ON THE EVALUATION OF TORNADO REPORTS AND A NUMERICAL METHOD FOR THEIR CLASSIFICATION [1]

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ABSTRACT

An attempt is made to rationalize the spectacular increase in the number of tornado reports during recent years and to make a logical segment of these reports compatible with reports of previous years. A numerical method of classifying tornado reports into "tornado," "possible tornado," "severe local storm," and "local storm" is suggested.

1. INTRODUCTION

In studying the problem of tornado definition and classification, the meteorologist might, at first, attempt to follow the general procedure used by scientists in other branches of science. For example, the zoologist, in defining and classifying a lion, will first consider it to be in the family "Cat", then in the genus "Felis", and finally in the species "Leo". He will discuss the similar characteristics of cats that distinguish them from other mammals; then, the similar characteristics of felines that group them into one genus, as well as the differences between the genus Felis and the other genera in the cat family. And finally, he will classify the Leo species on the basis of its individual properties as well as its differences from other species in the genus Felis. When a particular animal is brought to the zoologist he is able to identify it by noting its similarities and differences from other animals and thus assigns to it a specific family, genus, and species.

Similarly a scientific classification and definition of "tornado" can be set up in somewhat this manner: A tornado belongs to the family "storm", to the genus "severe local storm", and the species "tornado". Without going into the details of the description of the properties of the family and genus, we might, if we so wished, set up a definition of the species "tornado" based on the fact that it is a rotating vortex, that it has reduced pressure in the center, that frequently it has been observed in the right rear quadrant of a cumulonimbus cloud, that it has a particular velocity profile, that it is formed in a micro-Low, etc., etc.

This would make a very interesting and undoubtedly an accurate classification. Unfortunately, it would not prove to be too useful. Unlike the usual problems in scientific classification, the storm that is to be classified cannot be brought to the scientist for his inspection and for his study of its similarity and differences to other species of its genus and family. In the case of tornado classification and identification, these must be made usually on the basis of hearsay reports. From this point of view, the problem with which we are faced is somewhat similar to the problem of the interpretation of flying saucer reports. In these the scientist must consider and evaluate only the *reports* that are submitted to him, and he must form a conclusion based on these *reports*.

With regard to the tornado reports, we must fully realize that they are provided to us by laymen who are not trained in meteorological phenomena; by laymen who, for the most part, have just lived through a most violent kind of storm experience and thus whose objectivity with regard to what they saw or what happened is limited; by newspaper accounts of storms which on one hand are based on observations by laymen and on the other are "flavored" to make interesting reading for the public. In a few instances—and these are so few in number that a general classification method can hardly be based on them—qualified observers, such as meteorologists or field survey teams, have gone into the area where the storm occurred and have tried to evaluate what happened. But even these reports have yielded doubtful conclusions in many instances.

2. STATISTICS

Keeping in mind that tornado statistics emanate from such unreliable sources, let us look at what these statistics are:

On figure 1 there is given by the heavier line the number of tornado reports per year for the period 1916 to 1956. These reports are based on the official annual summaries put out by the Office of Climatology of the U. S. Weather Bureau. We note that the curve continues in a jagged fashion until about 1948 or 1949, when a progressive climb begins and continues in a most determined manner. On the right hand side is indicated the range of reports

