

ART. XXIII.—*Tornadoes*; by HENRY A. HAZEN.

"THE true tornado," says R. H. Scott, "occurs off the west coast of Africa and is identical with the arched squall of other waters." This restrictive definition of a tornado is not accepted generally in the United States, where it is applied to an intense, seemingly local, outburst, ordinarily preceded by a funnel-shaped cloud, having a rapid rotation and a more or less slow up-and-down movement. The better designation would undoubtedly be "whirlwind," but the term tornado has become so well understood that it hardly seems wise to attempt a change.

The importance of a proper study and a good knowledge of the forces, which underlie the formation of a tornado, will be easily recognized when we consider the enormous loss of life and property that is annually occurring in the west and south. As the western States become more thickly settled year by year, it is manifest that this loss of life will become greater unless means for individual safety are provided in cellars and dug-outs as already recommended, or some more general means be employed for destroying or diminishing the force of the storm as it approaches a large city. Such an idea may seem chimerical; but if Franklin in the eighteenth century devised so simple and effective a means as the lightning rod for protecting buildings from lightning, surely the genius of the nineteenth century may determine some means of mitigating, if not of wholly avoiding, the evils under consideration. The devastation of large villages and the great terror induced at the possible approach of a tornado in a heavy dark cloud are sufficient reasons for the closest study of these phenomena.

It is the object of this paper, first, to set forth some of the ordinary theories that are advanced for explaining the origin and development of these outbursts; secondly, to show some of the seeming difficulties in these theories; and thirdly, to point out a few of the characteristics of these outbursts and to attempt to show lines of investigation upon which a further advance may be made toward a true knowledge of the forces underlying them.

Unfortunately, their origin is involved in much obscurity, due in part to a lack of observation of the conditions immediately preceding the sudden and destructive manifestations. The following quotations from authorities will suffice to show some of the views at present entertained. One writer says: "The inward rush of winds toward a depressed center is the cause of our thunder-storms, which are only infant cyclones and tornadoes. The whole country for 500 miles square from the Missouri to the Ohio valley is covered with a mass of warm moist

air flowing northward. At numerous spots in this region this acquires an upward motion, thereby giving rise to local upward currents of air which cool rapidly as they rise. The cooling is a mechanical result of the expansion of the rising air and very soon a temperature is reached low enough to condense clouds from the hitherto invisible moisture. With the formation of clouds, the tendency to rise increases, so that in fact an upward suction is experienced under the cloud and more air is drawn in from all sides to feed this suction."

"Whatever causes a sudden uprush of moist air contributes to the formation of the cloud or the tornado. Hills or low mountains are very effective. But it is equally important to consider the cool dry air that flows from the north toward a low center and becomes a west wind as it turns around the low, runs into the mass of warm moist air coming from the south, and being denser, underruns and lifts up this warm air and is in many cases more effective than a mountain in starting the formation of a cloud and local storm."

Another writer gives a theory directly the opposite of this last and says: "Suppose a mass of warm, moist southerly wind has pushed itself below a colder northwesterly stratum. The warm wind, feeling about for a point of escape through its cold cover, soon makes or finds a vent where it can drain away upward, and then the entire warm mass even a mile or more in diameter and often more than one thousand feet in thickness, begins a rotary motion, rises at the center and passes away."

It is probable that theories upon the effect of the sun's heat upon the lower atmosphere have been at fault. It has been assumed that "this heat is developed in certain central portions of greatest heat." It is ordinarily considered also that the heat at the earth's surface is greatly increased and causes masses of heated air to rise to great heights. We cannot determine precisely the area uniformly heated by the sun during the hottest part of the day; however the temperature is well nigh at a maximum for at least an hour. This would give a circle of heated air over one thousand miles in diameter, which, if inland and at sea-level, would be heated with nearly equal intensity on clear calm days. Experiment shows that, while the earth's surface in sunshine becomes very hot, yet this heat does not extend to more than two or three inches in the atmosphere. At six inches the temperature is frequently from thirty to forty degrees less than at the surface, and from this point it diminishes not more than one half a degree in six feet, showing that there is no appreciable rising of heated air from the earth's surface.

