cumulus head appeared above the scarf, and at 6:24 but little of the scarf remained (Fig. 1). At this level was a band of shadow marking the level of the false cirrus clouds not far west. The sun being near the horizon, this shadow was like a narrow girdle round the cloud. At about 6:26 another cumulus head beside the large one made a scarf cloud, and at 6:28:30 it appeared above the top of the scarf. Another hump of the same cloud mass grew rapidly upward from the shadowy lower levels. I watched the air above the tip. At 6:30:25 the scarf cloud suddenly appeared above the rising column (Fig. 2); 30 seconds later the cumulus entered it, and in 55 seconds more it appeared over the top. At 6:32:40 the scarf was entirely gone. Sometime between 6:39:15 and 45 a scarf appeared over another cloud head; at 6:40:5 the cumulus entered the scarf. At 6:40:20 a second scarf cloud appeared above the first. Then at 6:41:30 the cumulus overtopped the first scarf, and at 6:42:35 the second. At the same time a secondary head rising toward the humid layer caused a fine three-leaved scarf cloud to form. By 6:43 the scarf clouds had disappeared. A minute later a thin sheet of cirro-cumulus was seen approaching the thunderhead; at 6:45:15 it reached the rising cloud and was there thickened into scarf formation. A scarf cloud was seen also on July 12, at 55:5 p. m., and another on July 14, at 6 p. m., on the rear side of a great cumulo-nimbus.

On July 18, from a train window between Trenton and New Brunswick, N. J., I observed in the southeast a series of ten scarf clouds between 4:44 and 4:54 on the rear of one cumulus cloud. The surface wind was a moderate breeze from the southwest; at the level of the base of the cumulus the movement was at about 40 kilometers per hour; while at the middle level, the movement was near 55 kilometers per hour, from the southwest. These velocity observations were taken on an accelerating train by noting the speed at which the clouds stopped their apparent forward motion and began to go backward. The train was running parallel to the cloud movement. The sheet of cirro-cumulus, alto-cumulus, and alto-stratus some distance above, was moving at a rate of less than 80 kilometers an hour toward the northeast. Above this false cirrus (?) sheet were some cirrus clouds with scarcely any perceptible forward motion. The level of maximum velocity within the cumulus layer seems to have been at about the middle of the cloud; and it was at this level that the scarf clouds formed. Above this height the top of the cloud seemed to have a dissolving tendency, and to move backward relative to the middle. Still higher, another stronger current from the west marked the top of the cloud; its presence was indicated by the apparent eastward lean of some projecting portions of the cloud. The total vertical thickness of the large cumulus probably did not exceed 2 or 3 kilometers. The ten sketches (Fig. 3) show how the scarf clouds formed successively as cumulus growths added themselves to the rear of the cloud. At 5:05 a small scarf cloud was seen just over one of the highest of the cumulus domes.

Conclusions.

These observations lead to three conclusions:

1. One reason why the scarf cloud is infrequently observed is the rapidity of its formation and disappearance. The total duration of each of the six scarf clouds observed July 13, between 6:22 and 6:43, was from two to three minutes only, and those of July 18, from one to two minutes each. Furthermore, only in the late afternoon do conditions seem to favor their formation.

2. The rapidly rising column of saturated air in a cumulus cloud *apparently* elevated the superincumbent layers. The time interval between the appearance of the scarf and the entrance of the cumulus cloud into it gives some measure of the distance to which this raising is effective. And the time the cumulus top takes in going through the cap gives a rough measure of the thickness of the humid layer. The apparent rising motion of the cumulus towers indicates an ascending current, say, of 7 meters per second (a value which the writer once determined instrumentally at Blue Hill Observatory). With the average interval of 30 seconds from the time of appearance of the scarf to the entry of the cloud, the distance may be 200 meters. The thickness of the scarf is less than 400 meters, probably less than half this, for the scarf is raised with the cloud, and also the cloud comes through before it becomes visible below. The diameter of the scarf may easily be 1 kilometer, yet it formed almost instantly.