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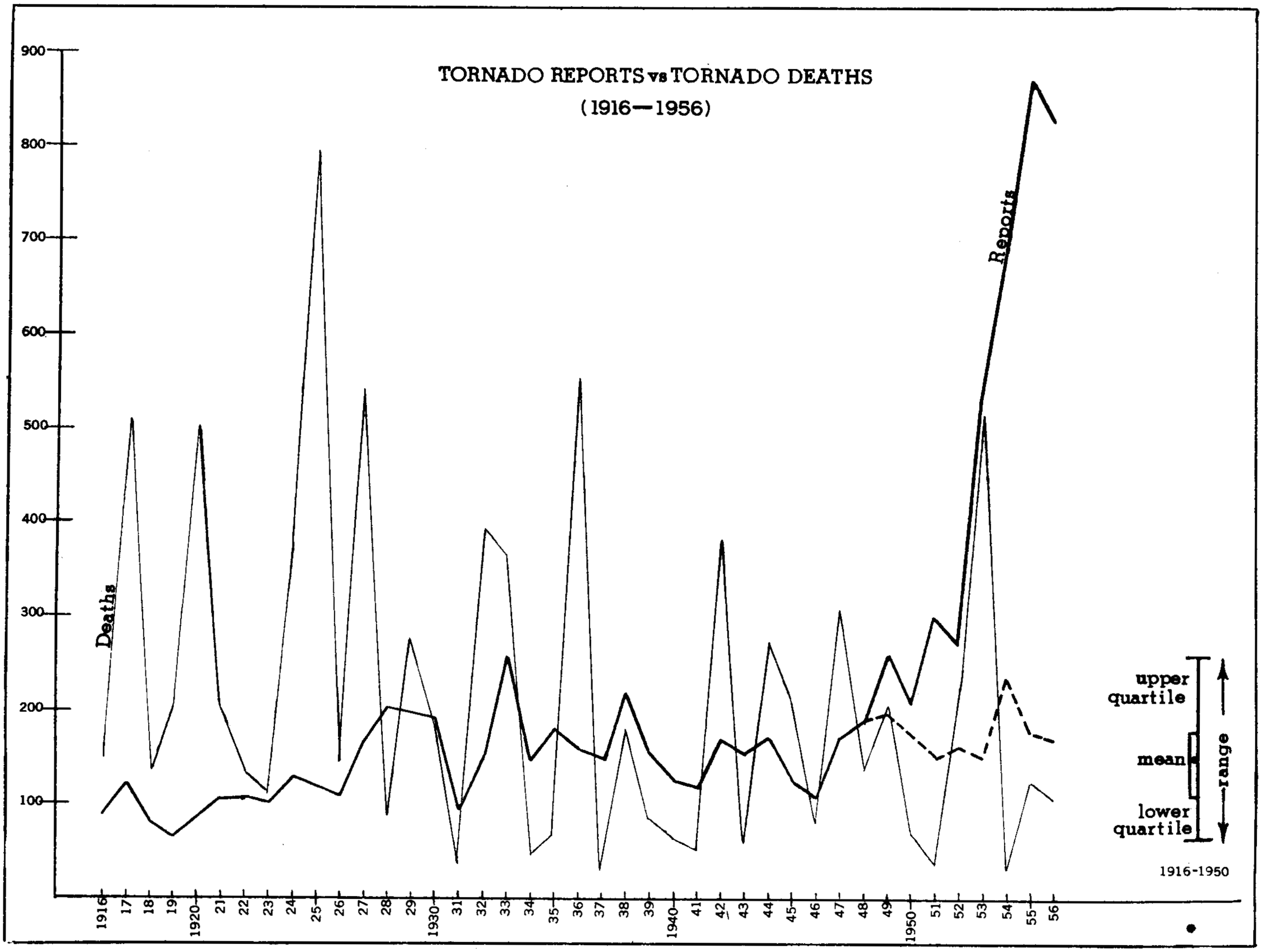

FIGURE 1.—Tornado reports and tornado deaths (1916–1956). Range, upper quartile, lower quartile, and mean of tornado reports are given in diagram, lower right. Dashed line after 1948 shows adjusted reports based on table 2.

from 1916 to 1950, as well as the upper quartile, the lower quartile, and the mean. Consequently, the rectangle on the side of the vertical line represents the range of the middle 50 percent of the cases. From 1916 to 1950, the range is between, roughly, 50 and 250, with the mean about 150 tornado reports per year. But, beginning in 1948 and thereafter, the number of tornado reports exceeds 300, 400, 500, until 1955 and 1956 when it exceeds 800.

The first obvious conclusion that might be drawn from a curve of this sort is that we have had more tornadoes in the past 8 or 10 years than we had during any other period in the past 40 years. If this were so, we should expect that the number of tornado deaths would increase as well. But we notice that the tornado death curve, which is given by the thin line, does not show any such spectacular increase during the past 8 or 10 years.

These data can be viewed a little bit better if we smooth out the high peaks, which represent particularly striking years, by means of 5-year running means. Figure 2 shows these means.

We see in figure 2 that the tornado report curve is now almost completely smoothed out until about 1948 and 1949, when the curve begins to climb and is quite high during the 5-year period ending 1956. On the other hand, the tornado death curve remains more or less the same as it was during the past 40 years.

We suspect, therefore, that while the *number of reports* has increased during the past 8 years, the actual number of tornadoes needs not necessarily to have increased as well. We may then ask: "To what may we attribute this increase of tornado reports?" First, let us look at what has happened since 1948 in this field, and see what are the events that might be related to this increase in tornado reports.

