of the driest months of the year. In the great corn and wheat growing districts of the central valleys there is a gradual diminution in rainfall from summer to midwinter. In the east Gulf and South Atlantic States November rainfalls are commonly light, and in the west Gulf districts they fall short of the summer average. From the Lake region and Ohio Valley, over the Middle Atlantic and New England States there is a general, though not well-marked, decrease in rainfall from midsummer to midwinter.

In the interior of the Gulf and South Atlantic States garden truck is subject to damage by frost, and damaging frost is likely to occur in central and northern Florida in November.

RAINFALL FROM CONVECTIONAL CURRENTS.

By H. H. KIMBALL, U. S. Weather Bureau.

A great deal of popular as well as scientific interest attaches to the excessively rapid rates of rainfall that are occasionally experienced in the United States, not only because of their effects, which are often disastrous, but also because they are manifestations of the tremendous amount of latent energy that nature has at her command.

TABLE 1.

Stations.	Rate per hour in inches for—		
	5 minutes.	10 minutes.	60 minutes.
Bismarck, N. Dak	9.00	6.00	2.00
Jacksonville, Fla..	7.44	7.08	2.20
Galveston, Tex	6.48	5.58	2.55

In Weather Bureau Bulletin D, Rainfall of the United States, Prof. Alfred J. Henry gives the foregoing as the maximum rates of rainfall that have been recorded at Weather Bureau stations, and in the MONTHLY WEATHER REVIEW for September, 1898, he has shown that one inch of rainfall is equivalent to 27,154 gallons, or 226,000 pounds of water per acre, the gallon containing 231 cubic inches, and a cubic inch of water weighing 252.286 grains. Rainfall at the rate of 9 inches per hour therefore represents a fall of 33,900 pounds, or 4,073.1 gallons per acre each minute, and in five minutes over an area of 4 square miles represents a fall of 51,000,000 gallons, an amount considerably in excess of the daily water supply and consumption of Washington, D. C.

What is the source whence the vast amount of water indicated by the above rates of precipitation is derived?

In the Smithsonian Report for 1888, page 410, Prof. Cleveland Abbe gives the water equivalent of the aqueous vapor in air for columns of different heights for various surface conditions. His table is here reproduced.

TABLE 2.—*Depths of water in the atmosphere corresponding to various dew-points at the earth's surface.*

Height of column of air.	Dew-point.			
	80°	70°	60°	50°
Feet.	*Inches.*	*Inches.*	*Inches.*	*Inches.*
6,000.....	1.3	1.0	0.7	0.5
12,000.....	2.1	1.5	1.1	0 8
18,000.....	2.5	1.8	1.3	0.9
24,000.....	2.7	2.0	1.4	1.0
30,000.....	2.8	2.1	1.5	1.1

It is evident from this table that there may be contained in the air column immediately above us, in the form of invisible vapor, sufficient moisture to produce over 2 inches of rainfall if it could all be precipitated, and if this column could be renewed each hour a rate of rainfall equal to any on record could be maintained.

It is not the purpose of this paper to discuss the various methods by which the vapor of water in the atmosphere may be precipitated, but rather to consider the condensation and precipitation that may result from ascending, or convectional currents.

We will first consider the nature of atmospheric moisture.

As is well known the atmosphere is not a simple gas like hydrogen or oxygen, but consists of a mechanical mixture of gases and vapors, the most important of which are nitrogen, oxygen, and aqueous vapor.

Gases are perfectly elastic, and the amount of gas a given space will contain varies directly with the pressure, and is inversely proportional to the temperature. If we diminish the pressure on a gas and allow it to expand against a lower pressure, work is done at the expense of the temperature of the gas and the gas cools off. Conversely, if the gas is compressed it becomes warmer.

The term vapor applies more properly to a gas near its temperature of condensaton. Near this point the gas ceases to be perfectly elastic, and either the cooling or the compression of the vapor may be carried to such an extreme that the space occupied can contain no more of it. The space is then said to be saturated. If the compression or cooling is continued beyond this point, some of the vapor will be converted into a liquid.