3. The top of the cumulus cloud actually does not move forward as fast as the flat clouds at the same level. This is to be seen when the false cirrus advances 50 or 100 kilometers before the oncoming thunderstorm; but rarely do we see a flat cloud overtake and surround the cumulus dome. Such was the case July 13; the great cumulus cloud, like a mountain, interrupts the free flow of the wind. Perhaps these scarf clouds like the helm clouds of mountains are formed by the winds rising to pass over the dome, rather than by the up-push of the rising cloud column.[3]

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SOME FIELD EXPERIMENTS ON EVAPORATION FROM SNOW SURFACES.

By F. S. BAKER, Forest Examiner.

[Utah Experiment Station, Ephraim, Utah, June 25, 1917.]

In the irrigated section of the Great Basin of the western United States, one of the chief factors affecting crop production is the amount of snowfall in the adjacent mountains, as melting snows give rise to most of the irrigation water. So important are these snows that annual surveys are made on some of the more important watersheds in order to forecast, in a general way, the amount of run-off likely to be available. In other places windbreaks have been built in attempts to divert the drifting snow to certain watersheds. The amount of snow that will be effective in yielding water for use in the valleys is therefore of considerable importance throughout this entire region. In making snow surveys it has, of course, been recognized that much of the snow water is lost to surface run-off by evaporation and by percolation into the soil, but the magnitude of these losses has bever been determined.

At the Utah Forest Experiment Station, located on the Manti National Forest in the mountains of central Utah, an experiment is under way dealing with the effects of grazing on the erosion of the high mountain ranges. Two small drainage areas have been selected and equipped with sediment basins and weirs at their lower ends to determine the run-off and amounts of sediment that come from these areas during rains and seasons of melting snow. One area is to be grazed while the other is to be revegetated. One of the effects of revegetation will probably be to increase the percolation of snow water into the ground. This loss can not be directly determined, however, but as the amount of water on the areas in the form of snow is determined by surveys and the amount of run-off is obtained from weir readings, the water lost

[3] See *Max Reinganum* in Meteorol. Ztschr., Mai 1912, 29:242-3.

through percolation and evaporation together can be determined by subtracting the run-off from the water equivalent of the snow. Of this amount the quantity percolating into the soil could be indirectly determined if the evaporation were known.

An investigation of the amount of evaporation from snow surfaces was therefore undertaken at the Utah Experiment Station in the winter of 1915–16. In this study the evaporation was measured by the periodic weighing of a "hyaline" glass battery jar filled with snow. The jar was cylindrical with an inside diameter of 16 cm. and a depth of approximately 25 cm. The walls were of heavy glass approximately .5 mm. thick, but clear and only slightly tinged with green. This type of jar was used on account of its nonabsorption of heat and poor conductivity, as in even the best substitute, white enameled pans, the snow melts considerably on days when the [air] temperature never exceeds 32° F. The jar was filled with snow and then sunk in the open until its top was flush with the general level of the snow surface. It was removed and weighed daily at 8:30 a. m. and 4:30 p. m., so that the diurnal and nocturnal evaporation was determined separately. The weight was determined on balances sensitive to 1 gm., which was equivalent to a depth of 0.002 inch of water in the jar. The jar was refilled whenever the snow had fallen appreciably below the rim, care being taken to have surface snow always on the top. The jar was exposed in a flat clearing of about 5 acres in the aspen (*Populus tremuloides*) timber in which the experiment station is located and within the inclosure in which the meteorological instruments are exposed, open to the sun during the entire day.

The meteorological data used in the evaporation studies were gathered in connection with the regular work of the experiment station, it being a Weather Bureau cooperative station. Air temperatures were taken from a thermograph checked by Weather Bureau maximum and minimum thermometers exposed in a standard instrument shelter about 10 feet from the jar, the mean being taken from hourly readings.

Mean wind velocity was taken from the triple register records, the anemometer being located on top of the laboratory building 75 feet distant [and — feet above ground]. Humidity was determined daily at 8:30 a. m. and 4:30 p. m. with a standard Weather Bureau sling psychrometer.