In 1948 Tinker Field was struck twice within the same month by tornadoes causing a considerable amount of damage. At that time, the Air Force established the

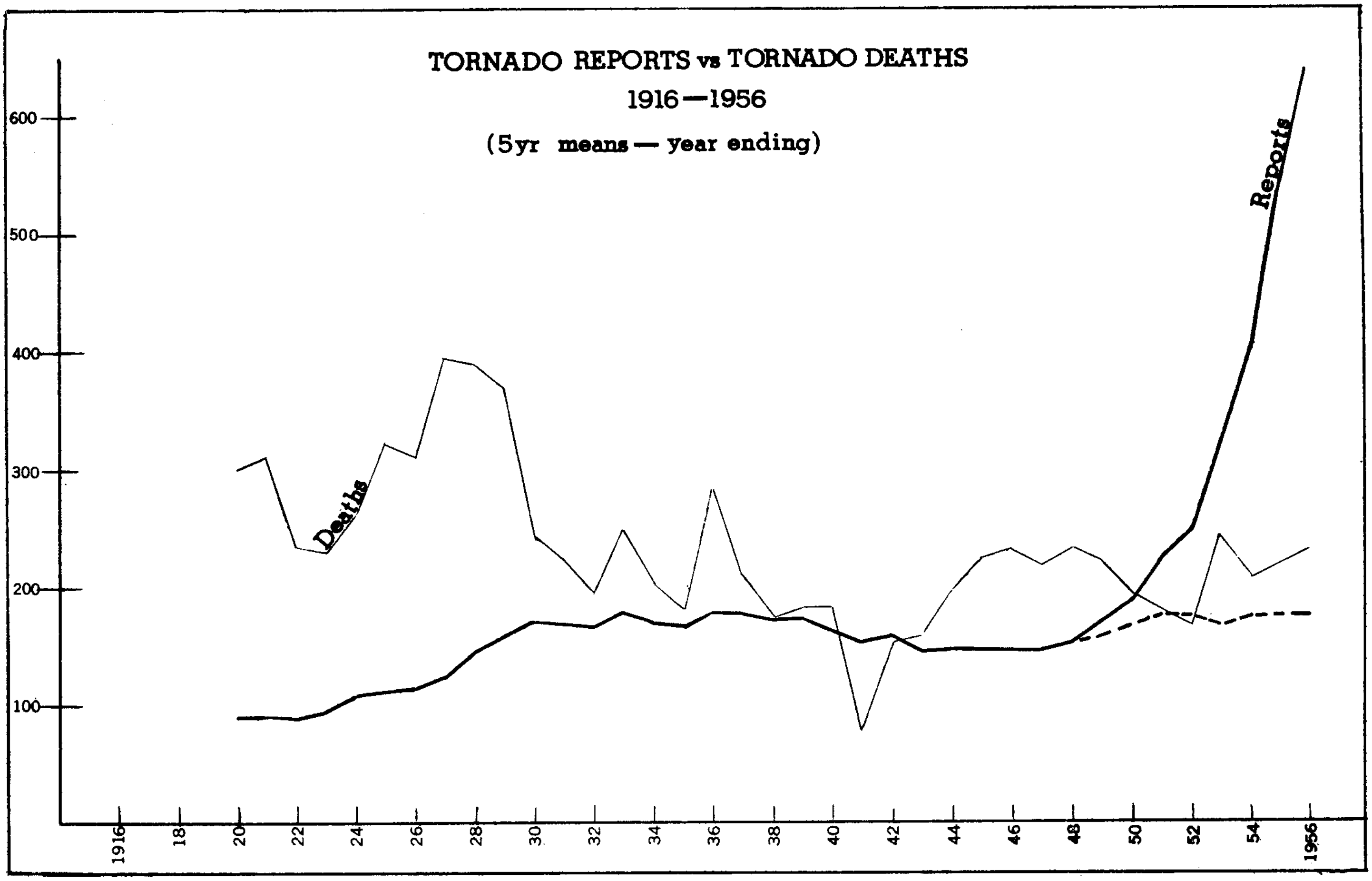

FIGURE 2.—Five-year means of tornado reports and tornado deaths (1916–1956). Dashed line after 1948 indicates adjusted reports based on table 2.

Severe Weather Warning Center under Fawbush and Miller, who were given the responsibility of forecasting tornadoes for the Air Force bases, in order to try to eliminate a repetition of this type of damage.

