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THE TORNADO

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BY
H. A. HAZEN,
Assistant Professor of the United States Signal Office.

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NUMBER V.

THE TORNADO

By H. A. HAZEN

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PREFACE.

In preparing this book for the public, the author has had in mind the desirability of presenting in somewhat of a popular style the various theories bearing on the subject of tornadoes, and the facts which have been collected from year to year, and which can now be had only by consulting many scores of volumes. It has been the aim to make the book as complete as possible, and yet it is easy to see that the matter inserted must be somewhat different from that which another would have chosen. The author has endeavored throughout to be absolutely unprejudiced, and to give impartially all the observations, researches, and theories that have seemed of importance.

This work is by no means a simple compilation, but there will be found material in several of the chapters which has never been dwelt upon before. Special effort has been put forth to sift all theories to their ultimate sources; to

review Espy's work, which, all admit, lies at the basis of the modern theories of tornado formation; to obtain a most careful estimate of the tornadoes that have occurred since 1873 in this country; and to compare the destruction by tornadoes with that by fire. The chapter on "Tornado Insurance" was specially prepared for the benefit of those who have that in mind, and it is hoped that this chapter alone will be of great service to every householder living in the seventeen tornado States. The preparation of such a work was really begun a year ago, in making studies for a prize essay on tornadoes, shortly to be published by the *American Meteorological Journal.* It is hoped that this publication will incite trained observers to make a special study of all the phenomena involved, and that ere many years have elapsed the mystery of the tornado will be unravelled, at least so far as it can be on the earth. The author has no hesitation in saying that the only possible solution of this problem is by making observations in the upper air, where the tornado has its origin, and where only it can be studied to the best advantage.

H. A. HAZEN.

WASHINGTON, D.C., July 17, 1890.

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THE TORNADO.

CHAPTER I.

FACTS.

THERE is no subject in the whole science of meteorology of such absorbing interest as this of tornadoes. Its importance may be judged from the hundreds of pages that have been written upon it, from the universal attention paid it by newspapers through the length and breadth of the land, and from the fact that many insurance companies have taken the matter in hand, and are prepared to take tornado risks. It is easy to see that the interest in this topic must gradually increase as the tornado districts become more thickly populated, and as the facilities for spreading the news of disaster become greater. There is no doubt that in many instances losses from a tornado have been greatly exaggerated, and fears of devastation have been increased because pictures of the very worst tornadoes are the only ones that have been printed.

The most important thing for us to do is to establish the facts, and these will serve as a basis from which we may

uproot false theories, and, if not now, at some time in the future, to build up a solid superstructure. It is to be noted that all studies on this question ultimately turn to the facts, either to support theories or to form them. We shall find the most diverse views in these discussions, and yet every one of them based upon facts. It is only because of a false or imperfect interpretation of what is observed that such antagonism can exist. A partial explanation of these conflicting views lies in the fact that the outburst of a tornado is accompanied by such terrifying manifestations, and observers are in such fear for their lives that they are totally unfitted to give an account of what they have seen. In many cases, also, there has been altogether too narrow a view taken of this phenomenon. We have been entirely absorbed in the immediate destruction, the demolition of houses, the twisting-off of trees, the distribution of *débris*, etc., and have neglected the atmospheric conditions which have led up to the disaster. All will agree that a thorough knowledge of all the circumstances attending these outbursts is indispensable, if we would learn the mechanism of a tornado, or if we ever attempt to guard against its devastation, or ever try to give warning so that others may protect themselves. We may enumerate some of the facts as follows:—

Quiescent State of the Atmosphere.

It is quite well known that tornadoes seldom occur singly, but many are formed over an extended region, five hundred or more miles in length and breadth, where the conditions are favorable for their development. In this region the air is remarkably quiet previous to the tornado. There is a general or wide-extended storm some two hundred or four hundred miles to the north-westward; and into this storm, which is usually intensified much above the average storms at that season, gentle southerly and south-easterly winds are blowing at a distance, which are freshened as the centre is

approached. Tornadoes rarely occur in any but the hotter season, say from April to August; and in this season, even when there are thunder-storms, high winds are an exception.

Temperature.

The universal testimony is, that there is an exceedingly warm and sultry air. Even if the sky be overcast, and the sun's direct rays be hidden, this same oppressive feeling is noted. This heat seems to have a special characteristic entirely unlike that from the ordinary bright sun's rays, and it has never been properly accounted for. The same heat is often felt just before a thunder-storm, and we may consider that the same cause is acting in both these cases.

Clouds.

The clouds have the general motion that they always have in the neighborhood of an extensive storm. This seems an exceedingly important consideration, and shows that the conditions leading up to the tornado are the same as are present at innumerable times when there are no serious outbreaks. A beginning in a study of these conditions has already been made (*Journal of the Franklin Institute*, July, 1888, p. 48). In that investigation it was learned that near the centre of the general storm, the clouds moved mostly with the surface winds, from right to left, or counter-clockwise, and if they had any other direction it was simply a slight turning toward the east in the line of the general flow of the upper current. This fact was also ascertained by Hildebrandsson in Denmark, though the storms there may have slightly different characteristics from the proximity of the ocean. A score of tornado regions have shown this tendency. It will suffice to give here illustrations from three tornadoes which have been specially studied; and a fourth will be found in the chapter on the Louisville tornado.

Washington Court-House, O.

This place was visited Sept. 8, 1885. The general storm was central in southern Wisconsin, and the cloud-movements were as follows: from south-west at Dubuque, Davenport, Keokuk, Springfield (Ill.), Chicago, Indianapolis, Louisville, Nashville, Cincinnati, Columbus, and Sandusky; from south at Cairo, Toledo, Pittsburgh, and Erie; from south-east at Detroit, Cleveland, and Buffalo. In all this region there was not a single cloud-movement from the north-west, or even west. On April 14, 1886, St. Cloud and Sauk Rapids, Minn., were injured by a tornado. The general storm was central in north-west Dakota, and the cloud-motions were as follows: from south-west at North Platte, Des Moines, and Valentine; from south at Deadwood, Omaha, Leavenworth, Springfield (Mo.), Springfield (Ill.), Cairo, St. Louis, Dubuque, and La Crosse; from south-east at Bismarck, Moorhead, St. Vincent, and St. Paul. Here not only are there no west or north-west cloud-movements, but also in the immediate tornado region the movement is markedly from the south-east.

Mount Vernon, Ill.

This tornado occurred Feb. 19, 1888. The general storm was central in eastern Iowa, and clouds were moving as follows: from south-west at Keokuk, Memphis, and Louisville; from south at Springfield (Ill.), Chicago, Indianapolis, Toledo, St. Louis, Cairo, and Chattanooga; from south-east at Milwaukee and Davenport.

This is an exceedingly important fact, as will be seen later on, and seems to be abundantly established.

Distribution of Tornadoes.

Rarely do these violent outbursts occur singly. In any region favorable for tornado development, two hundred to four hundred miles to the south-east of the centre of the general storm, we shall find, after the hottest part of the

day, a series of tornadoes occurring one after the other, and moving almost invariably to the north-east. An hour or so later, another line will be found parallel to the first, and about fifty miles south-east of it. In some cases, as in the great Louisville tornado, there may be six or even more of these lines. They are entirely independent of each other, and very clear cut, there being no destruction between. The last line may not begin until 8.30 P.M., more than five hours after the hottest part of the day.

Velocity.

A marked feature of these outbursts is their most rapid translation across the earth for two hundred and sometimes three hundred miles. The speed is rarely under forty miles per hour, and there have been well-authenticated cases where it has reached over eighty miles per hour, notably in the Louisville tornado. It should be noted that the general storm, while travelling in the same direction, attains a velocity only half as great; for example, at Louisville it was thirty-eight miles per hour, which is very much above the average.

Thunder-Storms.

All through this region thunder-storms are very numerous, and are an invariable accompaniment. Sometimes vivid displays of lightning occur in the tornado, and undoubtedly these would be observed much oftener were not the beholder awe-struck by the terror-inspiring phenomenon. A careful study of thunder-storms, occurring at any time, has shown that they have a velocity double that of the fostering general storm, and are always found within the region six hundred miles to the south-east. It has come to be generally admitted that tornadoes and thunder-storms are analogous phenomena, and that the former are an intensification of the latter. If this be true, we see at once what an enormous advance has been made. We do not need to wait for

the full-fledged monster, whose very appearance drives away all thought save flight for safety, but we may study him in his gentler moods.

Lurid Sky.