The observations on evaporation, air temperature, and wind velocity are shown in detail in Table 1. Naturally no data could be obtained on days when snows occurred nor usually directly after storms when the wind was strong enough either to blow the light snow off or drift it over the battery jar. In the latter part of February the work had to be discontinued, as the water from the melting snow would freeze at night and break the jars. Therefore no data were obtained for evaporation during storm periods, high winds, or the spring thaw, but those obtained fully cover the calm, clear days of winter. Observations began November 11, 1915, and continued until December 9 with three interruptions due to storms. The latter part of December and all of January were very stormy and observations were not resumed until February 14, 1916, after which they were continued to February 25. Snow lay on the ground at the Utah Experiment Station from November 7, 1915, to May 4, 1916, a period of almost six months.

The mean diurnal and nocturnal evaporation from the snow surface, together with the mean temperature and wind velocity for the same period, are shown graphically in figure 1. Evaporation can not be strictly correlated

TABLE 1.—*Observations on snow evaporation, air temperature, and wind velocity at Utah Forest Experiment Station, Manti National Forest.*

Date.	Time of observation (*)	Weight of jar.	Loss in weight.	Loss in depth.	Loss per hour.	Mean temperature.	Mean wind velocity.
		Grams.	*Grams.*	*Thousandths of inch.*	*Thousandths of inch.*	*°F.*	*Mis./hr.*
1915. Nov. 11	A. M.	2,487					
	P. M.	2,482	5	10	1.25	17.8	3.9
12	A. M.	2,481	1	2	0.12	13.8	5.0
	P. M.	2,473	8	16	2.00	24.8	13.4
13	A. M.	(1)					
	P. M.	(1)					
14	A. M.	2,493	(2)				
	P. M.	2,489	4	8	1.00	20.9	2.2
		2,496	(2)				
15	A. M.	2,500	−4	−8	−0.50	15.0	3.9
	P. M.	2,497	3	6	0.75	27.8	2.3
16	A. M.	(1)					
	P. M.	2,500	(2)				
17	A. M.	2,508	−8	−16	1.00	9.4	4.1
	P. M.	2,507	1	2	0.25	16.5	2.9
18	A. M.	2,504	3	6	0.37	22.0	2.7
	P. M.	2,504	0	0	0.00	31.7	4.0
19	A. M.	2,510	−6	−12	−0.75	24.1	3.4
	P. M.	2,505	5	10	1.25	38.4	2.7
20	A. M.	2,491	14	28	1.75	38.1	6.0
	P. M.	2,486	5	10	1.25	39.0	7.4
