ART. XV.—*Verification of Tornado Predictions;* by H. ALLEN HAZEN.*

IN taking up the study of the verification of tornado predictions, we must carry in mind the exact words of the prediction which are: "Conditions are favorable for the development of tornadoes in region . . . ." It is generally understood that in these predictions the country east of the 102° meridian is divided into eighteen districts, and tornadoes are predicted for in each of these. For the present study the predictions for the month of June, 1885, are to be discussed. One scheme of verification that has been suggested is that of Prof. Gilbert, of the Geological Survey, published in *American Meteorological Journal* for September, 1884. Prof. Gilbert divides the predictions and occurrences into three general classes. 1. Suc-

* In the number of the *American Meteorological Journal* for July, 1884, Mr. Finley published a statement as to success in tornado prediction claiming over 97 per cent. This statement aroused quite a lively discussion in Science and other journals, notably one by Prof. Gilbert, in which he credited Mr. Finley with 23 per cent. In October, 1885, several persons were desired by Mr. Finley to take up the discussion, and the following paper is now presented as written then, it having been found impossible to publish it before this, through circumstances beyond the writer's control.—Washington, D. C., July 4, 1887.

cessful predictions. 2. Unsuccessful ones. 3. Failures to predict. In other words, every district in which a tornado occurred as predicted counted as one in favor of the predictor in the final summing up, and each district which did not have a tornado as predicted for, together with each district in which a tornado occurred which was not predicted, counted as one against the predictor. Taking the predictions of tornadoes for the month of June, 1885, and summing the three classes in the table, we find 8 successful; 32 unsuccessful; and 13 failures to predict: total, 53. This (according to Prof. Gilbert) gives a verification of 15 per cent for the predictions as made. It seems as though this method of verification is open to most serious objections, some of which may be enumerated as follows:

1. The verification depends on the occurrence of a tornado anywhere within an imaginary line and does not make any allowance for the nearness to that line, e. g., if a tornado should occur just at the edge or within five miles of the district for which it was predicted, it would count as *two* against the predictor, or if we should simply verify for that single prediction we would find a difference of 100 per cent. in the verification in going five miles, just across the imaginary line from one district into another. As an illustration of this, we may take a prediction of rain for the central of three contiguous districts, and as a system of verification we may adopt the principle that the occurrence of rain in any district where it was predicted shall be a success, and its occurrence in a district not predicted for shall count as a failure. In the case before us, let rain be predicted for the central district, and let it fall almost over the whole of it but lap a little on the districts to the right and left. According to the principles adopted, we would have one successful prediction and two failures and a verification of 33 per cent, while it must be admitted that any rational system of verification would allow a success of at least 90 per cent for such a prediction.

2. We cannot assume that all the tornadoes have been heard from in each district.

3. It is extremely difficult to distinguish between tornadoes and destructive storms, as one may merge into the other.

4. If there be any law in the occurrence of tornadoes, we would certainly expect that they will have a tendency to greater frequency in certain portions of an atmospheric disturbance, and if they occur outside of those portions that they will be more or less sporadic. The above system, however, regards all tornadoes precisely alike and gives no more weight to the occurrence of five in a district predicted for, than to the occurrence of one, perhaps of half the intensity of each of the other

five, which has occurred in a district not predicted for. We certainly cannot regard the occurrence of a tornado of so definite a nature, as, for example, a rifle-ball from a marksman's rifle, and we ought not to apply a method of verification which would be perfectly proper in the case of rifle-balls and a target to one utterly dissimilar.

5. No account is taken of the fact that the law of occurrence of tornadoes is very different in one portion of the country from that in another; for example, conditions which would almost invariably produce a tornado in the Mississippi valley would not be at all efficient in the region east of the Allegheny Mountains or in Texas.

6. It is entirely unsatisfactory to group together districts where only one tornado occurs in a year with those where thirty or more occur each year. This may be better seen by a slight exaggeration. Suppose we have a district where only one tornado occurs in ten years, it is very plain that a very good knowledge of the laws of tornado occurrence would be of little avail in predicting for such a region, and the chances of getting even one per cent. would be exceeding small, while if there were a region having 100 tornadoes in a single year, the chances of getting 50 per cent would be much better than of getting 1 per cent in the previous case.

In seeking for a satisfactory system of verification it should be distinctly borne in mind that the character of the occurrence is very indefinite and that we cannot apply rigid mathematical analysis to the questions, but must seek for a rational system which will best treat the prediction as worded and an occurrence so indefinite.