The oxygen and nitrogen of the air can be liquified only under a combination of extremely high pressures and very low temperatures, but the aqueous vapor, if present in any

considerable quantity, may be condensed by comparatively slight cooling under normal pressure.

The following extract from Prof. C. F. Marvin's moisture tables (W. B. No. 171) shows the maximum number of grains of aqueous vapor that may be contained in a cubic foot of space. The quantity is the same whether the vapor occupies the space alone, or in conjunction with various gases.

TABLE 3.—*Maximum weight of aqueous vapor contained in a cubic foot.*

	Temperature, Fahrenheit.									
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
Grains of aqueous vapor.....	0.481	0.776	1.235	1.935	2.849	4.076	5.745	7.980	10.934	14.790

A cubic foot of space saturated with aqueous vapor at a temperature of 80° contains 10.934 grains, and if cooled to 70° could contain but 7.980 grains. It follows that 2.954 grains would be condensed into liquid drops, that would either remain suspended as fog, or be precipitated as water. If the cooling continue to 40°, 8.085 grains of moisture would be condensed, leaving only 2.849 grains of the vapor.

We will suppose the temperature in our cubic foot of space to be 90°, and the amount of moisture only 70 per cent of that required for saturation; that is, the *relative humidity* is 70, and the weight of the vapor is 10.353 grains. Should the temperature fall to 40° only 2.849 grains could continue in a state of vapor, the remaining 7.504 grains being condensed.

This weight of the vapor in a unit volume is called the *absolute humidity*.

In nature, any process that will cool the atmosphere below its saturation temperature will cause condensation of moisture. It is generally admitted that the expansion that takes place in ascending currents, is a fruitful source of cooling and consequent condensation of the aqueous vapor of the atmosphere.

The process by which this cooling is accomplished can best be understood by first considering what takes place when a small quantity of heat is imparted to a known mass of air. A portion of the heat is converted into work, and is employed in overcoming the resistance that the pressure of the air exerts against expansion. The remainder is available for raising the temperature of the air mass.

In adiabatic expansion we have expansion without the receipt of heat from any external source, and the energy necessary to do the work of expansion is obtained at the expense of the heat already present in the air. It is therefore evident that the work of expansion must cool the air.

After the air has been cooled to such an extent that it is saturated with aqueous vapor, a small portion of the heat required in the work of further expansion is furnished by the liberation of the latent heat of the water condensed, and the rate of cooling is thereby diminished.

From our knowledge of physics we are enabled to express these adiabatic processes in mathematical language, as has been done by Kelvin, Ferrel, Hertz, Bezold, and others. A convenient arrangement of their results may be found on pages 492–494, equations 71–127, of Part II, Report of the Chief of the Weather Bureau, 1898–99; but the equations are so cumbersome for purposes of computation that but little practical use has been made of them.

In order that these equations may be more easily applied to the adiabatic thermodynamic problems of the atmosphere, Prof. Frank H. Bigelow has developed them in the form given on page 496, equations 144–148, of the above report. Equations 145 and 146, which follow, express the adiabatic processes within expanding and cooling air until it cools down to the freezing temperature.

For air unsaturated with moisture:

$$\text{I}\alpha.$$

$$(145)\ldots\ldots\left(0.2374+0.1512\,\frac{e}{B}+0.0232\,\frac{e^2}{B^2}\right)\log T$$

$$\text{II}\alpha.$$

$$-\left(0.06858+0.02592\,\frac{e}{B}\right)\log B=C\alpha.$$

For air saturated with moisture:

$$\text{I}\beta.$$

$$(146)\ldots\ldots\left(0.2374+0.4743\,\frac{e}{B}+0.145\,\frac{e^2}{B^2}\right)\log T$$

$$\text{II}\beta.$$

$$-\left(0.06858-0.04266\,\frac{e}{B}\right)\log(B-e').$$

$$\text{III}\beta.$$

$$+\left[\frac{497.5}{T}-0.4404-\left(\frac{309.4}{T}-0.2739\right)\frac{e}{B}\right]\left(\frac{e'}{B-e'}\right)=C\beta.$$

The equations for temperatures below freezing are not here considered, since the general absence of hail during periods of excessive precipitation indicates that it is only in exceptional cases that convectional currents extend to a sufficient height to reach freezing temperatures.