		2,601	(2)				
21	A. M.	2,597	4	8	0.50	34.5	3.9
	P. M.	2,587	10	20	2.50	42.7	6.9
		2,648	(2)				
22	A. M.	2,640	8	16	1.00	38.0	3.7
	P. M.	2,634	6	12	1.50	37.5	4.2
23	A. M.	2,629	5	10	0.62	33.9	3.5
	P. M.	2,616	13	26	3.25	47.4	5.9
		2,775	(2)				
24	A. M.	2,760	15	30	1.87	33.4	7.4
	P. M.	(1)					
25	A. M.	2,269	(2)				
	P. M.	2,267	2	4	0.50	14.0	2.6
26	A. M.	(1)					
	P. M.	(1)					
27	A. M.	(1)					
	P. M.	(1)					
28	A. M.	2,401	(2)				
	P. M.	2,397	4	8	1.00	14.5	4.6
29	A. M.	2,392	5	10	0.62	20.3	3.1
	P. M.	2,383	9	18	2.25	34.2	3.7
30	A. M.	2,379	4	8	0.50	28.5	3.2
	P. M.	2,376	3	6	0.75	27.2	3.3
Dec. 1	A. M.	2,379	−3	−6	−0.37	17.0	3.5
	P. M.	2,372	7	14	1.75	30.0	6.3
		2,419	(2)				
2	A. M.	2,415	4	8	0.50	23.8	4.6
	P. M.	2,410	5	10	1.20	36.2	3.1
3	A. M.	2,401	9	18	1.13	30.0	3.7
	P. M.	2,397	4	8	1.00	37.4	6.9
4	A. M.	(1)					
	P. M.	(1)					
5	A. M.	(1)					
	P. M.	(1)					
6	A. M.	2,639	(2)				
	P. M.	2,636	3	6	0.75	30.0	1.6
7	A. M.	2,637	−1	−2	−0.12	25.9	3.0
	P. M.	2,635	2	4	0.50	33.7	2.9
8	A. M.	2,635	0	0	0.00	27.2	3.9
	P. M.	2,628	7	14	1.75	40.4	2.5
9	A. M.	2,625	3	6	0.37	36.8	4.4
	P. M.	2,617	8	16	2.00	34.6	6.0
1916. Feb. 14	3:30 P. M.	2,538	(2)				
15	9:30 A. M.	2,535	3	6	0.33	25.8	3.7
	4:30 P. M.	2,530.5	4.5	9	1.30	35.8	3.0
		2,749	(2)				
16	9:30 A. M.	2,746	3	6	0.37	24.4	3.7
	4:30 P. M.	2,738	8	16	2.00	38.0	3.0
		2,770	(2)				
17	11:00 A. M.	2,766.7	3.3	6.6	0.35	24.8	4.2
	4:30 P. M.	2,763	3.7	7.4	1.35	32.9	2.4
18	10:00 A. M.	2,748	15.0	3.0	1.72	27.4	11.6
		2,794	(2)				
	4:30 P. M.	2,785	9	18	2.77	35.8	9.3
		2,812	(2)				
19	9:30 A. M.	2,811	1	2	0.12	27.8	5.4
	4:30 P. M.	2,804	7	14	1.75	36.9	3.1
		3,217.4	(2)				
20	8:30 A. M.	3,216	1.4	2.8	0.17	25.7	5.9
	4:30 P. M.	3,210.9	5.1	10.2	1.27	34.2	3.2
		3,067.1	(2)				
21	8:30 A. M.	3,065.2	1.9	3.8	0.22	27.6	7.6
	4:30 P. M.	3,057.7	7.5	15.0	1.87	34.4	8.0
22	A. M.	(1)					
	P. M.	(1)					
23	11:00 A. M.	3,073.4	(2)				
	4:30 P. M.	3,069.2	4.2	8.4	1.58	33.7	2.5
		3,095	(2)				
24	8:30 A. M.	3,092.6	2.4	4.8	0.30	22.0	4.0
	4:30 P. M.	3,089.2	3.4	6.8	0.85	37.7	3.0
		3,137.9	(2)				
25	9:30 A. M.	3,133.2	4.7	9.4	0.59	22.0	4.6
	4:30 P. M.	3,128.0	5.2	10.4	1.30	37.3	2.2