In seeking such a system I have carefully studied the occurrence of tornadoes and destructive storms, and have found the following comprise all the districts having more than thirty storms each: (No. 5) 35, (6) 35, (7) 35, (8) 30, (9) 35, (11) 35, (12) 35, (13) 60, (14) 40, (15) 32. Of these districts there are 3 in which the occurrence of tornadoes can hardly be said to be under precisely the same laws as in the rest; these are 5, 8 and 12. It has seemed wise to include in the discussion, though with less weight, hurricanes and destructive storms. As a working hypothesis, I have assumed that tornadoes occurring in a district half way between the center and edge shall have weight 1; in the rest of the district $\frac{3}{4}$; to the center of the district next outside $\frac{1}{2}$; to the outside of that $\frac{1}{4}$; all outside of these 0. A study of the predictions and occurrences has developed an approximate result as in the last column of the table herewith and a percentage of verification of 49.

TABLE.

Prediction, occurrence, and non-occurrence of tornadoes by Mr. Finley, for June, 1885.

	DISTRICTS.					SUCCESS.
Day.	Predicted for.	Occurred in.	Successful.	Unsuccessful.	Failures.	By weight.
2	9, 15	13		2	1	1, ½, ½
3	13, 15	15, 13	2			¾, ¾
4	9,			1		¾
5	2, 4	16		2	1	
6	15, 16, 18, 17, 12			5		0
7	8, 9, 12, 13	15, 8	1	3	1	½, ½
8	5, 6, 4, 7, 12			5		0, 0, 0
9	12, 11			2		0
12	13, 14, 15, 16	18, 16, 15	2	2	1	½, ½, 1
13	15, 16			2		½
14	13, 9, 15	16, 15	1	2	1	1, ¾, 1, ½
15	15, 17			2		¾, ½, ½
19	14				1	0
20	13, 16	14, 13	1	1	1	1, ½
21	8, 2	14, 13, 8	1	1	2	0, 0, ½
22	1	12, 2		1	2	
27	16	18, 15		1	2	½
						0, ½, ¾, 1
Total,			8	32	13	8, 13, 5, 5

By weights. Total, 31 cases, 15¼ success. Verification, 49 per cent.

A better knowledge of the degree of destructiveness of the storms would give much more rigid results. I have also refrained from giving the occurrence of a large number in any district as much weight as they should have; this would have given a slightly higher percentage of success.

There is also another important question that I have not touched upon, it is this: The occurrence of tornadoes in any districts must necessarily be connected with their non-occurrence, i. e., given a large number of districts in which tornadoes are possible, if one had a perfect knowledge of the laws governing the occurrence of tornadoes he would be forced to state or infer that in certain portions of these districts they would *not* occur, where to the uninitiated there would be an equal probability of occurrence or non-occurrence. Now, since it is difficult to decide what the probability of occurrence is, it would be well nigh impossible to assign a proper weight to a given occurrence, but one thing would certainly seem eminently just and that is that if in any district contiguous to one in which a tornado is predicted, the occurrence of a tornado not predicted receives full weight against a predictor, then the non-occurrence of one in a neighboring district not predicted for should have equal or nearly equal weight in favor of the predictor. It will be seen that if an allowance of the above nature be admitted the 49 per cent already found will be somewhat increased.

It may be objected, however, that the probability of any tornado occurring at all is so small, that the probability that one will occur in any one of the districts not predicted for is entirely overborne by the former consideration. This objection, however, is only plausible. If we should take the occurrence of a tornado on any single day of a year as a criterion, it must be admitted that the probability of such occurrence is very slight, but in the case before us we are not considering the occurrence of a tornado on any one of 365 days but rather on any one of, say, 50 special days when they are very likely to occur. It is easy to see that in this case the probability that a tornado will occur in any one of a large number of districts, on any one of a small number of special days, exceedingly favorable for its development, is vastly greater than the general haphazard guess that one will occur on any day of the year and especially on an unfavorable day. It seems as though this important principle has been overlooked in the general discussions of this question.

It seems probable that the division of the country into districts, in each of which predictions are to be made, is hardly wise. The whole subject is still on the border-line of uncertainty and indefiniteness. Possibly it would be more satisfactory to predict, in a region where at least 25 or 30 destructive storms and tornadoes occur each year, a central point or locus of destructive storms, giving boundaries, more or less definite, to the limit of destruction, and in verifying to give weights to storms occurring at distances of 50, 100, etc., miles from that locus. It is also essential that we pay the closest attention not to the probability of a tornado occurring on any day in general, but rather to the probability of its occurring on any one of a few special days when the general meteorological conditions and our knowledge of the laws of such storms (for example, their occurring in the southeast quadrant of a low area), would lead us to infer that they are extremely likely to occur.

Dec. 4, 1885.