In 1950 a severe local storm network of observation stations was established in the vicinity of Washington, D. C., for the purpose of studying pressure jump lines and the relation of these lines to severe local storms. In 1951 this network was transferred to the severe local storm belt in the Midwest where it has been since. Associated with the establishment of this network, a press clipping service was procured to give detailed information about severe local storm occurrence in the research network area.

In 1952, the Weather Bureau established, first in Washington, and later transferred to Kansas City, the SELS Forecast Center for the purpose of coordinating and integrating tornado and severe local storm forecasts.

In 1953, the press clipping service was extended to the eight major tornado States in the Midwest, and in 1954 to all States east of the Rocky Mountains. At the same time a special reporting form called "Form 614–4" was sent out to all State Climatologists to assist in the completion of additional information about the nature of storms. In 1955 the severe storm reporting Form 614–4 was replaced by 614–5, which was a much more complete form and requested much more detailed information about severe storms. In 1956 the situation was about the same.

Also, during this period extensive research on severe local storms and tornadoes was initiated and pursued not only in government agencies but also in academic institutions (among which are Texas A. and M. College, University of Chicago, St. Louis University, and Oklahoma A. and M. College).

Thus, in recent years there has been a considerable amount of technical activity in the field of severe local storms and tornadoes. In addition, there has also been provided an additional and very fruitful source of severe storm reports, in the form of the press clipping service. There is another interesting and auxiliary proof of the growth of interest in tornadoes during this period, and this is provided in figure 3. This is a 5-year running mean of the number of publications on tornadoes as listed in *Meteorological Abstracts and Bibliography* of the American Meteorological Society. We see that this curve, too, shows a remarkable increase beginning in 1948 and 1949 and continuing through 1954, the last year for which more or less complete data are available.

Our conclusion, therefore, is that due to the increased interest in the problem, and due to the increased facilities for the accumulation of reports, the number of *reports* of