Let us take a slightly closer view. Almost the first warning after the appearance of dark and threatening clouds in the west, as in a thunder-storm, is a peculiar lurid or greenish tinge in the sky from the south to the west. This "tornado-sky" is a characteristic feature, and it is believed that to those who have studied the phenomenon this will always serve as a warning for the more serious results which soon follow.

Two Clouds.

Many observers have seen very black clouds,—one to the west or north-west, and the other to the south-west,—which seem to rapidly advance, and, when they meet, to form the tornado. This is believed to be in the nature of a perspective effect, and the clouds to be an immediate accompaniment of the tornado. A full explanation of this phenomenon will be given later.

Cloud of Dust.

It is a very significant fact that in a great many cases the funnel-cloud, which has a sharp outline and should be the first thing seen at a long distance, is not seen till it is just upon the observer. This is due to an enormous cloud of dust directly in front of the tornado, rising oftentimes to a great height. Such a cloud of dust has often been seen in thunder-storms in regions never visited by the tornado. It is produced by a tremendous outrush of air from the tornado, and indicates almost conclusively that there is a *plenum*, and not a *vacuum*, at the centre. That this outrush of air could be produced by the fall of raindrops carrying air with them, has been proved impossible. The calculation showed that the heaviest rainfall that ever occurred

could not produce a velocity greater than one-tenth of a mile per hour, which is practically inappreciable (see *American Meteorological Journal*, September, 1887, pp. 206–211).

Loud Roar.

As the tornado approaches, an indescribable roar is heard. It has been likened to the bellowing of a million mad bulls, the roar of ten thousand trains of cars, etc. This is certainly a most significant fact, and one that has not been sufficiently dwelt upon. The roar was analyzed by one observer, and was found to be precisely similar to a continuous roar or rumble of thunder. There is no question but that it is a marked electrical phenomenon, though just the manner of its production demands most careful investigation. Another explanation will be found in Chapter II.

The Tornado.

These warning sights and sounds are quickly followed by the funnel-cloud itself, like a great balloon sweeping its neck round and round with terrible fury, and destroying every thing in its path. It has been likened to an enormous elephant's trunk. It whirls with almost incredible velocity in its mad career, with a motion back and forth, sometimes leaving the earth a moment, then bounding back to continue its dire havoc. The whole destruction occupies but three or four minutes; but in that time the stanchest houses of brick or stone have been demolished, and sorrow and ruin have been spread all along its path.

Clearing Sky.

The exceedingly circumscribed nature of the tornado is shown by the blue sky or stars appearing a few minutes after it has passed. The wind turns to the south again, every thing quiets down, and no one would think that a terrible catastrophe had occurred, except for the devastation that is all about, and the cries of the unfortunates.

Width of Path.

The width of the destructive path has been given as high as a mile, but this is undoubtedly due to an erroneous estimation of the real track. There are always south-westerly indraughts which produce more or less destruction on the south side, but these should be carefully distinguished from the track proper or the region of greatest destruction. This may reach a thousand feet, though its width is rarely over two hundred or three hundred feet.

Distribution of Débris.

In the central line of the tornado all timbers and trees are strewed in the same direction, as though a mighty river had passed and left them behind. Where trees are not completely uprooted on either side of the path, they all lie with their tops inclined to the central line; that is, on the south side they are toppled or bent over toward the north-east, while on the north side toward the south-east. This appearance may be due to the indraughts, and should be carefully distinguished from the effect of the tornado proper. The same remark may be made as to the distribution of fences and light objects on either side of the path.

Velocity of the Destructive Wind.

This should not be confused with the onward motion of the tornado, which is comparatively slow. The whirling of the cloud is thought by some to be the cause of the great destruction, but it may be due to some other action little understood at present. This has been estimated as high as a thousand miles per hour; but such a velocity as that is highly problematical, and is due to erroneous assumptions. Probably the most accurate measurement of this velocity ever made was at Wallingford, Conn., on Aug. 9, 1878. Here the tornado blew off monuments in a cemetery without chipping either the upper or lower stone. In one case the

stone was 2×2×4 feet in dimensions, and would have required a velocity of about two hundred and sixty miles per hour to blow it off.

Direction of Whirl.

This has been reported again and again as from right to left, "counter-clockwise;" and this has caused a notable modification of the old theory that the whirl in a tornado may be either way. It is probable that this unanimity of opinion is due to other causes than careful observations. The determination of the direction of a whirl is practically impossible, unless the observer is within a very short distance, as any one may see for himself in the whirls of a dusty street. The only possible way to determine the direction of the whirl is to be near enough to see the actual motion of the leaves and twigs upon the ground. If one looks at the whirling column, he can learn nothing positive. This question is by no means settled yet, and there are reasons for thinking the old theory correct.

Air-Pressure.

Until very recently it has been assumed that there is a partial vacuum at the tornado centre. It is admitted that in a thunder-storm the pressure rather suddenly rises, nearly a tenth of an inch oftentimes; and, if the tornado is analogous, we may reason that the pressure rises in that. Professor Davis, in the *American Meteorological Journal* (February, 1890, p. 452), says that this fails to take account of the causes of increased pressure in thunder-storms, and of the decreased pressure in tornadoes. This seems a remarkable argument. Where does the severest thunder-storm and greatest increase of pressure leave off, and the tornado, with an absolutely reversed pressure, begin? The strongest argument that has ever been advanced has been the seeming bursting or exploding of houses in a tornado. This could have been occasioned by a sudden blow on any side of the

house, whereby the pressure inside would be increased, and the walls thrown outward. This view was advanced some years ago, and has received a recent most remarkable confirmation in the report of a destructive storm at St. Louis, Jan. 12, 1890. The observer, a very intelligent man, writes, "In all cases of falling walls, it was noted that they fell outwards. In all cases of houses which at first sight appeared to have exploded, it was ascertained that immediately before or at the time the walls gave way, the wind forced in some portion of the south wall, as a window or door, thus probably accounting for the outward pressure on other walls." The most important observation in connection with these exploded houses at St. Louis was the record of a barograph, which just at this moment showed a remarkable *rise* in pressure. In the Louisville tornado, also, a barograph within a mile or two of the track showed first a slight sudden fall and recovery, due probably to the wind, and afterward the tornado-rise, as at St. Louis. This evidence is cumulative; and when we consider that the wind blows away from the tornado in front, and that of two similar objects standing side by side, one very heavy and the other light, the former is swept away while the other remains untouched, the evidence seems almost conclusive that there is no diminution of pressure in a tornado. It is probable that there is no fact in the whole observation or make-up of a tornado of such extreme importance as this, and it will be touched upon again in an explanation of a seeming rush of objects into the funnel. It will undoubtedly be thought, that, after all that has preceded, we really know very little of the mechanism of a tornado. This is true; but, if we have advanced far enough to be able to say what it is *not*, we may congratulate ourselves, and feel that our labor has not been entirely in vain.

CHAPTER II.

APPEARANCES.

WHILE it would appear that the most encouraging line of research is in determining the conditions leading up to a tornado, yet thus far the most time has been spent in studying the destruction, distribution of *débris*, violence of the wind, whirling of the clouds, etc, just at the tornado proper, and where investigation would be the most difficult. A tornado appears to be such a definite phenomenon, that it seems at first sight as though the testimony of different observers would be cumulative, and that there ought to be no difficulty in obtaining definite information regarding all its peculiarities. A very short research, however, dispels this view. The reasons for this are so well and concisely given by Dr. Wadsworth, who investigated the tornado of April 14, 1879, at Collinsville, Ill., that I quote from him.

"It must be borne in mind that this phenomenon came upon our people without warning, and passed before their vision with a probable speed of more than a mile a minute. The impression thus made would necessarily be far from complete. Of those in or near the path of the tornado, one would observe the lower, another a higher portion, very few noticing just the same features. It came to some with the

shock of an explosion, or, if they were so fortunate as to have it lift as it passed over them, they might see that a lumber-yard was being poured down upon them, which would be equivalent to not seeing the real cause at all, only a secondary result. To others, again, personal preservation was the first law of nature. To those to the north or south, or some distance in advance, and so fortunate as to have their attention properly directed, are we most indebted for what little history we have been able to gather, otherwise than that to be obtained from the study of the destruction it left behind." To this may be added, (1) no two tornadoes ever had the same appearance; (2) in the same tornado the movements are so complex that it is practically impossible to grasp the whole scene; (3) it is believed that it is almost impossible to avoid preconceived opinions, which give an observer a bias one way or another (this is recognized by the most skilled physicists); (4) in many cases leading questions would tend to cloud the truth; (5) it is probable that sometimes a storm not a tornado is mistaken for one, and this serves to confuse the appearances. This was much more of a difficulty forty years ago than now. A good illustration of this (5) may be found in the so-called Natchez tornado.