The effect of the sun's heat may be considered as follows: the stratum of air nearest the earth will first be heated and

gentle convection currents set in motion, these will heat the next stratum, and so on.

This is the explanation given by Prof. Hann of Vienna, who furthermore considers the formation of cumulus cloud in summer to be due to the action of vapor immediately at a height where the dewpoint is reached, but that no great interchange of air from the lower to the upper atmosphere will take place from the action of heat alone.

Again, the evaporation and condensation of moisture are advanced as important factors; it is stated for example: "Of great importance is the action of vapor, as a great storehouse of solar energy, required in the process of its evaporation, generally known as 'latent heat,'" and "condensation is attended with the production of just as much heat energy as was lost in the process of evaporation." Admitting for a moment that a warm vapor-laden current of air has found its way to some height above the earth, where is the evidence that a condensation will produce any more forcible effect than would have been noted in evaporation? If the process of evaporation goes on by insensible degrees, why may not the converse process of condensation take place in the same way? It would seem a hasty conclusion that a mass of vapor can be cooled and condensed so much more rapidly than it can be evaporated. Either process requires time and certainly that of cooling a large mass of air can only be accomplished slowly. That a rapid upward rush and consequent expansion would cool the air is evident, but it is by no means certain that there is this uprush, and again that the cooling would produce any sudden display of force. The fact that efforts at a computation of the probable liberation of energy arising from such action have given most diverse results, with even an absolute denial of any sudden release of energy, shows that such an hypothesis must be accepted with caution and should be supported by indubitable practical tests.

The theory that tornadoes occur where there are great contrasts of temperature in warm southerly and cooler northerly winds is not supported by the facts. This theory is partly based on the assumption that tornado action occurs near the center of a low area. It is admitted that immediately to the north and south of a storm center there are strong contrasts of temperature and there is a partial meeting of warm and cool winds, but there are no tornadoes at or even near that point.

Let us take a map of any region having upon it, very near the time of the tornado, lines of equal pressure and temperature and directions of the wind. There will invariably be upon it a storm-center. Through the center of this draw a line from southwest to northeast and we shall find on the north-

west side low temperature and cold and dry northwest winds, due to an advancing high area. On the southeast side, however, the air is laden with moisture and is hot, there are frequent rains, and well nigh uniform south and southeast winds. On the southeast side also the isotherms are much farther apart than on the northwest side. If now we project the tornado tracks upon the map we shall find them in the region to the southeast, and generally hundreds of miles from the storm-center, where there are no northerly winds. A critical study of tornado tracks upon a weather map will develop these points in nearly every instance. Frequently there are in the tornado region higher temperatures in the north than in the south, and very seldom will there be a lowering of temperature from south to north any greater than the constant difference due to the difference in latitude.

Again, there seems to be a disposition to advance some general and sweeping theories about cold or hot winds underrunning hot or cold winds, etc. It may be said that, in a condition of equilibrium, the cooler air must flow beneath and, at all times there would be a more or less insensible diffusion of the two masses. It would seem difficult to account in this way for the definite formation of a tornado and its onward advance dipping here and there sometimes even across a state.

In seeking for a probable solution of the problem, and in testing the assumptions made, we have to-day a powerful adjunct in the weather map showing at any hour of the day the precise meteorological conditions existing over the region of tornado action. Such maps for three nearly equidistant hours of the day have been published by the U. S. Weather Bureau from 1872 to 1880. In order to ascertain the prominent facts connecting tornado action with storm centers there have been selected for this paper forty-one of the tornadoes described in Sergeant (now Lieut.) Finley's paper, "Characteristics of 600 tornadoes," also published by the Weather Bureau. Before the tracks were projected upon the maps, every tornado having special destructive action and at the same time a fairly well determined note of time, was tabulated and of these none were left out in the final result. Tornadoes between September, 1872, and September, 1879, have alone been considered.

TABLE.