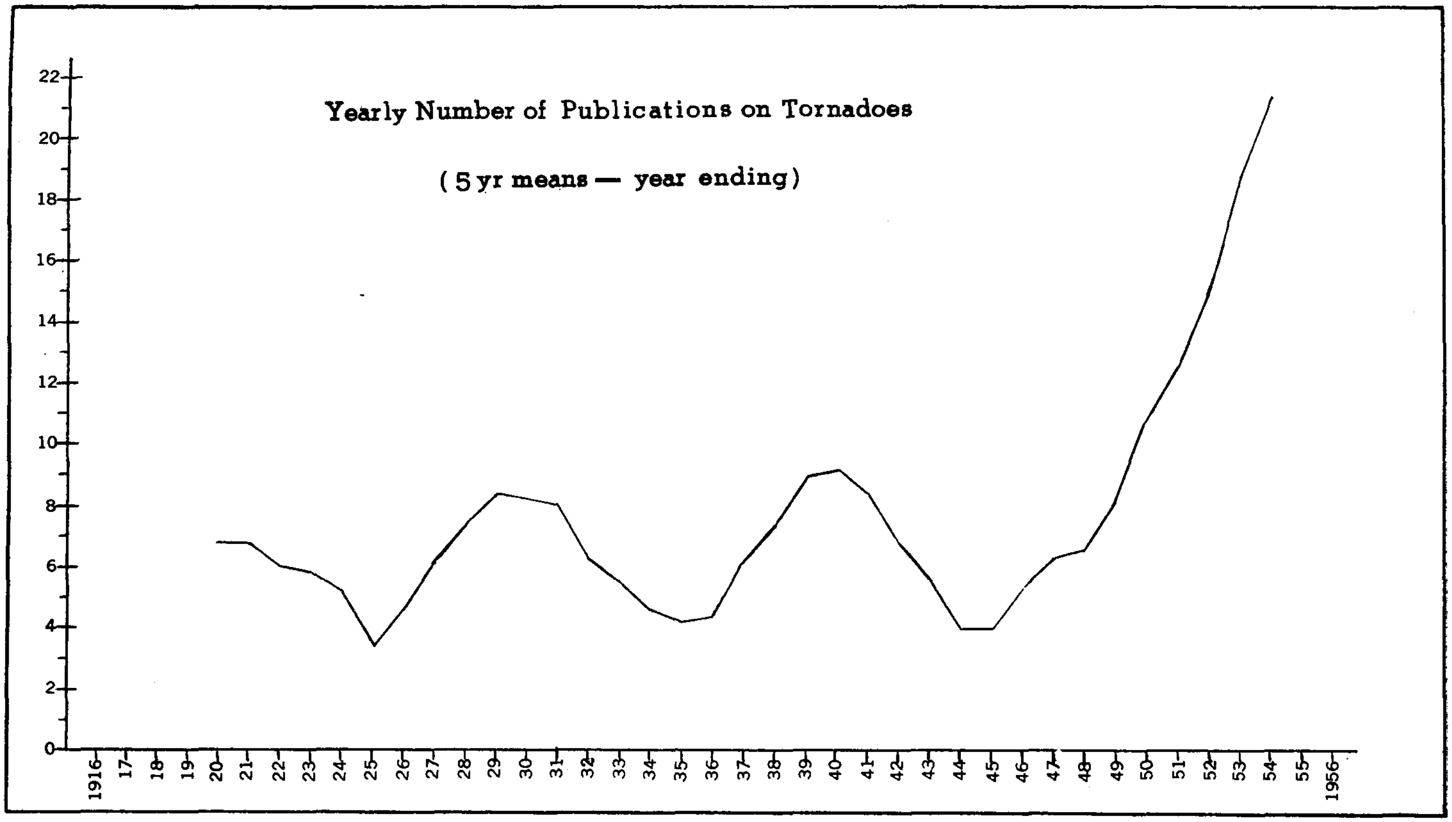

FIGURE 3.—Annual number of publications on tornadoes (5-year means).

tornadoes has been steadily increasing during the past 8 to 10 years. On the other hand, we have found no evidence on which to base an hypothesis that the number of actual tornadoes has increased.

In this regard, it would be pertinent to refer to a statement from the Final Report (dated March 1957) of the Tornado Damage Survey Project conducted by the Research Foundation at Oklahoma A. and M. College and sponsored by the U. S. Weather Bureau: " . . . in areas where severe storms have been forecast, many more tornadoes are reported. These investigations indicated that most of these reported tornadoes were lightning shadow, virga and/or scud-type cloud fragments." It should be kept in mind that active forecasting of tornadoes began in 1948 by the Air Force and in 1952 by the U. S. Weather Bureau.

3. RATING OF TORNADO REPORTS

The next problem is how to evaluate the tornado reports of recent years in order to make them compatible with the tornado reports which preceded them.

After reading literally hundreds of tornado reports which have been submitted during the past 10 years, the author was struck by the fact that certain reporting items appear to be more significant than others. As a matter of fact, there emerged a certain pattern of the relative importance of the various tornado reporting items. Unfortunately, there was no way to evaluate this relative importance objectively, so that at this stage only a subjective rating schedule can be offered, but nonetheless, a schedule based on a considerable amount of experience with tornado reports. This schedule of relative importance of tornado reporting items has been set up in the form of a table and listed in the order of importance in table 1.

To the right of each of the items is indicated a relative numerical rating. The author can justify neither the specific individual rating, nor its specific relative value other than by saying that this is what they appear to him. Certain items have been given the same relative ratings, and others have not. Still other items, such as rotation and wind speed have been omitted since they did not seem to be reliable reporting items. If a rating schedule such as this is adopted it is felt that with practice and use, a better and more objective system will eventually emerge. This, then, should be considered as a first attempt in the evaluation of tornado reports. Let us adopt this rating schedule for the moment and proceed to the next step.

Every reported storm listed as a tornado in the monthly

TABLE 1.—*Proposed numerical ratings of tornado reports*

a. Funnel observed	100
b. Distinctive noise	50
Total destruction	50
Extraordinary damage	50
c. Explosive-type damage	30
Narrow path ($\leq$¼ mile)	30
Skipping action	30
d. Twisting-type damage	20
Lifting of objects	20

Table 2.—*Number of tornado reports in severe local storm rating groups 1941–56, based on numerical ratings in table 1. For explanation of heavy line see text*