Natchez (Mississippi) Tornado.

This hurricane, for it was undoubtedly a West India cyclone or hurricane, occurred May 7, 1840. Mr. Tooley's description is quoted from. "At 12.45 P.M., the roar of the approaching storm began to be distinctly heard, the wind blowing a gale N. E., 6 (Beaufort). The roar and commotion of the storm grew more loud and terrific, attended with incessant coruscations and flashes of forked lightning. As the storm approached nearer, the wind veered to the E., 7. At 1.45 a blackness of darkness overspread the heavens; and when the annulus approached the city, the wind suddenly veered to the S. E., 8, attended with such crashing thunder

as shook the solid earth. At 2 the tornado, 10, burst upon the city, attended with such murky darkness, roaring and crashing, that the citizens saw not, heard not, knew not, the wide-wasting destruction around them. At this moment the barometer fell to 29.37″ (it had been 29.49″ at noon). The wind that desolated Natchez was from the S. E. A brick house on the north side of Main Street had the leeward gable end thrown out, the windward end remaining uninjured. The windward gable end of a large house adjoining the Commercial Bank bursted outward against the face of the storm; the leeward end was uninjured." It is plain, from the veering of the wind and the steady fall of the barometer, that this storm was not a tornado, and we shall avoid a good deal of difficulty by throwing it out in our studies.

Two Epochs of Study.

It is rather remarkable that between the years 1840 and 1850 there was most diligent attention paid to this subject by the most noted physicists and meteorologists of that day,—Joseph Henry, A. D. Bache, Loomis, Espy, Reid, Redfield, Hare, and others; and after that period for nearly twenty years, or till the Signal Service was established, there appear to have been very scanty studies of the phenomenon. In some respects this will be an advantage to us, as we can compare the later studies, having all the advantages of weather-maps, concerted action, simultaneous observations, etc., with the meagre data of the earlier explorers in this enchanting field. These appearances have been so differently described, and there seems to be so much confusion in some cases, that it is best to quote quite freely from the testimony of those who were eye-witnesses or personal investigators.

New Brunswick, N.J., June 19 1835.

One of the best studied of all tornadoes was this one in New Jersey. *I quote from Professors Johnson and Henry.*

"In a few cases, in which the ridge of a building lay north and south, the eastern slope of roof was observed to be removed, or at least stripped of its shingles, while the western slope remained entire. I do not recollect to have encountered a single case in which the top of a tree, with its roots in the ground, was lying towards the west, though I cannot say that none occurred. None were seen with the tops from the centre of the path. A lad of eight or nine years was carried upward and onward with the wind a distance of several hundred yards, and afterwards descended in safety, being prevented from a violent fall by the upward forces. Rafters which penetrated buildings south of the track, entered them on the north side. Their descent, in some instances, was with great violence, contrary to what happened in the range of the upward motions, where a lad, already referred to, was deposited in safety after a journey of one-fourth of a mile." Professor Bache also investigated this tornado. He says, "I think it entirely made out that there was a rush of air in all directions at the surface of the ground towards the moving meteor, this rush of air carrying objects with it. The effects all indicate a moving column of rarefied air, without any whirling motion at or near the surface of the earth."

New Haven, Conn., July 31, 1839.

A short time before this tornado the wind blew fresh southeast. It changed suddenly south, and in a moment west, where it continued. Professor Olmstead says, "Accompanying these changes, a heavy rumbling noise was heard, not unlike the passing of a long train of cars, which was audible in every part of the city. All describe it as a strange cloud of terrific aspect, white, like a driving snow-storm or light fog, and agitated by the most violent intestine motions. It came suddenly upon them with torrents of water. Trees and other objects that mark the direction of the wind which prostrated them are, with a very few exceptions,

turned inwards on both sides towards the centre of the track; while near the centre the direction of the prostrate bodies is coincident with that of the storm. A barn was demolished, and a dove-cote scattered in fragments, while a hen-roost which stood feebly on blocks was unharmed. In a barn that was blown down, a boy that was on a load of hay in the barn was transported across the street and deposited in a neighboring field unharmed. In other cases, however, forces seem to have acted with great violence upon the individual parts of bodies. Numerous instances occurred where hens were completely stripped of their feathers. Trees and other heavy bodies, that were raised into the air and transported to a distance, did not generally appear to have fallen with the ordinary force of falling bodies. Forces appear to have acted in contrary directions. The legs of the same table were found deposited at the distance of many feet from each other in different directions."

Pine Plains, N.Y., June 19, 1835.

The day had been very sultry. Clouds highly charged with electricity darkened the horizon at 3 P.M. At 6 P.M. "our attention was arrested by the peculiar manœuvring of dark and heavy clouds a little south of west. As the black cloud arose (it had the appearance and commotion of dense volumes of smoke bursting from a burning building), light and windy clouds from all that part of the heavens veered toward it with unspeakable confusion and velocity. Mr. Anthony Simmons, near Best's, was on the road with his team loaded with a hogshead of sugar (1,250 pounds). Horses, wagon, and sugar were hurled over a stone wall into a perfect wreck; himself blown in an opposite direction about fifteen rods."

Stow, O., Oct. 20, 1837.

Professor Loomis gives a graphic account of this tornado. There was a tremendous roar heard. "Several of the fowls

were picked almost clean of their feathers, as if it had been done carefully by hand. There were two powerful currents of wind blowing from opposite sides of the track,—that is, within a few rods of each other,—and with such violence that the stoutest oaks fell before it. What then became of the air thus accumulated in the centre? That there was a powerful current upward from the surface of the earth, near the middle of the track, is proved by the objects which were elevated. A tree which was levelled as this whirl was approaching it, would be turned to the right; and another, which fell as the whirl was receding, would be inclined to the left."

Mayfield, O., Feb. 4, 1842.

Professor Loomis has given us a description of this tornado also. "The lightning was quite sharp just before the blow came on, and thunder was distinctly heard above the roar of the tornado. This roar was almost deafening, and was compared to a heavy surf upon the seashore, or to the Falls of Niagara." Professor Loomis loaded a six-pounder with a pound and a quarter of powder and with pieces of board. These were fired into a side hill, and from the penetration he decided that some of the boards in this tornado were driven into the earth with a velocity of 682 miles per hour. The stripping of fowls attracted much attention in this and other tornadoes. In order to determine the velocity needed to strip these feathers, the above six-pounder was loaded with five ounces of powder, and for a ball a chicken just killed. Professor Loomis says, "The gun was pointed vertically upwards and fired. The feathers rose twenty or thirty feet, and were scattered by the wind. On examination, they were found to be pulled out clean, the skin seldom adhering to them. The body was torn into small fragments, only a part of which could be found. The velocity was 341 miles per hour. A fowl, then, forced through the air with this velocity is torn entirely to

pieces; with a less velocity, it is probable most of the feathers might be pulled out without mutilating the body."

Professor Loomis gives a list of twenty-one tornadoes down to March, 1842, and the following *résumé* of all the appearances: "1. No season of the year is exempt, but they are most numerous in May and June. 2. They occur chiefly between noon and sunset. 3. The temperature at the time is unusually elevated. 4. They are invariably accompanied by lightning and rain, and frequently by hail. 5. Their progress in this country is invariably eastwardly, the mean being twelve degrees north of east. 6. Their average breadth is about 120 rods; length, 15 miles; velocity of progress when violent, about 30 miles per hour; duration of destructive violence, 45 seconds. 7. Light objects are frequently transported 3 to 20 miles. 8. Very few human lives are lost, about one to a tornado. 9. Leeward roofs are generally taken in preference to windward (Professor Loomis thought the windward side of a roof would be pressed down on the rafters, while the wind would cause a partial vacuum on the leeward side, which would suffice to throw that off). 10. Fowls are frequently picked of most of their feathers. 11. In passing over ponds or rivers, water is invariably raised in considerable quantity."