Place.	Lat.	Long.	Date.	Hour.	Distance (miles) to and direction from low center.	Temperature falls 10° in miles.	Winds near tornado.	Distance to nearest N. wind.	Pressure at low center.
Charlotte, N. C.	35° 2'	80° 8'	Sept. 8, '72	5 p. m.	650 S.E.	500	S. & S.E.	650	29° 76
Keokuk & Washington Co's, Ia.	41° 3'	92° 0'	May 22, '73	2.15 p. m.	440 S.E.	200	S. & S.E.	370	29° 28
Cloud Co., Kans.	39° 6'	97° 7'	June 29, '73	3 p. m.	480 S.S.E.	520	S. to E.	520	29° 60
Cairo, Ills.	37° 0'	89° 2'	Mar. 18, '74	4 a. m.	370 E.S.E.	210	S. & S.E.	260	29° 76
DeSoto Co., La.	32° 0'	93° 6'	Apr. 7, '74	4 p. m.	260 E.S.E.	140	S.E.	220	29° 70
Butler Co., Kans.	37° 8'	96° 9'	June 22, '74	p. m.	660 S.S.E.	400	S. & S.E.	none†	29° 44
Troy, N. Y.	42° 7'	73° 6'	Aug. 2, '74	p. m.	580 S.S.W.	260	N. & N.W.	----	29° 55
Dixon, Ills.	41° 8'	89° 5'	Aug. 10, '74	p. m.	620 S.E.	200	S.W. to S.E.	none†	29° 33
Montevallo, Ala.	33° 1'	86° 9'	Nov. 22, '74	p. m.	490 S.E.	130	S.	670	29° 04
Fulton, Miss.	34° 2'	88° 3'	May 1, '75	p. m.	600 S.S.W.	120	N.W.	----	29° 10
St. Joseph Co., Ind.	41° 6'	86° 3'	June 1, '75	p. m.	610 S.E.	150	S. to E.	none†	29° 31
Quincy, Ills.	39° 9'	91° 4'	June 14, '75	p. m.	540 E.S.E.	112	S.W. to S.E.	350	29° 41
Omaha, Nebr.	41° 3'	95° 9'	June 17, '75	p. m.	270 S.E.	160	N.E.	----	29° 60
West Point, N. Y.	41° 3'	74° 0'	July 13, '75	7.10 p. m.	420 S.	150	S.W.	390	29° 54
Salem Co., N. J.	39° 5'	75° 3'	July 29, '75	3 p. m.	550 S.E.	100	S.W. & S.	290	29° 72
Lomonauk, Ills.	41° 6'	88° 7'	Aug. 5, '75	7.20 p. m.	210 S.E.	390	S. & S.W.	410	29° 50
Milford, Pa.	41° 3'	74° 8'	Oct. 30, '75	p. m.	350 S.E.	270	S. & S.W.	800	29° 53
Chicago, Ills.	41° 9'	87° 6'	Apr. 26, '76	5.10 p. m.	780 S.E.	210	S. & S.W.	none†	29° 41
Carbondale, St. Clair Co., Ills.	37° 8'	89° 2'	May 6, '76	9.30 p. m.	360 S.S.E.	240	S. & S.E.	200	29° 41
Saline Co., Kans.	38° 8'	97° 7'	June 6, '76	3.30 p. m.	480 S.S.E.	400	S.W. to S.E.	600	29° 45

* Lat. and long. of center.

† No north wind.

TABLE—CONTINUED.