In the equations above given we have to do with the following quantities:

T = absolute temperature = $t + 273$, in degrees centigrade.

B = barometric pressure, in millimeters.

e = pressure of the aqueous vapor, in millimeters.

e' = pressure of the aqueous vapor, in millimeters, in the saturated stage.

$C\alpha$ = the numerical value of the equation for the unsaturated stage, which *is a constant for any given value of* $\frac{e}{B}$.

$C\beta$ = the numerical value of the equation for the saturated stage, which is *also a constant for any given value of* $\frac{e}{B}$.

The logarithms are Naperian logarithms.

The unit is 1,000 grams.

If we observe B, t, and e at the surface of the earth and determine the constant $C\alpha$, equation 145 can then be solved for any desired value of B, and the corresponding t determined, or vice versa. Equation 146 can then be solved, as will be shown later.

In tables 94 to 99, inclusive, pp. 550–556 of the report above quoted, the values of the quantities in these equations are tabulated in such form as to render the computation for the four following cases quite simple:

(1) At Washington, D. C., on June 29, 1895, 0.93 inch of rain fell between 7:05 p. m. and 9:10 p. m., 0.80 inch falling during the first fifteen minutes. (2) On August 13, 1896, 1.73 inches fell between 5:20 p. m. and 8:24 p. m., 1.57 inches falling in forty-five minutes. On both these dates 0.42 inch fell in five minutes, which is at the rate of 5.04 inches per hour. (3) On August 12, 1898, 4.96 inches of rain fell between 9:20 a. m. and 11 p. m. (4) On June 2, 1900, 3.48 inches fell between 2:15 p. m. and 6:30 p. m.

If we introduce into equation 145 the values of B, t, and e, observed at Washington on these four dates, we shall be able to compute the respective temperatures and pressures at which the air in ascending currents would become saturated, and clouds would commence to form. With the B and t thus determined, which we will designate B_s and t_s, we may now

compute from equation 146 the respective pressures at which freezing temperature would be reached.

Having determined t and B, we may compute the corresponding altitude by the aid of the hypsometric formulæ which Professor Bigelow has evaluated in tables 91 to 93 of the Report of Chief of Weather Bureau, 1898–1899. The resulting heights are given in the accompanying Table 4, where the altitude corresponding to the saturation temperature is designated by h_s, and that corresponding to the freezing temperature is designated by h'_o.

The equation $\mu = 622\,\frac{e}{B} + 235\,\frac{e^2}{B^2}$ = grains of aqueous vapor in a kilogram of saturated air, will enable us to determine at any point what percentage of the aqueous vapor originally present has been condensed, and, in conjunction with the *absolute humidity* at t_s, will also enable us to compute the number of cubic feet of air that must be cooled from t_s to any desired temperature, as the freezing point, in order that the equivalent of one inch of rainfall may be condensed.

Finally, by dividing this last result by 5280, we shall obtain, in miles per hour, the velocity of an ascending current that will condense the equivalent of one inch of rainfall per hour.

Tables 10 and 157 of the Report of the Chief of the Weather Bureau, already quoted, will enable us to check our results. Table 10 gives the mean heights of the bases and tops of cumulus and cumulo-nimbus clouds, as determined from theodolite measurements at Washington, and Table 157 gives the fall in temperature from the surface to different heights, as determined from all available balloon observations.

The diagram of our several results is very instructive. (See fig. 1.) We notice at once that the 8 a. m. conditions give us t_s at a much lower altitude than the 2 p. m. conditions, and that in general the higher the surface temperature the greater the height at which the saturation temperature will be reached.