The omissions in this summary of any ascending motion in the centre of the tornado, any whirling from right to left or left to right, and any evidence of a partial vacuum, are most extraordinary and well-nigh inexplicable. Professor Loomis also adds several significant facts. The Morgan (Ohio) tornado of June 19, 1823, is thus described: "At 9.30 P.M the observer heard a roaring as of heavy thunder, which called him to the door. Upon opening it, he immediately discovered a bright cloud, having precisely the color of a glowing oven, apparently of the size of a half-acre of ground, lower than the dark canopy which remained un-

broken above, and moving rapidly in the direction of his house. The brightness of the cloud made the face of things light above the brightne s of a full moon. There was neither hail nor rain during the passage of the tornado, neither flashes of lightning nor distinguishable peals of thunder, but an intense brightness of the cloud and a continual and tremendous roar." Such descriptions as these might be given for hundreds of pages; but the above is a fair sample of them, and must suffice. Before remarking upon these quotations, it will be of interest to bring down such descriptions thirty years later.

Signal Office Notes.

In making investigations of tornadoes, the observer was furnished with fifteen to twenty topics of search, and usually framed a number of questions to be asked each person. It is also probable that in these answers all classes of replies by the more interested and by those less so are mingled together. Oftentimes the localities were visited some weeks after the tornado, and when many valuable facts could not be ascertained. To any one desiring a more connected account of these tornadoes, they will find them in the annual reports of the chief signal officer for 1873 and 1875. I will here simply make quotations without giving names.

Iowa and Illinois Tornadoes of May 22, 1873.

"Saw two clouds—one in the south-west, and the other in the north-west—which appeared to rush together in the west."

"Saw tornado approaching like two dark clouds, with an intervening lighter-colored space between them. These two clouds presented a funnel-shaped appearance. It whirled contrary to the hands of a watch. Heard some thunder previous to tornado, but saw no lightning."

"Heard it roaring a long time before it arrived. As it approached, saw two funnels distinctly. Saw funnel on the south side, which was the smaller, swing around in a half-

circle and join the larger one. When it struck the ground it seemed to smoke, the smoke surging up like spray upon a wave-beaten rock. Saw lightning during the tornado."

"Saw lightning during the tornado, and heard thunder above its roar."

"Saw the funnel whirling contrary to the sun. Saw lightning flash up and down the funnel. Saw a tree thrown out from the top of the funnel about one foot in diameter."

"The roaring was terrific. It resembled the sounds of machinery magnified a million times. It was a combined 'woo-oo-oo' and 'whir-r-r-r.' When the funnel came near, it grew as dark as midnight."

"Observed sheet lightning in the tornado several times. When the tornado had passed about a mile and a half, it appeared to stand still; and a strong gale, with rain, blew directly from it, so that I thought the storm was coming back."

"The tornado first appeared as two clouds—one from the south-west, and the other from the west—rushing to one point."

"Heard roaring about half an hour before it came."

"Heard roaring an hour before the storm came. Did not hear it after it passed. Saw a cloud rushing from the south, and another rushing to meet it from the north."

"The roaring was very loud for an hour previous to its arrival. Did not hear it after it passed. Saw no lightning."

"It was impossible to hear thunder, owing to the noise of the storm, which was terrific."

"Noticed a very black cloud in the west, with a lighter space on each side of it. Did not hear the roaring very distinctly until it was nearly opposite. Then it was an awful ocean-like roaring."

"Saw two clouds—one in the north-west, and one in the south-west—rushing together with great rapidity. A whirl-

ing began right where they met, assuming the form of a funnel. Saw it whirling with the hands of a watch at the distance of about two miles."

"There seemed to be a dark cloud to the south-west, another to the north-west. The roaring, like the whirring of a thousand threshing-machines, was so loud that I could not hear the breaking of the buildings."

Georgia and South Carolina Tornadoes, March 20, 1875.

"The cloud was very black, with a reddish appearance beneath. Approached with a rising and falling motion, and sometimes bursting upward, like dense, black smoke from a furnace."

"The cloud was fiery in appearance, throwing up, at times, what looked like tongues of flame."

"The form of the cloud was that of an inverted cone, and its appearance luminous. The red cloud moved with great velocity."

"The roar of the tornado was terrific, as if a thousand locomotives were racing across the country at full speed."

"Saw a bright column reaching from the ground to a height of nearly a hundred yards."

This tornado occurred just about noon, and it is not a little strange that many of the observers saw a more or less bright light connected with the funnel. A photograph of the ruins of Massey's house, near Sparta, Ga., shows a remarkable parallelism in the distribution of the *débris*. The house stood directly in the path of the tornado, and was built of heavy hewn timbers dovetailed together at the corners. The south-east side was first crushed in; then the whole house was moved ten feet east, and torn to fragments. The present writer saw precisely the same lines of *débris* parallel to the tornado-track in the Wallingford (Connecticut) tornado of Aug. 9, 1878. This illustration (Fig. 1) of a tornado-cloud is given as a good representation of the phenomenon. It will be

found that nearly every picture has waving lines upon it, as though the funnel were whirling, but the amorphous appearance here given is probably more accurate. Dr. McPherson gives this description: "The horizontal whirl, contrary to watch-hands, was plainly visible, together with a rolling motion inward and upward, giving the appearance of dense volumes of black smoke ascending from a tar-kiln. Coruscations were observed shooting out on the right or

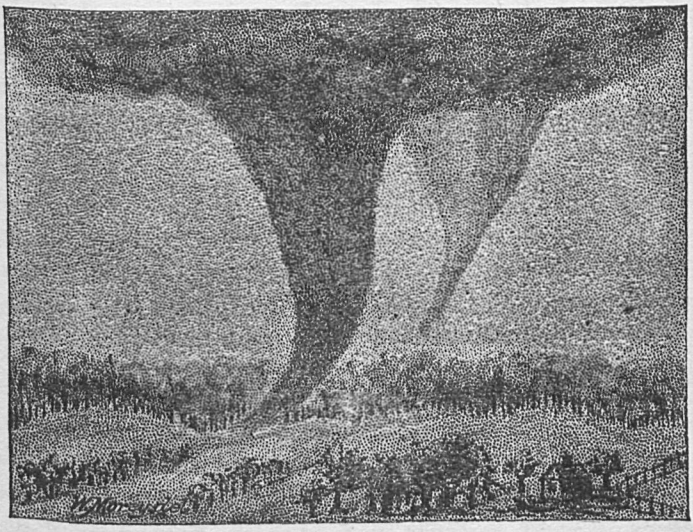

FIG. 1.—TORNADO-CLOUD.

south side of the cloud. A light funnel-shaped cloud, looking much like white steam, immediately preceded the black cloud."

Summary.

I have read over about a thousand pages of tornado literature in making these quotations. They are extremely disjointed, as must be necessarily the case in the scope of this

paper. I have had no theory to support, and in consequence the quotations are without bias. It is hardly probable, however, that any one person can read such a mass of matter and make the best selections to give the more prominent appearances; and it is much to be hoped that some one will go over this ground and make independent selections of the salient points. I think the omissions in these appearances are oftentimes more suggestive than the positive statements.

The Loud Roar.

The well-nigh universal testimony is, that there was an indescribable roaring in connection with the tornado. It is probable that this was heard in the earlier cases, but was not regarded of enough importance to note. It is hardly probable that the loudest of this roar could be heard more than a few minutes before the outburst. Little weight can be attached to the observations of a few, that it was *not* heard after the passage. It is entirely improbable that this can be caused by the wind, or by the tornado whirling in the air. We very much need more careful observations. Attention should be directed especially to a comparison of the sound with a continuous rumble of thunder.

The ascending current has also been largely commented on. The attempt to show an updraught by the fact that some persons were let down gently is more than counterbalanced by the fact that pieces of board and timber were driven into the ground many inches. The evidence on this point of an ascending current is very contradictory, and it is highly probable that a fierce blast from two directions, together with the assistance of the topography, will account for most of the phenomena. There is almost overwhelming evidence that air rushing into a partial vacuum does not produce this updraught. The evidence shows that the direction of the path of the tornado is pre-eminently toward the north-east.

Whirling of Tornado-Cloud.