Rating	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956
0	26	39	45	49	37	26	50	57	66	80	104	45	88	157	161	98
10																
20	1			1		1	4	1	3		6	1	4	18	9	8
30	33	39	24	28	25	35	50	63	71	65	73	73	120	115	92	82
40										1	1	4		1		1
50	6	3	8	7	10	8	19	22	35	4	21	24	38	30	44	35
60	2	1	5			1	3	5	6	4	10	3	7	12	9	15
70	2		1			1					3		3	5	10	1
80	7	6	9		9	8	25	32	36	14	11	26	60	43	48	42
90											1			1	2	1
100	4	13	4	2	15	11	9	18	33	26	66	58	145	210	251	356
110				1	1			2	8			9	2	9	3	8
120			1				1			1		3	2	13	4	7
130	5	3	3	3			6	8	31	16	23	27	39	60	71	61
140															1	
150	1	1	1				3	2		1	5	13	17	9	29	30
160		2	1		1	1		1	2			10	2	12	12	6
170							1			2			1		1	1
180		1			1		1	3	3	1	9	6	9	18	26	22
190													1			2
200						3	1					2	3	2	14	2
210								1	1	1		4	2		2	15
220			1										1	1	1	3
230		1										2		2	5	3
240															1	1
250											2			1	6	1
260														1		1
270																
280															2	1
290															1	
300																
310																4

summaries of the Office of Climatology from 1941 to 1956 was reviewed and, *on the basis of the information available to the Office of Climatology and listed in these reports*, each of these tornadoes was then assigned a numerical rating. The results are shown in a frequency table as given in table 2.

The first thing that we notice as our eyes wander from left to right, across each one of the horizontal rows, is that the numbers tend in general to increase, perhaps a little more so after the period of 1948 and 1949, than previously. This reflects what we have already seen, namely, that the number of reports has increased during this period. However, there is another feature that is significant, and that is that the limit of the maximum rating per year seems to have a negative slope. This means that the *quality* of the details of the reports has also increased; that is, that we are receiving now more information in the reports than we have had in previous years. And finally, if we look at the numbers themselves we find that there have been marked increases in particular categories—in 0, 30, and 100. It is of interest to keep in mind that certain kinds of reports contribute in a major way to each of these categories, as follows:

1. The contributor to the 0 category is, of course, the report wherein none of the tornado rating elements has been included.
2. The primary contributor to the 30 category is the report of a storm with narrow path width (less than or equal to a quarter of a mile) but with no other rating element present.
3. The primary contributor to the 100 category is the report that a tornado has been observed but with no supporting evidence of any kind.

The conclusion is drawn that these types of reports have been included in increasing numbers in recent years because of the increased interest in the tornado problem; but *in all probability they were not part of the tornado statistics of previous years.* It is reasonable that in previous years, if a storm occurred with a narrow path, or if a funnel was reported to have been observed the storm would not have been classified as a tornado unless there was other evidence to substantiate a tornado classification.

A similar rating was made for all the other storms listed in the monthly summaries of the Office of Climatology, and table 3 gives the distribution for hail storms and other storms.

Here we see that, by far, most of the reports fall in a category of less than 50, very few between 50 and 100, and a negligible number over 100. For 1955 and 1956,

Table 3.—*Number of hail and other storm reports in severe local storm rating groups, 1955–56*

Rating	Hail		Other storms	
	1955	1956	1955	1956
0	488	161	253	677
10				
20			5	7
30	13	1	8	7
40				
50	17	1	13	32
60				
70				2
80			2	3
90				
100	1			2
110				
120				
130				1
140				
150				
160				
170				
180				
190				
200				
210				
220				1

therefore, the rating of less than or equal to 100 seems to include practically all of the reports of general storms, while practically no general storm ever is rated above 100.

Let us return to table 2. We repeat that it is our conclusion that:

1. tornadoes have not necessarily increased during the past 8 or 10 years;
2. an additional number of storms have been reported as tornadoes; and
3. these additional storms were essentially in the categories of 0, 30, and 100.

Figuratively speaking, it would seem that tornado reports since 1948 and 1949 have been "descending" in this distribution so that their numerical ratings have been increasing, while additional reports not given in previous years have been "poured on top". This suggests that we might, in a way, compare tornadoes with high ratings in recent years with tornadoes with lower ratings in the earlier years. On the other hand, the tornadoes with lower ratings in recent years were probably not reported as tornadoes in the early years. With this as an hypothesis, we counted upwards, starting from the bottom of each column, until we reached a total of in the vicinity of 150, the number which is comparable with the annual mean of all previous tornadoes, and the heavy line drawn on the table indicates where this cut-off is. We note that:

1. in 1955 and 1956 in accordance with what was stated earlier we eliminate all tornado reports equal to or less than 100,
2. the heavy line also has a negative slope comparable to the limit of the maximum numerical rating alluded to before, and
3. in certain cases the heavy line has to pass through a figure since taking it one side or the other would yield an annual number which would be out of line with the distribution of tornado reports in previous years.