Place.	Lat.	Long.	Date.	Hour.	Distance (miles) to and direction from low center			Temperature falls 10° in miles.	Winds near tornado.	Distance to nearest N. wind.	Pressure at low center.
Washington Co., N. Y.	43.2°	73.2°	May 18, '77,	1.30 p. m.	220	S.S.W.	202°	200	S. & S.W.	400	29".59
Memphis, Tenn.	35.1	90.0	June 17, '77,	7 p. m.	1040	S.E.	135	1000	S. & S.E.	650	29.28
Elkhart, Ind.	41.7	86.0	July 2, '77,	4.30 p. m.	1030	S.E.	135	200	S. & S.E.	580	29.58
Council Bluffs, Ia.	41.3	95.6	Aug. 6, '77,	2.30 p. m.	520	S.S.E.	158	580	S. & S.E.	190	29.75
Fayetteville, N. C.	35.0	78.9	Feb. 8, '78,	7 a. m.	420	S.E.	135	420	S. & S.W.	430	29.30
Cairo, Ills.	57.0	89.2	Ap. 23, '78,	4.10 a. m.	400	S.S.E.	158	240	S.E.	350	29.43
Carolina Landing, Miss.	33.0	91.1	May 18, '78,	p. m.	720	S.E.	135	120	S.	490	29.28
Barrington, Ills.	42.2	88.1	May 23, '78,	6 p. m.	600	S.E.	135	130	S.W. to S.E.	340	29.32
Cash Co., Mo.	38.6	94.3	July 16, '78,	2 p. m.	420	S.	180	700	S.	350	29.54
South Hartford, N. Y.	43.3	73.2	July 26, '78,	5.30 p. m.	290	N.E.	45	90	S. & S.W.	270	29.29
Wallingford, Conn.	41.5	72.9	Aug. 9, '78,	6 p. m.	480	S.	180	150	S. & S.W.	300	29.40
Near Dover Mines, Va.	37.7	77.9	Sept. 12, '78,	4 p. m.	300	N.E.	45	160	E. & S.E.	300	29.48
Monticello, Jones Co., Ia.	42.2	91.2	Oct. 8, '78,	5.30 p. m.	320	E.N.E.	68	90	S. & S.W.	260	29.54
Collinsville, Ills.	38.7	90.0	Apr. 14, '79,	2.45 p. m.	160	S.S.W.	202	100	N. & N.E.	----	29.50
Dallas, Tex.	32.8	96.8	Apr. 15, '79,	2 p. m.	240	S.E.	135	100	E. & N.E.	----	29.34
Walterboro, S. C.	32.9	80.7	Apr. 16, '79,	3.45 p. m.	320	S.E.	135	210	S. & S.E.	420	29.47
Barnard, Mo.	40.2	94.8	May 29, '79,	3.30 p. m.	420	S.	180	300	S.W. & S.	600	29.29
Lees Summit, Mo.	38.9	94.3	May 30, '79,	5.30 p. m.	260	E.	90	240	S.E. & S.	330	29.40
Delphos, Kans.	39.3	97.8	May 30, '79,	4 p. m.	60	E.N.E.	68	150	N. & N.W.	----	29.40
Erie Co., O.	41.4	82.7	July 11, '79,	3 p. m.	230	S.W.	225	300	S. & S.W.	300	29.46
Sandy Spring, Ind.	39.2	77.0	Sept. 3, '79,	6 p. m.	420	S.E.	135	270	S. & S.W.	510	29.33
Means	----	----	453	S. 39° E.	141	259	-----	----	29.45

In this table, column six gives the distance in statute miles to the storm-center; the next two columns contain the direction of the tornado from "low," the numbers indicate the number of degrees from the north counting by east. Column nine shows the approximate distance between isotherms ten degrees apart, or the distance giving a temperature fall of ten degrees. This column is presented here as only a rough approximation; it was found necessary frequently to take the line of measurement at right angles to the line toward "low," and the measurements are vitiated by great irregularities in the conformation of the isotherms. Column ten contains the general course of the winds in a large region surrounding the tornado. Column eleven gives, as nearly as possible, the distance to the nearest north wind; this was seldom measured in the direction of "low;" if it had been, the distances would have been much greater. The last column contains the lowest pressure at the center. This table brings out many most interesting facts and merits careful study.

It has been assumed that a definite relation exists between a "low," and the place of tornado action. Certain it is that no extensive tornado action ever takes place without the presence of a "low" of rather marked intensity. The probable influence of "high areas" is for the present neglected.

A general average of this table gives the mean distance from "low" 453 miles; mean direction, S. 39° E.; mean temperature fall, ten degrees in 259 miles. The winds are almost uniformly from the south and southeast, and if from any other quarter, all are from that direction. The distances to the nearest north wind are variable, in many instances there were no north winds on the map near the "low" or the tornado; the mean distance in thirty-one cases was 407 miles.

We may conclude then, first, that in the region of tornado action there is no upward rush such as is supposed to take place at a low center; secondly, that the winds are uniform and there is no meeting of cool northerly with warm southerly breezes; thirdly, that there are no contrasts of temperature, the fall of ten degrees in 259 miles being no more than would be expected from the influence of latitude.

Another most important point is the existence of extensive hail and thunder storms in the neighborhood of the tornado, which would seem to show an intimate relation between the two.