(*) Readings were taken in November and December at 8:30 a. m. and 4:30 p. m.; in February, somewhat irregularly as noted.

[1] Snowstorm. [2] Refilled to top.

with temperature or wind velocity as the factor of humidity is also a variable quantity. The graphs in figure 1 show that in this winter evaporation varied closely with temperature, and that where deviations occurred they could frequently be explained by the wind velocity curve, as on the night of November 19, of November 22, and particularly the night of February 17 and the day of the the air, f is the maximum vapor pressure at the temperature of the snow layer, and t is the time of exposure in hours. This formula was used in a number of typical cases in the work done at the Utah Experiment Station, to test the applicability of the formula to local conditions. The computed values, however, varied widely and irregularly from the observed quantities, the actual

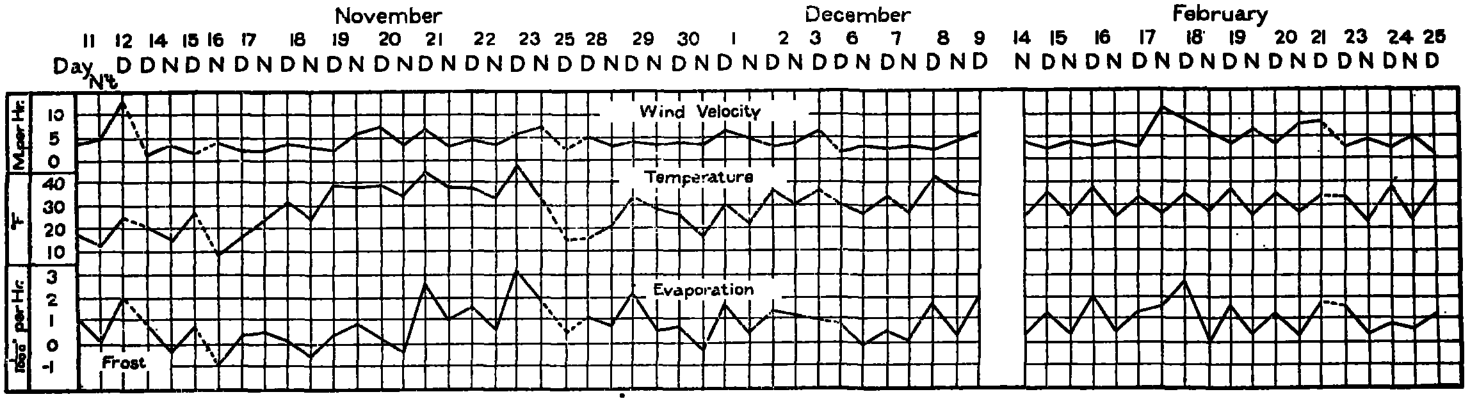

FIG. 1.—Mean daytime and nighttime evaporation from a snow surface in Manti National Forest, Utah. Also, temperatures and wind velocities (miles per hour) there, November 11, 1915, to February 25, 1916.

Solid lines indicate continuous observations; broken lines indicate interrupted observations.

18th. In other cases it will be noted that the evaporation was in accord with neither temperature nor wind velocity, as on November 20, when the deviation was apparently due to the great change of humidity accompanying a cyclonic disturbance.

In figure 2 the evaporation is plotted on the basis of temperature, the curve showing a rapid increase of evaporation with rising temperature. In preparing this graph the evaporation values for each day and night appearing in figure 1 were segregated into 5-degree groups, according to the mean temperature of the period of evaporation. Thus the mean hourly evaporation recorded on days and nights whose mean temperatures were between 10° and 15° F. were placed in one group, those recorded in periods whose mean temperatures were 15° to 20° in the second, and so on. The widely varying values in each group were then averaged and the means plotted on the chart, these points being indicated by small circles, which formed the basis for drawing the harmonized curve. The mean hourly diurnal evaporation for the period of observation was also determined, with the mean diurnal temperature for the same period. The mean nocturnal evaporation with the corresponding mean temperature was also ascertained. The first is represented by the X above the curve and the second by the X below. The fact that the diurnal evaporation is higher than it should be considering the mean diurnal temperature and that the nocturnal evaporation is abnormally low, can not be explained by wind velocity as the mean daytime velocity is 4.52 miles per hour and the nocturnal 4.58, but must be due to the higher humidity at night and to the direct effect of insolation during the day.

Rolf [1] has reported a similar investigation conducted in Lapland in which enameled pans were used instead of glass jars, from which formulas were deduced for determining the condensation upon a snow surface under a number of different conditions. For the winter season while the ground is entirely snow covered, his formula is:

$$C = +0.0174(F\text{-}f)t,$$

in which C is the condensation (evaporation when its sign becomes minus), F is the actual vapor pressure of

evaporation usually being two or three times greater than computed, particularly at higher evaporations. This was not due to high wind velocities as they were about the same as those recorded by Rolf in Lapland. It therefore appears that so far as the writer's observations go this formula is of little value in attacking the problem of snow evaporation under conditions found in