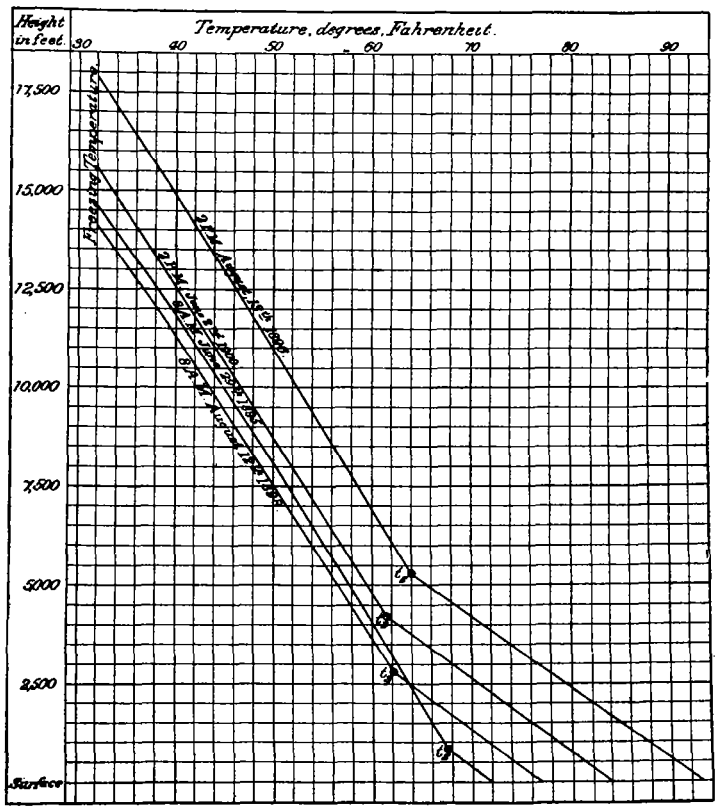

FIG 1—Diagram showing adiabatic rates of cooling.
(The dates June 29, 1895, and August 12, 1898, should be transposed).

This is as we find it in nature, since the morning clouds form lower than the midday clouds, the height advancing with the temperature. But since the diurnal range of temperature is much greater at the surface than at the cloud level, the diurnal variation in the cloud heights is not nearly so marked as is indicated by the results of the computation.

It has been found, from the study of temperatures obtained by kite and balloon observations, that the actual vertical temperature gradient averages much less than the adiabatic rate of cooling, but approaches to it, and even passes it on warm summer afternoons. As soon as the air near the surface becomes heated to such an extent that the vertical temperature gradient exceeds the adiabatic rate of cooling, convectional currents will be set in motion. If sufficient moisture is present the ascending current will become saturated, a cumulus cloud will form, and the rate of cooling will be much retarded, as indicated by the change in the inclination of the lines on the diagram (fig. 1) at t_s. The velocity of the ascending current and the thickness of the cloud will depend not alone upon the overheating of the air near the surface, but also upon the amount of vapor present.

The following is the computation of our four cases by equations 145 and 146:

TABLE 4.—*Adiabatic changes, computed from Bigelow's equations* 145 *and* 146, *and tables* 94–99 *for four cases at Washington, D. C.*