The hypothesis, therefore, is that all the reports listed *below* the heavy line for all years are of comparable storms and their totals are comparable for the year. The reports *above* the heavy line are the additional reports that have been included in the statistics due to the increased interest and the increased activity in the tornado problem in recent years.

4. ADJUSTED TORNADO STATISTICS (1949–1956)

If we use only the reports below the heavy line and refer back to the curve of 5-year running means (fig. 2) we see that the adjusted values given in the dashed line represent quite well a continuation of events of previous years. Although based on justifiable deduction, this might seem somewhat artificial since, presumably, any grouping of numbers with values within the range of the previous 1916 to 1950 mean would provide a similar, nice, smooth 5-year curve. However, there is some additional evidence to substantiate this cutting off at the heavy line as given in table 2. This evidence is given in figure 4.

In figure 4 we have the monthly distribution of tornado reports from 1916 to 1950. The range for each month is given by the upright vertical line, on which are represented the upper and lower quartiles and the mean. The tornado reports listed below the heavy line in table 2 were reviewed and tabulated according to their monthly occurrence. If indeed these reports are comparable and compatible with the tornado reports from 1916 to 1950, they should be revealed as part of the same population, namely, they should fall within the general range and means of previous statistics for previous years. This figure shows that they do, indeed. The small numbers, from 0 to 6, represent the years of the 1950 decade—that is, 0 stands for 1950, 1 for 1951, etc. The numbers that have the dot next to them represent the upper and lower limits for that month for that year. In three years, 1950, 1953, and 1954, two limits were required because the heavy line in table 2 had to cut through certain numbers and one could not tell which report to omit and which one not to omit. It can be seen from this frequency distribution that the reports that have been used do indeed appear as if they were part of the population of all previous reports for the months from 1916 to 1950.

In this manner we are able to make the statistics for tornadoes during the past 8 or 10 years compatible with the tornado reports of previous years.

5. CLASSIFICATION OF TORNADO REPORTS

We next ask ourselves if we can utilize the analysis which we have just gone through in future tornado classification. Table 4 is a recommended classification. Utilizing the numerical ratings as given in table 1, the details of any report may be reviewed and a total rating assigned. The classification would then be as follows:

A. All tornado reports whose total numerical rating is greater than 100, shall be classified as *tornado*. (The five items listed under this group in table 4 represent the various combinations that may yield this type of report. The letters refer to the items in table 1. For example: "1. a+ . . . " means that a tornado report will be classified as a tornado if a funnel was observed *and* if any one other of the items below is also reported. This would give a number greater

TABLE 4.—*Recommended classification of tornado reports. Numbers refer to total ratings as assigned to report (table 1) and letters to the specific rating items of table 1*

A. >100 (Tornado) 1. a+ . . . 2. 2b+ . . . 3. b+2c 4. b+c+2d 5. 3c+d	C. 30–70 (Severe local storm) 1. b 2. 2c 3. c+d 4. c 5. 2d 6. c+2d
B. 80–100 (Possible tornado) 1. a 2. 2b 3. b+c 4. b+c+d 5. b+2d 6. 3c 7. 2c+2d 8. 2c+d	D. 0–20 (Local storm) 1. d 2. –