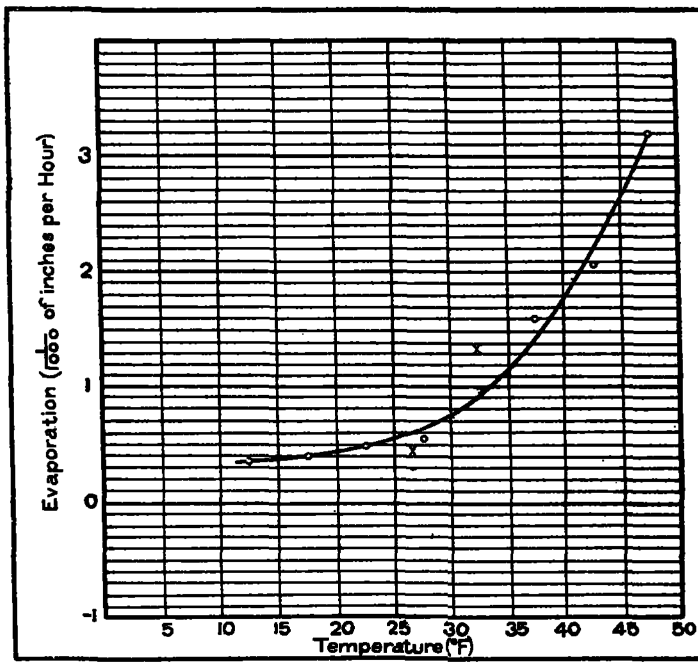

FIG. 2.—Relation of evaporation to temperature at Manti National Forest station, Nov. 11, 1915–Feb. 25, 1916.

the western mountain ranges. A possible source of inaccuracy lies in the assumption worked out by Rolf that the temperature of the superficial snow layer remains about 3.5 degrees (C.) lower than the surrounding air. When actual snow-surface temperatures shall have been taken the results may be more consistent. It seems certain that the difference in temperature between the snow and air would not be the same under conditions found in Lapland and those in the mountains of Utah, where the humidity is much lower and the insolation much more intense.

[1] *Rolf, B.* Note sur la condensation et l'evaporation qui se produisent à la surface p'une couche de neige. Ark. f. Mat., astron. och fysik, Bd. 9, No. 35, p. 47.

Horton[2] concluded, after noting the evaporation of snow in the outer can of the standard raingage, that for fairly cold weather without heavy winds, with air usually clear, the evaporation amounts to about 1 inch of water per month during the winter at Albany, N. Y. This is about twice the average monthly value obtained in Utah by the writer.

Church[3] mentions a single instance of excessive evaporation in Nevada where 0.1 inch of moisture was evaporated in a single night, with an average wind movement of 33 miles per hour, the temperature being below freezing.

Total evaporation, winter of 1915–16.—The figure capable of the most practical application in this work is, of course, the total evaporation for the snow season. This value has been obtained in two ways: *First*, the mean daily evaporation of 0.0175 inch multiplied by the length of the snowy season, 180 days, gives 3.15 inches as the winter evaporation. The *second method* is probably more accurate. For each 10-day period the mean temperature was ascertained, together with the number of hours without precipitation in which it was assumed that evaporation was taking place. Then by means of the curve in figure 2, the total evaporation for the 10-day period was determined. By adding all of these periods together, the total of 2.80 inches was obtained for the winter. It seems evident therefore that under conditions existing at the Utah Experiment Station—and which may hold for all the higher parts of the mountains of Utah—3 inches is a fair figure for the winter evaporation of 1915–16. The water equivalent of the snowfall in the same locality for the winter of 1915–16 was 21.91 inches, so that approximately 14 per cent of the total snowfall was evaporated into the air. In making careful snow surveys in the Great Basin this figure should prove of value, particularly in cases similar to the erosion and stream-flow experiment at the Utah Experiment Station in which the losses by percolation into the soil under different conditions are to be determined.

Effect of forests.—The effect of forest cover on evaporation can hardly be determined from these data since it acts partly through its influence on wind velocity, a matter which could not be investigated in a satisfactory manner on account of drifting and erosion during high winds. The few readings that were secured, however, indicate a considerable increase in evaporation with increased wind velocity, which Church's data also corroborate. Forest cover also reduces the direct insolation upon the snow and probably reduces the evaporation in consequence. If Rolf's formula quoted above is based on sound principles, it appears that insolation would be an important factor in accelerating evaporation, depending chiefly on the rise in temperature of the surface snow. It seems probable, therefore, that forests, by shading and checking the wind movement, diminish the evaporation from the snow cover especially in wind-swept situations; but this may be partially counteracted by the greater area exposed to evaporation by the snow clinging to the branches of the trees, particularly the conifers which form the forests at higher elevations throughout the Rocky Mountains.