		June 29, 1895.		August 13, 1896		August 12, 1898.		June 2, 1900.	
		8 a. m.		2 p. m.		8 a. m.		2 p. m.	
		Units of measure.							
		English.	Metric.	English	Metric.	English.	Metric.	English.	Metric.
Surface conditions.	B	30.16	766.1	30.01	762.3	30.05	763.3	29.91	759.7
	t	77.0	25.0	93.0	33.9	72.0	22.2	84.0	28.9
	e	0.616	15.65	0.707	17.96	0.707	17.96	0.629	15.98
	$\frac{e}{B}$	.0204	.0204	.0236	.0236	.0235	.0235	.0210	.0210
Ca, from equation 145 using surface B, t, and e.	Ia	.....	+1.3703	.....	+1.3800	.....	+1.3707	.....	+1.3739
	IIa	.....	−.4589	.....	−.4592	.....	−.4592	.....	−.4585
	Ca	.....	.9114	.....	.9208	.....	.9115	.....	.9154
Saturated conditions from equation 145.	ts	62.15	16.75	63.7	17.6	68.2	20.1	61.3	16.3
	e'	.....	14.18	.....	14.95	.....	17.47	.....	13.77
	Ia	.....	1.3636	.....	1.3672	.....	1.3690	.....	1.3637
	Ca	.....	.9114	.....	.9208	.....	.9115	.....	.9154
	IIa	.....	−.4522	.....	−.4464	.....	−.4575	.....	−.4483
	Bs	.....	694	.....	634	.....	744	.....	655
	ht.=hs	2,815	858	5,298	1,615	782	223	4,245	1,294
	$\frac{e'}{B}$	.....	.0204	.....	.0236	.....	.0235	.....	.0210
	$\frac{e}{B-e'}$	.....	.0209	.....	.0242	.....	.0241	.....	.0215
	μ	....	12.75	.....	14.81	.....	14.75	.....	13.17
	abs. hum.	5.972	.....	6.499	.....	7.336	.....	6.001	.....
$C\beta$ from equation 146 and Bs and ts.	$I\beta$	.....	+1.4010	.....	+1.4105	.....	+1.4123	.....	+1.4023
	$II\beta$	.....	−.4416	.....	−.4343	.....	−.4453	.....	−.4374
	$III\beta$	.....	+.0263	.....	+.0303	.....	+.0298	.....	+.0271
	$C\beta$	.....	.9857	.....	1.0065	.....	.9968	.....	.9920
Beginning of freezing conditions from equation 146.	t	32.0°	0.0°	32.0°	0.0°	32.0°	0.0°	32.0°	0.0°
	e'	.....	4.57	.....	4.57	.....	4.57	.....	4.57
	$I\beta$	.....	1.3863	.....	1.3949	.....	1.3946	.....	1.3879
	$C\beta$	.....	.9857	.....	1.0065	.....	.9968	.....	.9920
	$II\beta+III\beta$	.....	−.4006	.....	−.3884	.....	−.3978	.....	−.3959
	$B-e'$	.....	454.0	.....	395.5	.....	443.5	.....	429.5
	$\frac{e'}{B-e'}$	.....	.0101	.....	.01155	.....	.0103	.....	.0106
	$II\beta$	.....	−.4143	.....	−.4041	.....	−.4118	.....	−.4103
	$III\beta$	.....	+.0137	.....	+.0157	.....	+.0140	.....	+.0144
	$II\beta+III\beta$	.....	−.4006	.....	−.3884	.....	−.3978	.....	−.3959
	B	.....	458.6	.....	400.0	.....	.448	.....	434
	h'_o	14,108	4,300	17,870	5,447	14,639	4,462	15,617	4,760
	h'_o-hs	11,293	3,442	12,572	3,832	13,907	4,239	11,372	3,466
	μ'	.....	6.24	.....	7.12	.....	6.37	.....	6.56

TABLE 4—*Continued.*

Heights at which other temperatures would be reached.

	June 29, 1895.		August 13, 1896.		August 12, 1898.		June 2, 1900.	
	8 a. m.		2 p. m.		8 a. m.		2 p. m.	
	Units of measure.							
	English.	Metric.	English.	Metric.	English.	Metric.	English.	Metric.
t'	53.6	12.0	53.6	12.0	59.0	15.0	53.6	12.0
h'	6,227	1,898	9,570	2,917	4,492	1,369	7,520	2,292
t'	46.4	8.0	46.4	8.0	50.0	10.0	46.4	8.0
h'	8,996	2,742	12,493	3,808	8,114	2,473	10,328	3,148
t'	39.2	4.0	39.2	4.0	41.0	5.0	39.2	4.0
h'	11,545	3,519	15,160	4,621	11,474	3,497	12,959	3,950

TABLE 5.