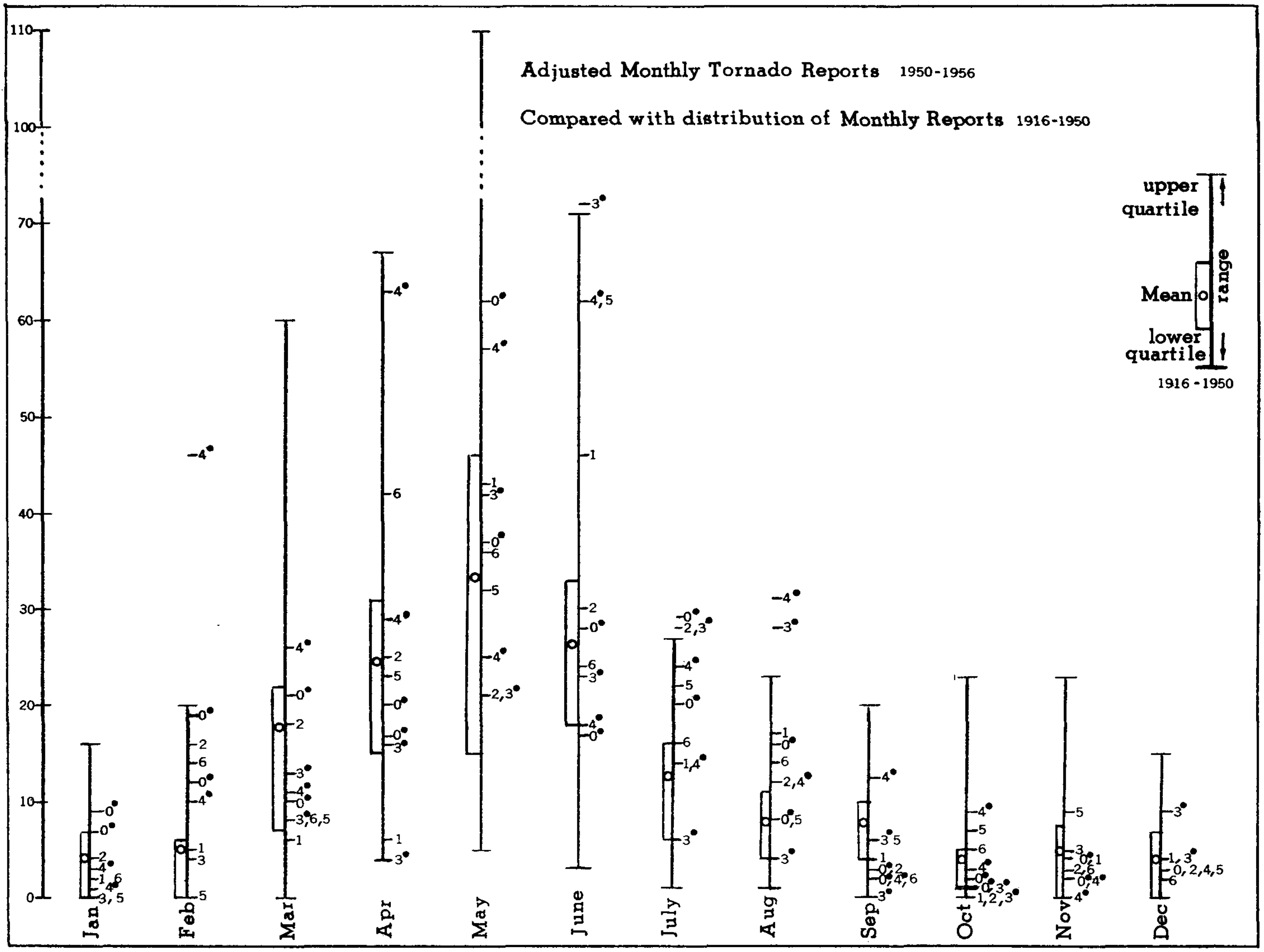

FIGURE 4.—Adjusted monthly tornado reports 1950–1956 compared with distribution of monthly reports 1916–1950. Range, upper quartile, lower quartile, and mean of monthly tornado reports 1916–1950 are given in diagram to right. Numerals refer to year of 1950 decade. Small dots indicate that two values appear for that year showing upper and lower limit.

than 100. "5. 3c+d" means that all three items under c.—explosive-type damage, narrow path, and skipping action—were reported plus one of d., twisting-type damage, or the lifting of objects.)

B. A total rating between 80 and 100 inclusive shall be that of a *possible tornado.* Again the various possible combinations are listed.

C. A total rating between 30 and 70 inclusive shall be that of a *severe local storm.*

D. Finally, those that do not have a rating of more than 20—that is 0 and 20—shall be classified only as a *local storm.*

6. SUMMARY

The classification as given in table 4 and the ratings in table 1 should not be considered inflexible but only as a point of departure; i. e., they are but a first attempt to give numerical ratings to the various items in reports that seem to be significant and then to group the ratings objectively as to a *tornado, possible tornado, severe local storm,* or *local storm.* This scheme may have many limitations. For example, it has a bias against nighttime tornadoes since there is less likelihood that a funnel can be observed at that time. On the other hand, one may well argue against calling a night storm anything more than a "possible tornado," if a funnel is not reported. With further thought put to this problem, this classification may have to be changed. It probably will be changed, but this seems to be a working tool with which to start.

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