It has been commonly accepted that thunder-storms are local phenomena, and that they are caused by heated air rising on warm and sultry days and condensing its moisture in the upper regions. The facts, however, seem to show a much more particular cause. Take a very recent instance, the earliest exten-

ded thunder-storm of this year in the eastern United States. This occurred February 14, 1884, and was first noted at Augusta, Ga., early in the morning. It appeared at Lynchburg, Va., at 4 A. M., and at Variety Mills, Va., about the same hour, where it seemed to come from southwest and passed off to east-northeast. It passed over Washington, D. C. from west-southwest at 6.25 A. M. toward east-northeast. It was noted at Haverford College, Pa., and at New Castle, Del., at 8.30 A. M. These times (about some of which there is a little uncertainty) give the following velocity: Lynchburg to Washington, about sixty-two miles per hour; Washington to Haverford College, the same. The velocity across Washington, as determined by counting the seconds between the flash of lightning and the thunder, on the west as it came up and on the east as it passed off, was a little less than a mile a minute.

It may not be that one and the same storm passed across this whole region, though the evidence favors that supposition. One thing is certain, namely, that the meteorological conditions were suited to just such a development of thunder-storms over a large extent of country. It seems probable that they could not have been caused by the rising of moist heated air in a single locality. It is believed that no thunder storm can occur without a storm-center or disturbed region existing somewhat near it. This center may not make itself known by distinct bendings of isobars, but it can be easily recognized by the presence of cloudy weather and rainfall, with more or less incurving of the winds. An attempt has been made to divide thunder-storms into two classes—first, those caused in the presence of a low center of pressure, and, second, those due to the sun's heat. It may be admitted that the sun's direct heat is an important factor in the formation of summer thunder-storms, but this only acts in conjunction with the disturbed region which is invariably present.

If, now, such a thunder-storm action is general, and is dependent upon the presence of a storm-center, may we not hope by careful observation at short intervals of time and space, in the region over which the tornado action is expected to occur, to obtain a sounder basis of fact to reason upon than we now have?

One step further we may venture. If we can correlate thunder-storms and storm-centers, may we not expect to obtain by a critical study of the former some evidence of the forces acting in producing the latter? By such critical study we ought to be able to obtain answers to the following, among the questions relating to tornadoes:

At what distances and in what directions do they lie from the low center? How are they distributed with respect to thun-

der-storms? How are they connected with each other and what is their movement? What wind directions prevail? What is the distribution of temperature? Is their relation to storm-centers an invariable one? What is the character and distribution of hail storms? and so on. As a partial answer to the last question, observation seems to establish a rule that hail storms occur only in immediate proximity to storm-centers of considerable energy.

In order to be able to predict violent local storms and tornadoes we can accomplish much, as has just been suggested, by a study of a map containing the weather conditions over a large region.

Some of the signs of probable tornado action may be enumerated, in conclusion, as follows:

First—There must be a storm-center fairly well marked, though this may be 600 or 700 miles away. Tornadoes almost invariably occur to the south and southeast of this point.

Second—It is believed that the temperatures in the above region should be above the mean. Great contrasts of temperature are not necessary, and if, in connection with these, an area of high pressure is found to the northwest or west, no tornado will ordinarily occur.

Third—In general the air should be moist.

Fourth—As extended thunder-storm action is an invariable accompaniment of a tornado, it is believed that these may give some indications of more severe action. It is not thought that the above will prove an infallible guide, but ordinarily no tornado will occur unless the above conditions precede it.

Prof. Tait of Edinburgh has recently published an article on the origin of atmospheric electricity, in which he takes grounds similar to those of certain French savants, namely, that as yet we know little or nothing of the origin of this manifestation of electricity. It would seem that J. Allan Broun's theory that it is due to the direct influence of the sun's electricity upon the moisture of the air, or possibly to the indirect effect from the sun's heat is more satisfactory than the multifarious theories of friction, evaporation, condensation, etc. However this may be, it seems that the present theories on the origin of tornadoes are no more satisfactory than those on the origin of atmospheric electricity which are abandoned by Professor Tait. Certainly as all theories in regard to lightning have proved inadequate upon actual tests, so it should be insisted upon that no mere paper theory of tornado action can be accepted.