DARK DAY IN JAMAICA.

In the MONTHLY WEATHER REVIEW for January, 1917, page 12, Mr. Maxwell Hall, meteorologist to Jamaica, reported an observation of the dark day of May 19, 1780, from Jamaica. The editor there suggested that the observation was perhaps that of the effects of a local or near-by forest fire. Mr. Hall replies that as there are no forest fires in Jamaica, the woods always being too green, the explanation must be sought elsewhere.

551.596

DISTANCE AT WHICH THUNDER CAN BE HEARD.

The following observations by Cooperative Observer Clarence E. Miller, at Carlisle, Pa., have been condensed from a report received through Section Director Geo. S. Bliss, meteorologist in charge of the Philadelphia office. They furnish interesting evidence and testify to the painstaking work of the observer. The following note of experiences in other countries is also of interest, and may rouse yet others to similar observations.—EDITOR.

On the evening of June 27, 1913, between 7:30 and about 8:30 o'clock, dense clouds were observed moving north to south far east of Bloserville, Pa., and sharp lightning in the summits of these clouds developed within a few minutes into vivid flashes covering the whole cloud system. Thunder could be heard very faintly after sharp streaks of lightning; and soon there came an almost imperceptible breeze from the east * * *. I then did the best thing I knew of to determine the distance of the lightning: I observed carefully what appeared to be the heaviest streaks of lightning and counted at such a rate that every 5 counts would be equivalent to a mile [traveled by the sound]. Two others with me I had do the same thing to check my counts. We kept this up for 10 minutes or more and were surprised to find that the report of the thunder followed the flash of lightning in from 170 to 175 counts. The time between flash and thunder was almost 3 minutes each time; and the report of the thunder was quite distinct although only the heavy "bump-ump-ump" was heard without a rolling, rumbling sound. This meant the storm was about 30 to 35 miles distant; and inquiries from other observers in Harrisburg developed the fact that this identical storm traveled north to south along a line through Hummelstown and Middletown, where it attained great severity. This storm was therefore actually 30 to 40 miles distant from us while observing it.

On the night of July 1, 1913, at dusk I observed contrasted against the dense, fog-like haze which had opposed the sun's rays for an hour preceding sunset, a lone small cloud of very dark appearance and slowly increasing in size. At dark I observed a flash of lightning in the cloud, followed in a few minutes by another flash, and then by many more in rapid succession, accompanied by heavy thunder. A number of persons were with me, and by counting the interval between lightning and thunder we estimated the storm to be 10 to 12 miles distant. It lasted about half an hour and died out as rapidly as it came up. The sound of the thunder was terrific and I am sure could have been heard at two to three times the distance we were from the storm. Later inquiry showed that this storm was the violent, tornado-like destructive one that visited Carlisle, Pa., and that it was 10 to 12 miles distant. I am certain the thunder carried twice as far.

On the night of August 18, 1913, we observed a storm south-southeast of Bloserville, Pa., in the direction of Gettysburg, with vivid and continuous lightning. Although there was a wind from the northeast [i. e., a cross wind], the thunder could be heard quite plainly at times. The exact location of this storm I have not been able to determine, but we could see plainly that it was not on the northern side [i. e., his side] of South Mountain which was 15 miles away, and the clouds suggested that it was considerably beyond the other side of that ridge. [It was therefore between 16 and 18, perhaps 20, miles distant].

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[2] *Horton, R. E.* MONTHLY WEATHER REVIEW, 1914, 42: 99.
[3] *Church, J. E., jr.* The progress of the Mount Rose Observatory 1906–1912. Science (N. S.), December 6, 1912, 36: 796.