Heights at which freezing temperature would be reached $= h$, as computed from Bigelow's Table 157.

h_b	14,764	4,500	17,716	5,400	18,701	5,700	12,139	3,700
$h_b - h'_o$	656	200	—154	—47	4,062	1,238	—3,478	—1,060

TABLE 6.—*Summary.*

	June 29, 1895.	August 13, 1896.	August 12, 1898.	June 2, 1900.
	8 a. m.	2 p. m.	8 a. m.	2 p. m.
(1) Percentage of vapor condensed between t_s and $t = 32°$ F., $= 100\ \% - \frac{\mu'}{\mu}$	51 %	52 %	57 %	50 %
(2) Grains of vapor condensed in each cubic foot of air cooled from t_s to 32° F., = absolute humidity at $t_s \times$ (1)	3.046	3.380	4.182	3.001
(3) Number of cubic feet of air that must rise from h_s to h'_o to condense the equivalent of one inch of rainfall = (252.286 × 144 = 36,329) ÷ (2)	11,927	10.748	8,687	12,106
(4) Velocity of ascending current at height h_s, in miles per hour, that would condense the equivalent of one inch of rainfall per hour = (3) ÷ 5280	2.26	2.04	1.65	2.29
(5) Velocity of ascending current at height h_s, in miles per hour, that would condense the equivalent of 5 inches of rainfall per hour = (4) × 5.	11.30	10.20	8.25	11.45

Mean height of base of cumulus clouds (Table 10) ..... 1,182 meters.
Mean height of base of cumulo-nimbus clouds (Table 10) ..... 1,750 meters.
Mean height of base of clouds computed from p. m. data, cases 2 and 4 ..... 1,455 meters.
Mean height of top of cumulo-nimbus clouds (Table 10) ..... 4,965 meters.
Mean height of freezing temperature (Table 157) ..... 4,825 meters.
Mean height of freezing temperature computed from p. m. data, cases 2 and 4 ..... 5,104 meters.

The values of h_b have been computed from the data in Table 157 which applies to high areas and clear weather. As a matter of fact, while the barometer was high on August 12, 1898, the entire day was cloudy, although only a few miles away the sky was only partly obscured, and little or no rain fell; on June 2, 1900, while the sun was shining until shortly before the rain began, the barometer was below the normal. We can not, therefore, consider the values of h_b to be very exact.

The comparison in Table 6 of the mean of our p. m. computed results with the determinations by both theodolite and balloon observations, indicates nothing in the results discordant with the conditions as they actually exist. It seems quite probable that convectional currents would have been maintained on these afternoons until a temperature of 32° F. was nearly or quite reached. In fact, a few hailstones fell on June 2, 1900.

The maximum temperature on June 29, 1895, was 87° F. Had this value of t been substituted in equation 145 instead of the 8 a. m t, our results would have shown that the conditions favored strong convectional currents on that day also. On the dates June 29, 1895, August 13, 1896, and June 2, 1900. the rain fell during a thunderstorm.

The rainfall of August 12, 1898, appears to have been of a different character. The maximum temperature of the day was 76° F., and local surface conditions, except the high humidity, did not favor convectional currents, although favorable conditions may have existed at the cloud level. No electrical display accompanied this storm.

The results indicate that it is not unreasonable to attribute the rapid rates of rainfall experienced during thunderstorms to condensation by adiabatic cooling of ascending air. An ascending current of 10 or 12 miles per hour would account for the most rapid rate that occurred during any one of these storms. Indeed, it is not necessary to assume so high a velocity as this; for no doubt the vertical movement, like the horizontal, is quite irregular; and since it is capable of sustaining a quantity of condensed vapor, which, if the water drops are large, may vary approximately as the square of its velocity, it follows that during the periods of relatively slow upward movement the accumulation of raindrops would be allowed to fall, and the rate of precipitation would thereby be made to greatly exceed the rate of condensation. The size of the raindrops is probably an indication of the velocity of the ascending current in which they were formed and supported.

It must not be supposed that all the moisture condensed by adiabatic cooling falls to the earth as rain. In fact, the equations 145 and 146 are based on the supposition that all the moisture is retained. The dense cumulus clouds so frequently observed indicate that a very considerable amount of condensation frequently occurs without any precipitation. But if the convectional currents are at all active and the dew-point is high, as was the case on the days we have considered, there comes a time when the cloud space can retain no more moisture and any further condensation will result in rainfall.