Perhaps the least satisfactory testimony is regarding this appearance. We may set down at once the uselessness of any one trying to determine this whirling if he is more than a thousand feet away, and probably the limit should be five hundred feet. Attention should be directed to the ground, and most careful observations made of the whirling fragments. The distribution of the *débris* is markedly against any whirling. It is impossible to see how a whirl of a hundred feet diameter could throw down one tree to the north-east, and its neighbor to the south-east on top of the other. Some one has well suggested, that, if the cloud is whirling, the trees on the edges of the tornado should lie parallel to the track, while those in the centre should lie at right angles; but we know that precisely the contrary is the appearance. The writer once made an observation which may help to elucidate this problem. In the streets of Washington, during the laying of the cable-road, there were employed furnaces for heating tar, and in these furnaces it was customary to consume the remains of the tar-barrels for fuel. The smoke from these furnaces was most dense and black. The draught was so strong that the smoke issued from the chimney at a velocity fully equal to the wind that was blowing. The top of the chimney was not more than three feet from the eye, thus giving a most excellent opportunity for noting the slightest movement. When it was nearly calm, the smoke ascended perfectly straight, and with no whirling motion. The moment the wind blew, an extraordinary phenomenon was seen. Taking a vertical plane in the direction of the wind, and looking with the wind at the back, it was found that on the right of the plane the smoke whirled from right to left, while on the left it whirled from left to right. The appearance of this smoke thus doubling upon itself was most interesting, and invariably occurred when the wind blew. It seems as though most of the contradictions in the

testimony would disappear if some such action as this took place. We may be certain that there is no uniform whirl in tornadoes in either direction.

Stripping Feathers from Fowls.

This is undoubtedly a true phenomenon. The attempts to prove that this could be caused by the expansion of air in the quills, due to the passage of a vacuum, have signally failed. Fowls under an air-pump could not be deplumed by exhausting the air. We must also regard Professor Loomis's experiment of shooting a fowl out of a cannon as an entire failure, I mean for elucidating this phenomenon. He thought, that, if the fowl could have been fired at a hundred miles per hour instead of three hundred and forty, the result would have been very different; but this certainly is very doubtful. A wind of a hundred miles per hour would have carried along the fowl, feathers and all. It would be an interesting experiment to fire a fowl at a hundred miles per hour; but it is entirely probable that no fowl could live under such a shock as that, and the feathers would not be driven off until the velocity became enough to dismember the fowl. It would also be interesting to hold a fowl before a blast, and determine, if possible, the velocity needed for depluming. The most singular fact is, that the fowl lives under the depluming process. In some cases roosters have been seen walking around, days after the tornado, crowing, and without a feather on their backs. The appearance can be readily accounted for on the supposition that an electric charge threw off the feathers, and this seems the only way of explaining the stripping of clothes from a person.

The conclusion seems forced upon us that we need, more than all else, much more accurate observations by persons accustomed to note physical phenomena. It will be seen that in later days the appearance of clouds from the north-west and south-west is attracting great attention. That this

fact was not emphasized before, may be due, in part, to the fact that it was not regarded as of any special importance in accounting for the phenomena. It seems that these appearances certainly attend the tornado, and are seen all along its course of a hundred or two hundred miles; so that they cannot be regarded as individual clouds, whose meeting produces the funnel.

CHAPTER III.

LIEUT. FINLEY'S VIEWS.

FOR the past ten years Lieut. Finley has devoted a great deal of attention to this subject, and has received reports of tornadoes from thousands of observers. His views, then, should have much weight as being a *résumé* of all the facts reported. Quotations will be made from his book entitled "Tornadoes," published in 1887 by the *Insurance Monitor*. No attempt has been made to classify these, but I have given them in the order in which they occur in the book. Speaking of the flow of air on either side of a large storm, we find, "As these conditions continue to prevail, there is a growing contrast of temperature to the north and south of the major axis (of the depression), owing to the long-continued movement of the atmosphere from opposite directions; such movement eventually affecting the disposition of air in the warmer regions of the extreme south, and likewise the colder regions of the extreme north. The contrast of temperature now naturally increases with marked rapidity, and the formation of clouds commences in earnest. Huge masses of dark and portentous appearance bank up in the north-west and south-west with amazing rapidity, and soon the scene becomes one of awful grandeur. The struggle for

mastery in the opposing currents is thus indicated by the gathering cloud-formations. The condensation of vapor from the extremely humid southerly currents by contact with the augmenting cold of their struggling opponents continues. It increases rapidly. Finally, when resistance to the unstable equilibrium can no longer be maintained (controlled by the rate of temperature change and rapidity of condensation), the opposing forces are, as it were, broken asunder, followed by the upward rush of huge volumes of air. The outward indication of this event is first shown in the whirling, dashing clouds over the broken surface of the heavy bank of condensed vapor, forming the background,—a scene not easily depicted or realized by one who has not witnessed it, but never to be effaced from the memory of the actual observer. There is an awful terror in the majesty of the power here represented, and in the unnatural movement of the clouds, which affects animals as well as human beings. The next stage in the further development of this atmospheric disturbance is the gradual descent of the funnel-shaped cloud from a point apparently just beneath the position of the enactment of the first scene. The tornado is now before us, not fully developed, but soon to acquire that condition when the terrible violence of its power will make the earth tremble, animals terror-stricken, and men's hearts quake with fear."

"There seems to be some strange connection between the almost simultaneous appearance of clouds in the south-west and north-west, possessing as they do such unusually threatening forms. As they approach from opposite directions, they are suddenly thrown into the greatest confusion, breaking up, as it were, into small portions, which dash pell-mell over each other and in every direction; now darting toward the earth; now rushing upward to considerable heights like sky-rockets, or at moderate elevations rolling over each other in a well-developed whirl. An observer, in describing

the approach of the clouds from the south-west and north-west, stated that they came together with a terrific crash, as if thrown from the mouths of cannons. Generally, following closely upon the existence of this condition, the funnel-shaped tornado-cloud appears against the western sky, moving boldly to the front from without this confused mass of flying clouds." Lieut. Finley describes four motions of the tornado: "No. I. is called the whirling or gyratory motion, which is invariably from right to left. Above all other motions, this is attended with the greatest violence. This gyratory motion forms what is termed the 'vortex' of the tornado-cloud, within which the velocity of the centripetal currents of air is almost beyond conception. No. II. is called the progressive motion of the tornado,—the motion which determines the cloud's track from one point to another. No. III. is termed the rising and falling motion of the tornado. No. IV. is called the zigzag motion, or swaying from side to side of the central line of cloud-movement. This movement is sometimes quite suddenly performed, but generally it is a moderately slow movement, and one that can be watched and easily identified. In completing the extent of a single act of this motion, the tornado-cloud will diverge about an equal distance on either side of the central line of movement, though these tangents to the major axis are not necessarily of equal length."

Lieut. Finley summarizes his study of the relations of a tornado to general atmospheric conditions as follows: "There is a definite portion of an area of low pressure within which the conditions for the development of tornadoes are most favorable, and this is called the dangerous octant. Tornado regions are to the south and east of the region of high contrasts in temperature (temperature gradient) and in dew-points. The area of tornadic action is to the south and east of the region of high contrasts of cool northerly and warm southerly winds,—a rule that seems to

follow from the preceding, and is of use when observations of temperature and dew-point are not accessible. The relation of tornado regions to the movement of upper and lower clouds shows that the former indicate the presence of the cold north-west current, and the latter the warm south-west current of air, which ultimately lead to the development of the high contrasts of temperature so essential to the birth of tornadic action. The study of the relations of tornado regions to the form of barometric depressions shows that tornadoes are more frequent when the major axis of the barometric trough trends north and south, or north-east and south-west, than when it trends east and west."

From Lieut. Finley's "Scientific Résumé of Tornado Characteristics," I have selected the following as touching upon points not already mentioned:—

"The time of day, the time of year, and the peculiar hot and stifling condition, indicate that heat is the physical agent developing the tornado. By the rotary action of the tornado-cloud the condensed vapor is whirled into a fine mist, giving it the appearance of steam, and lighting the interior of the cloud. The tornado is accompanied by a rumbling noise (very peculiar), which never ceases while the funnel-shaped cloud is upon the earth or a short distance above it. The funnel form of the cloud is due to the peculiar ascensional movement of air-currents, the vapor being condensed along the central line of movement by the cold of elevation. The motive power of a tornado, and the agency which lifts objects or carries them long distances, is that motion of the air in the cloud set up by the variable heat conditions of large masses of air over adjacent regions.

"The tornado vortex may be formed either by an ascensional movement of a mass of heated air, giving rise to unstable equilibrium, or by the meeting of opposite currents with high temperature gradients, or by a combination of these. Two currents of air approaching each other from

opposite directions will not come directly together, because of the influence of the relative motion of the earth. The mass of air coming from the south would have a greater velocity eastward than that coming from the north: therefore, instead of meeting each other in a direct line, the two currents will form an angle at their intersection, and the combination of the two masses will give rise to a rotation in a direction contrary to the hands of a watch with its face upwards. These conditions account for the spiral movement of the air-currents and the formation of the vortex in the tornado. The cold air from the northward will under-run the warmer air from the southward, because of the difference in density of the two masses, and as a result will aid in the formation of the whirl.