In Bulletin No. I, 1899, of the Blue Hill Meteorological Observatory, Mr. H. Helm Clayton has computed that the precipitation from a current ascending with a velocity of 3.6 miles per hour, through a cloud layer 1,640 feet thick should occur at the rate of 0.12 inch per hour, the mean temperature of the cloud being 34.8° F. The temperature and thickness of the cloud layer were determined by a kite meteorograph record. It is interesting to note that his estimate of the velocity of the vertical current, based on its effect upon the kite, is one-tenth that of the horizontal current.

The effect of mountains in causing condensation of the moisture in the air that is forced upward in passing over them is well understood. In the well-developed cyclones that cross the central and eastern parts of this country there is usually a warm, moist current from the south in front, and a cold, dry current from the northwest in the rear, both moving spirally inward toward the center. As these currents push against each other there must be a tendency for the warm, moist current to rise above the other on account of the difference in their specific gravities.

With the surface conditions such as were recorded at Washington on August 12, 1898, if we suppose the cloud layer to extend from the computed saturation height, 732 feet, to a height of 4,492 feet, where adiabatic cooling would have reduced the temperature to 59° F., and 20 per cent of the vapor would have been condensed, then a vertical velocity of 1 mile per hour throughout the cloud layer would condense the equivalent of 0.21 inch of rainfall per hour, or 5 inches in twenty-four hours.

But here again we must not commit the error of supposing that all the moisture condensed as cloud will fall as rain. Mr.

Clayton found on the day that the kite observations were made, on which he based his calculation, that the observed rate of precipitation was only one-tenth of the computed rate. He concluded that much of the condensed moisture was reabsorbed by the unsaturated lower layers of the atmosphere.

While this might be true with a saturation temperature of 34.8° F., such as he observed, since the total amount of vapor present in the air would necessarily be small, as shown by Table 3, we can not suppose that any such proportion of the moisture condensed under conditions such as we have here considered would be so reabsorbed.

Undoubtedly there are many considerations that will contribute to reduce the precipitation to a rate much below that of condensation. Nevertheless, Professor Bigelow's tables for computing the adiabatic changes under various surface conditions have opened up to us a profitable field for study.

RAINFALL ON THE ISLAND OF ST. KITTS, W. I.

By W. H. ALEXANDER, Observer, Weather Bureau, dated Nov. 19, 1900.

This paper is the fulfilment of a purpose expressed in an article on the Climatology of St. Kitts, published in the REVIEW, Annual Summary, for 1899, and for obvious reasons the two should be considered together, the one being supplementary to the other.

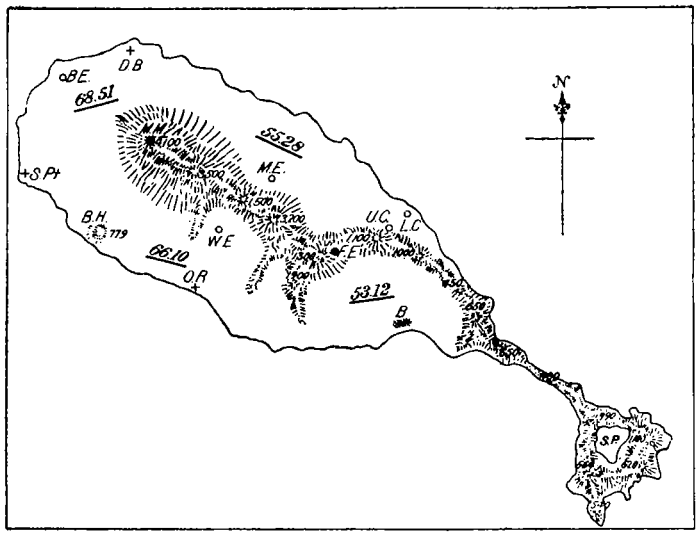

FIG. 2.—Island of St. Kitts, W. I., latitude 17° 18′ north, longitude 62° 48′ west.

Explanatory.

B. Basseterre, the capital and chief town; location of U. S. Weather Bureau. O. R. Old Roads, a small village. B. H. Brimstone Hill, at one time a celebrated fortress. S. Pt. Sandy Point, a small village. D. B. Dieppe Bay, a small village. M. M. Mount Misery, an extinct volcano, about 4,100 feet high. S. P. Salt Pond. W. E. Wingfield Estate. M. E. Molyneux Estate. L. C. Lower Canada. U. C. Upper Canada. F. E. Fountain Estate. B. E. Brotherson Estate.

Attention is first invited to the careful consideration of the accompanying map of St. Kitts, which together with the descriptive matter found in the article in the Annual Summary, ought to give the reader a very clear idea of the contour and physical features of the island. Very great pains have been taken in the construction of this map, and it is believed to be entirely trustworthy for all purposes, being simply a reduced form of a map issued by the Admiralty of the English Government. Only such places as are referred to elsewhere in the text, and those of peculiar interest, have been noted on the map, the main purpose being to render more intelligible the divisions made of the island for this discussion. The guiding principle in the division was to group those estates similarly situated with reference to the hills and mountains, and so, if possible, arrive at some estimate of the local influences which obtain on the island with regard to rainfall. We make four divisions as follows, viz:

1. *The north end.*—This includes all that portion of the island to the north of a line drawn, say, from Sandy Point (S. Pt.) in a nearly northeasterly direction, crossing the foot hills of the mountains and then to the sea. Roughly speaking, this embraces about twenty-eight per cent of the cultivated portion of the island. The rainfall in this district is, perhaps, the least influenced by the elevated portions of the island, or if at all, certainly very differently affected thereby. The average annual rainfall on this area, as determined by the records of the thirteen stations covering a number of years, is 68.51 inches, as indicated on the map, and also in Table 1. The greatest annual rainfall on record, 114.68 inches, occurred at Brotherson's estate, within this division, in 1898.

2. *The east side.*—This division embraces all the estates on the windward side of the island, and represents about twenty-seven per cent of all the cultivated portion of the island. The influence of the mountains upon the rainfall of this district is attested by a marked decrease of more than 13 inches in the yearly average from that of the north end, being only 55.28 inches. This decrease may be partly accounted for by a phenomenon frequently noticed, especially on days when strong convectional currents are present—the passing of the clouds around instead of over the mountains. For instance, a large cumulo-nimbus cloud may be seen approaching from the east, but as it nears the land it will be seen to change its course and pass either around the mountains or perhaps will be drawn over the depression in the mountain range of the main body of the island. As a result, we find a very heavy rainfall on both sides of this depression, as shown by the records of the two estates, Molyneux and Wingfield, given in the table. The clouds sometimes divide, one portion going north or south of the mountains, and the other over the depression just mentioned.

3. *The south end.*—This division includes the picturesque and fertile Valley of Basseterre, and is encircled on three sides by hills and mountains of heights varying from 400 to 1,300 feet, as shown on the map; it contains about twenty-nine per cent of the cultivated land of the island, and has the smallest average rainfall of the four districts, it being only 53.12 inches, or more than two inches below the east side and 15 inches below the north end.

4. *The west side.*—This division contains only about 16 per cent of the cultivated lands of the island and is situated on the leeward side of the great mountain range, which runs ridge-pole like through the central part of the main body of the island. The average for this district—66.10 inches—is not far below that of the north end. Perhaps the most interesting point in this district as regards our present discussion is that of the Wingfield estate mentioned above.

Taking the island as a whole the records seem to indicate an annual average of 59.25 inches, which is an appreciable increase upon the average given in the discussion in the Annual Summary for 1899, namely, 51.66 inches; which, however, was the average for Basseterre alone. The greatest downpour at any one time was that known as the flood of 1880, an account of which may be found on page 196 of the REVIEW for January, 1899. In addition to what has been said I will add a note found in Mr. Evelyn's old records made at the time of the flood. It reads:

> Supposed that 36 inches fell during the time from 12 o'clock (noon) to 3 a. m. of 12th. Town flooded; immense damage to houses; 230 lives lost and missing.

The month of March, 1891, is the driest month on record. The average for the island was only 0.16 inch, whereas the normal amount for that month is about 1.57 inches. Attention is called to the fact that there is a difference of only 0.08 inch in the annual mean at Molyneux and Wingfield estates.