"The electrical tension of the air cannot, under the most favorable atmospheric conditions, cause the movement of oppositely electrified air masses, because of the excellent conductivity of free air, which always tends to equalize electric potential. The presence of ozone is usually detected in the wake of the tornado. People are stripped of clothing, fowls and birds denuded of feathers. The peculiar roaring noise which accompanies the progress of the tornado cannot be ascribed to the intervention of electrical forces: it is far more reasonable to assert that the noise is produced by the resistance which the rapid and violent indraughts of air encounter while passing into the tornado's vortex. The vortex approximates a vacuum, and the air rushes into it at the spout end near the earth with great violence, attended by a hollow, sucking sound of marked intensity.

"The peculiar sensations of what are termed 'burning,' 'scorching,' or 'stifling' heat, which are reported by those who experience the violence of the tornado, must be due to the latent heat of vaporization, which is given off in great quantities by the extremely rapid condensation that attends the tornado as a constant feature."

A very interesting comparison may be made between these later views and the appearances noted earlier. Lieut. Finley seems to have slightly confused the conditions which prevail at the centre of the general storm with those at the tornado. Great contrasts of temperature and dew-point, meeting of hot south with cold north winds, etc., can only occur at the centre of the general storm,. but that point is four hundred miles from the tornado. It seems probable that altogether too much emphasis has been given to the two clouds,—one in the north-west, and the other south-west—which are described as gathering themselves together as two giants eager for the coming contest. We have already seen that these clouds are an accompaniment of the tornado. They are probably never more than one or two miles apart. They seem to rush together, because, when first seen, a cloud of dust hides the true tornado, and these appendages appear prominently on either side. In a minute or two the observer is enveloped in the dust, and the next instant he sees the death-dealing funnel, and his heated imagination at once leads him to the conclusion that the funnel is produced by the forcible meeting of the clouds.

Contrasts of Temperature.

Lieut. Finley especially insists on such contrasts as a *vera causa* in the formation of a tornado, but it would seem as though he has entirely mistaken the mode of action generally ascirbed to an unstable equilibrium. We are impressed with the fact that the clouds and resulting contrasts are on the same level, whereas, in order to have a contrast capable of causing an upsetting in the atmosphere, it is absolutely essential that the cold air be *above* the hot. Lieut. Finley expressly declares against this disposition by stating that the colder air, by its density, under-runs the warmer. It is a matter of deep regret that other writers on this subject have not seen that such a condition as the last mentioned entirely negatives their theories of tornado formation.

Tornado Whirls.

No one who has read all that precedes can be more astonished than the present writer to find that the evidence proving a whirl is so inconclusive and conflicting. I had fully made up my mind that there must be a whirl, though in doubt as to its direction. In fact, the best testimony we have, scattering of *débris*, is strongly in favor of the view that there is no whirl. Figs. 2 and 3 will show better than pages of text the nature of this testimony. Let us ask what would be

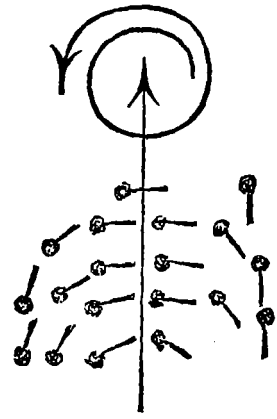

FIG. 2.—ORCHARD BLOWN DOWN BY A WHIRL FROM RIGHT TO LEFT.

the effect of a whirl, in a direction counter-clockwise, passing through an orchard (see Fig. 2). Facing the tornado as it approaches, we would see trees passing our eyes at right angles to the track, or leaning over to the right. After the tornado passes, we would see trees on the south side lying parallel to the track, with tops to east, while on the north side their tops would lie to the west. Fig. 3 shows the true conditions which are found. The *débris* and trees in the centre all lie parallel to the track, while on the north and

south sides the trees point inward and forward toward the centre. The writer made a most careful investigation of the conditions at the Wallingford (Connecticut) tornado; and these appearances were repeatedly met with, though the true significance of the facts was not fathomed. The strongest argument that has been advanced in favor of a whirl has been the position of tall trees which have crossed each other. Almost invariably the under tree is the one pointing north or north-east, while those above point south-east or

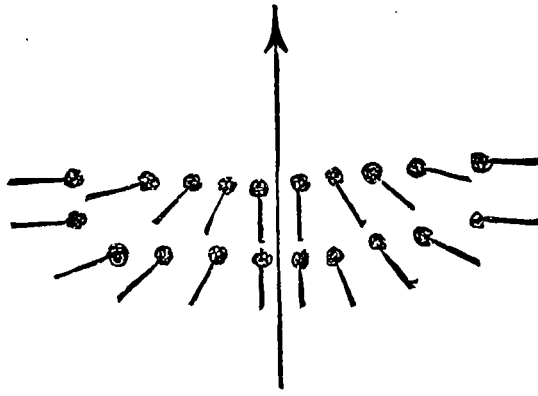

FIG. 3.—ORCHARD AFTER ACTUAL TORNADO HAS PASSED.

south. The proof is very unsatisfactory. If there is a steady whirl in a mass of air, why would it not break down neighboring trees in the same direction?

Further Research.

We are impressed with the imperfection of the evidence regarding the true mechanism of a tornado. Even the apparent drawing-up of water from a pond cannot be regarded as evidence of an uprush. We know, that, even if there were a perfect vacuum, water could not possibly be raised more than thirty-four feet. It is probable that the depression noted as the tornado passes is due to the wind, and the

apparent rising of a mass of water is simply fine water-particles or mist borne on the wind. The fact of the existence of a whirl is one of the most important that can be established. While we can never expect that an observer would remain near enough to a very severe tornado to make accurate observations, yet it seems as though this fact might be established by skilled observations in a less severe tornado. If you are on the south side of a tornado, there is little use in looking for a whirl; but attention should be given to the starting of objects into the air. See whether, when a tree starts, it goes suddenly, as if shot from the ground, or is swayed violently at the top first; see whether the *débris* that rises goes up in great confusion, whirling over and over, or whether it is carried lengthwise, as in a stream; etc. If you are on the north side, get as near as you dare, and cling to a large tree, or, better, to a post; note whether a single object near the ground or up in the funnel has any motion whatever toward your right hand as you look at the funnel. The moment the tornado has passed, run with the greatest possible speed to its rear, and, if possible before the dust has enveloped you, see if a single object on the ground or up in the air is moving to your right. If the tornado has moved through an orchard, establish as near as you can the centre line, and then pace off one hundred, two hundred, three hundred, feet to north and south, examine trees at the same distance on either side, and see if those on the south are uprooted or broken more than those on the north. If the tornado is moving at the rate of eighty miles per hour, and the whirl a hundred and twenty, on the south side the resultant velocity would be two hundred, while on the north side it would be only forty miles per hour. The greatest care must be taken that we do not blind our eyes with preconceived notions. When some observer who has a barometer has been so fortunate as to take it to a dug-out, and has kept his eye upon it rather than upon the more absorbing tornado, we may

hope from his testimony, if the funnel goes over his head, to clear up more doubtful points, and establish more certainties, than can ever be done by any other means. Finally, as the West becomes more thickly populated by skilled observers, we may hope to some time establish many points now very uncertain.

CHAPTER IV.

THEORIES.

It is somewhat difficult to give an adequate idea of the development of theories or pure speculations in this subject. Owing to the complex nature of the phenomenon, and the well-nigh utter lack of observations in the region of tornado-formation, the earlier views were more or less crude, and in some particulars have been slightly modified as broader and more comprehensive generalizations have been made. We shall be surprised, however, to find, on a careful study, how few changes the last fifty years have wrought. The original and essential ideas of tornado-generation and of sources of its power remain to-day as first propounded by Espy in 1840. Since his day, Professor Ferrel has been the most prominent exponent and amplifier of his views; and, with very few exceptions, theorists have followed Ferrel down to the present time. In many respects it would be a great advantage if one could give an impartial and trustworthy summing-up of the views of these men, and could bring out distinctly their gradual development. It will be far safer, however, since there are scores of students to-day who call in question many of these deductions, to give, as far as possible, an unbiassed *résumé* of these theories in the exact words of their

defenders, and thus enable any one for himself to examine their adequacy for explaining the phenomena as they are manifested before our eyes.

Espy's Views.

It is not a little remarkable that the first investigator of any note in this field based all his theories on direct experiment in the laboratory. All theorists since Espy's day have not considered that there was any need of propounding any of these questions to Nature herself, but have contented themselves with the assumptions and necessarily imperfect and crude results obtained by the first experimenter. This is the more remarkable when we consider the extreme gravity of the subject, and the methods employed in all other sciences, except meteorology, to establish upon a firm and impregnable basis such profound and far-reaching theories. Espy's few and simple experiments at almost the very dawn of this science have never been repeated by theorists, as far as the writer is aware. This one fact would seem of the extremest importance; and when we see, further, that even Espy himself was entirely unable to account for some of the anomalies in these very experiments, we can but feel the extreme necessity of further light. This feeling has borne fruit in other countries, as is shown by the diligence recently manifested in researches with rapidly revolving fans, which cause a supposed simulation of the phenomena in nature. While we can never hope to completely unravel the mysteries hidden in our storms until we question Nature herself in her own great laboratory, yet we can insist upon an examination of the original researches used as a basis for these theories, and demand a determination of their adequacy upon which to base the completer speculations of modern times.

Nephelescope.

The apparatus Espy used he called a "cloud-examiner." It consisted of a glass cylindrical vessel, having attached to

it by an opening at the top (1) a condensing syringe, by which the air in the vessel could be compressed; (2) a glass U-tube half full of mercury, by which the amount of compression could be measured; (3) a stop-cock between the syringe and the vessel. "After the instrument is charged, the stop-cock is turned, and the pump removed. When the air within acquires the temperature of the air without, a measure is carefully applied to the barometer gauge to ascertain how much higher the mercury stands in the outer leg than in the inner; the stop-cock is then turned, and the air permitted to escape; and at the moment of equilibrium the stop-cock is closed again. Now, as the cock is closed at the moment the greatest cold is produced by expansion, the mercury in the outer leg will begin to ascend, and that in the inner leg to descend, because the air within receives heat from without; and the difference of level, being measured as before, will indicate the number of degrees cooled by a given expansion. When dry air is used in the experiment, the temperature is reduced about twice as much as when moist air is used, on account of latent caloric evolved in the latter case by the formation of cloud which is plainly visible." Saturation of the air was attempted by placing a little water in the bottom of the vessel. The amount of compression varied from two to twenty-five inches; that is, the gauge indicated an increased pressure inside the vessel, amounting in some instances to nearly that of an atmosphere. These experiments were certainly unique; and, while we shall see that they by no means prove Espy's theory, yet they must be regarded as a step in the right direction, and a faithful effort to elucidate a most complex problem. As all clouds in these experiments were formed by expansion of compressed air, it is not a little remarkable to read the following as Espy's method of forming clouds, given by Professor Ferrel: "As Espy with a few strokes of the handle of an air-pump produced a cloud in the receiver from

the expansion and cooling of the moist air within, so nature, by means of a whirl in the open atmosphere, produces a cloud in the vortex of a tornado, from the expansion and cooling of the air there, on account of the partial vacuum caused by the centrifugal force of the gyrations." It is entirely probable that the rapidity of this expansion and consequent cooling was very much greater than can ever occur in nature. It is also probable that his air was far from saturation, and that the cloud he saw was due to dust which was pumped in. Experiment has shown that such a cloud can be formed in quite dry air, provided the expansion is quick enough.

One very important element does not seem to have been considered, and that is the velocity of escape of the compressed air needed to form a cloud. It is probable that this was more than five hundred feet per second, or at least fifty times as great as can ever take place in the formation of cloud in our storms. It is a little singular that Espy himself did not discover more than he did. He found, that,

Minutes.	Ratio.	Minutes.	Ratio.
13,160	4.2	360	6.9
10,080	7.5	180	7.3
7,200	4.5	180	6.9
5,760	4.5	180	7.4
5,760	4.2	180	7.0
5,040	4.3	90	6.9
4,320	4.4	60	7.4
4,320	4.5	60	7.4
1,800	4.4	15	5.5
1,680	4.5	10	7.8
1,200	4.7	10	5.1
1,080	5.5		

while the results he obtained with dry air were very regular and constant, yet with moist air they were just the contrary; and the irregularities seemed to depend in part upon the interval after the compression, before the escape of the air. The above table is of much interest, and shows, in

the first column, the number of minutes after compression, before opening the stop-cock, and, in the second column, the ratio between the amount of compression and the final reading of the gauge. In dry air this ratio was found to be from four to five; so that if Espy's statement just given is correct, that the temperature with dry air is reduced twice as much as with moist, the ratios should be eight to ten in this second column, according to his reasoning. Espy considers this result, "so contrary to all our notions since the experiments of Dalton on the subject of the dewpoint," very remarkable.

We have not all the data needed to give a complete explanation of Espy's results, but this much we do know: if Espy had allowed a slower escape of the moist air, there would have been no cloud, and he would have had no difference between dry and moist air. When the explosion was very sudden, a cloud was formed, and the conditions inside the apparatus were very different from those with dry air, but not because of the liberation of latent caloric. At the end of ten minutes he found the ratio much smaller, apparently, than at the end of an hour or two; and after that the ratio diminished until it became exactly what it was in dry air. It is plain that this final result could not be attributed to the gradual non-saturation of the air, as Espy thought. There are no other experiments made by Espy under exactly similar conditions of temperature in moist and dry air. The evidence is conclusive, from these and other more recent experiments by the writer, that practically no different result will be produced, whether moist or dry air be introduced into the nephelescope.

I have dwelt upon these experiments at some length for the reason that they form the sum and substance of all efforts in this line up to very recent times.

Upon these experiments depend all of Espy's theories as to tornado-formation, and he has been quite closely followed in

all views as to the essence of the forces underlying our most violent tornadoes. Mr. Espy gives the following *résumé* of his theories as ascertained and promulgated by the French Academy of Sciences:—

"If a very extended stratum of warm and humid air at rest covers the surface of a region of land or sea, and by any cause whatever (for example, a less local density) an ascending current is formed in this mass of humid air, the ascending force, instead of diminishing in consequence of the elevation of the rising column, will increase with the height of the column exactly as though a current of hydrogen was rising through the common air, which current would be pushed towards the top of the atmosphere with a force and velocity in proportion to its height. This column of heated air may also be compared to that in chimneys and stove-pipes, of which the draught is in proportion to the height of the pipe containing the warm air. What, then, is the cause which renders the warm and humid ascending current lighter in each of its parts than the air which is found at the same height with these different portions of the ascending column?

"This cause, according to the sufficiently exact calculations of Mr. Espy, is the constantly higher temperature which the ascending column retains, and which proceeds from the heat furnished by the partial condensation of the vapor mixed with the air, making this ascending column a true column of heated air, that is to say, of a lighter gas; for the weight of the water which passes into the liquid state is far from compensating the excess of levity which proceeds from the more elevated temperature which the air preserves.

"Thus the higher the column is, the greater is the ascending force; and the rushing-in of the surrounding air on all sides will be produced with more energy. To understand this effect better, let us consider a mass of warm and dry air rising in the midst of a colder atmosphere. In proportion

as this air rises it will expand, because of the less pressure which it will experience, and consequently become colder; it will arrive then quickly at an equilibrium both of temperature and pressure with a layer more or less elevated, which it will soon reach, and in which it will remain; but if this only cause of cold, expansion, is overbalanced by a cause of heat (for example, the heat furnished by the vapor which is condensing), this air will remain constantly warmer than would have been necessary to attain the same temperature

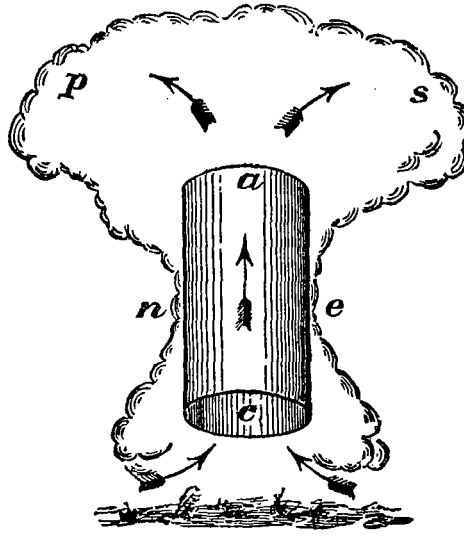

FIG. 4.

and pressure as the surrounding air. It will then be constantly lighter; and the higher the column, the greater the ascending force."

This statement contains, perhaps, as clear a view of Espy's theories as can be obtained. There are, however, one or two additional opinions, regarding tornadoes specifically, that should be mentioned. Mr. Espy says, "Suppose a receiver

(Fig. 4) only a few hundred yards in diameter, but so lofty that its top would reach to where the barometer would stand at 10 inches, and that it contained air about 25.25°, for example, hotter than the air on the outside, this latter being at a mean, 32°. The column of air then in the inside of the receiver would be expanded $\frac{25.25}{505.25}$ of the whole, or one-twentieth of the whole bulk. Now, as the air on the outside of the receiver, from the surface of the earth to the top of the receiver, weighs 20 inches of mercury, the air on the inside will weigh only 19 inches; and of course it will be pressed upwards against the upper end of the receiver at *a* with a force of about half a pound on the square inch, the bottom of the receiver being open at *c*.

"Also, if a barometer should be placed in the inside at the top *a*, it would stand an inch higher than one on the outside at the same height: therefore, if a small hole should be made in the top of the receiver, the air would spout out with a velocity due to a head of pressure equal to one inch of mercury. This is equal in weight to about 900 feet of air of mean density at the earth's surface. The velocity with which it would spout, on supposition of its having this density, will be found to be $8\sqrt{900} = 240$ feet per second (164 miles per hour). But the air at the top *a* is only one-third the assumed density, provided no allowance is made for temperature; and as the velocity of spouting fluids under equal pressure is inversely as the square root of their densities, the real velocity with which the air will spout out at *a* will be $240\sqrt{3} = 415$ feet per second (283 miles per hour).

"If, now, we suppose the whole top of the receiver to be taken off, the velocity will be the same, if there is no friction up the sides of the receiver, and the air gets freely in at the bottom; an allowance, of course, being made for the reaction of the air in the upper part of the receiver on the air below, in consequence of the velocity increasing all the way

up. If we remove the entire sides of the receiver, it is manifest that the heated column of air, which we suppose to be the same as before, would spread out laterally in ascending, in the form of an inverted cone, or mushroom, as exhibited by the dotted lines *p*, *s*, *n*, *e*.

"When the air near the earth's surface becomes very much heated, or very highly charged with aqueous vapor, such an ascending column as is here imagined may actually take place, and be kept up for a long time. The difference of temperature of the ascending column and that of the atmosphere through which it passes may be much greater than that here supposed, partly caused by its greater temperature below, but chiefly from the great quantity of latent caloric evolved by the condensation of vapor into cloud."

These quotations might be multiplied by the score; but enough has been given to show that Espy relied upon his experiments with the nephelescope for the facts upon which to base his theory, and that, according to his view, the setting-free of latent caloric by the condensation of moisture in an uprushing current was the principal factor to be considered in tornado-generation.

Ferrel's Views.

Professor Ferrel began writing upon mathematical theories in meteorology more than thirty years ago, and it will be of some interest to quote from both the earlier and later works. According to these earlier views, we may consider that there are two forces acting in the production of a tornado or hurricane: 1. A primitive impulse, such as an abnormal heating of the air, thus giving rise to an upward tendency; 2. A constantly acting force. "This force (2) may be furnished by the condensation of vapor ascending in the upward current in the middle of the hurricane, in accordance with Professor Espy's theory of storms and rains. According to this theory, all storms are produced by an as-

cending current of warmer atmosphere saturated with moisture, and this current is kept in motion by the continual rarefaction of the atmosphere above by means of the caloric given out of the vapor which is condensed as it ascends to colder regions above. The violence of the hurricane, and also its duration, depend upon the quantity of vapor supplied by the currents flowing in below" (see *Nashville Journal of Medicine and Surgery*, 1856).

Again: "The preceding condition, found in the unequal distribution of temperature, must be regarded simply as a primary cause of disturbance, giving rise merely to the initial cyclonic disturbances; for without other conditions, depending upon the hygrometric state of the atmosphere, and upon the rate of decrease of temperature with increase of altitude in the atmosphere generally in which the cyclone exists, we would have no cyclone of long continuance or of much violence. If air is saturated with vapor, after ascending to only a moderate elevation, its tension and temperature are so much diminished that the vapor is condensed into cloud and rain; and the heat given out in the condensation of the vapor as the air ascends prevents the rapid cooling which takes place in dry air, and the rate of cooling with increase of altitude is reduced, in ordinary temperatures and elevations, to less than half of what it is in dry air. Tornadoes are simply very small cyclones, extending over so small an area that the effect of the earth's rotation has no sensible influence; and the gyrations arise from a disturbed state of the atmosphere in which the tornado occurs, which renders it impossible for the air to flow from all sides towards a centre without running into gyrations around that centre." An illustration of this principle is given in the flow of water from a basin by an opening at the bottom. "In a tornado the diminution of pressure and tension in the centre arises almost entirely from the centrifugal force. On account of the rapidity of the gyrations near the centre, this

diminution of pressure may be very great there, while at a very short distance from the centre it is imperceptible. When these gyrations begin above, as they usually do, since the air there is most frequently in the state of unstable equilibrium (i.e., having a tendency to rush upward), they gradually extend downward; for the gyrations cause a great diminution of tension and of density, and the air consequently in the centre rushes up with great velocity, and that below of the still unagitated strata is drawn in to supply its place, which likewise runs into gyrations around the centre, so that the gyrations in a very short time extend down to the earth's surface. The whole column of gyrating air is like a tall flue containing very rarefied air, the centrifugal force of the gyrations acting as a barrier to prevent the inflow of air from all sides into the interior; and if the gyrations at the earth's surface were as rapid as those above, it would be similar to such a flue with all the draught cut off. But very near the earth these gyrations, and consequently the centrifugal force, are very much diminished on account of the friction at the surface, and this allows the air to rush in quite near the surface to supply the draught of the interior ascending current" (see *American Journal of Science*, July, 1881).

These views are repeated or amplified in "Recent Advances in Meteorology" (1886), with the following suggestions added: "When the air expands as it is heated, it requires a greater quantity of heat to raise its temperature through 1°, since in this case work is done, and it is done at the expense of heat supplied. An additional amount of heat, therefore, the equivalent of the work done, has to be supplied." "The complete temperature conditions of a cyclone, therefore, rarely extend down to the earth's surface, but the interchanging and gyratory motions, commencing first up in the cloud regions, are soon propagated downwards to the earth's surface by the action through friction of the

upper strata upon the lower ones." Speaking of unstable equilibrium, we find, "Currents of air at the earth's surface which come from a warmer latitude are caused to flow under the colder upper strata, where the normal motion is nearly eastward. In the south-east octant within the cyclone, the surface currents are from the south, bringing warm and moist air northward under the cold-air currents above from the north. This increases the temperature below, and decreases it above, and gives rise to the large vertical gradient of temperature, decreasing with increase of altitude, which is necessary to the unstable state."

A few final quotations are made from "Popular Treatise on the Winds" (1889):—

"The pressure near the centre of tornadoes becomes very much diminished, and in their passage over a place there is sometimes a very sudden change in pressure. Corks fly from empty bottles, cellar-doors are burst open against the force of a strong wind blowing against them on the outside, the walls of houses are thrown outward on all sides." "The direction of the general drift of the air is very nearly that of the progressive motion of the tornado, and so mostly from south-west to north-east. The velocity of this is always considerable in comparison with, though generally much less than, the gyratory velocity of the violent part of the tornado." Professor Ferrel quotes a statement regarding the fall of trees in the Gentry County tornado: "Those on the south (right-hand) side of the centre were pointing to the east and north-east, and even north-west when very near the centre. On the north side they were pointing north-west, west, south-west, and south-east."

Hail-Storms.

"A hail-storm is simply a tornado in which the ascending currents are so strong, and reach so high up into the upper strata of the atmosphere, that the raindrops are carried up

into the cold regions above, where they are frozen into hail." The theoretical velocity needed to keep up a hail-stone 2.58 inches in diameter is one hundred miles per hour. The fall of rain and hail is said to always precede the tornado by ten to thirty minutes.

Thunder-Storms.

"The fundamental conditions of thunder-storms, as of cyclones and tornadoes, are the state of unstable equilibrium, at least for saturated if not for dry air, and a high relative humidity. In what are usually called thunder-storms, the conditions are nearly or quite absent which give rise to a gyratory circulation over a large area, such as takes place in the case of cyclones, and usually the conditions are wanting which give rise to small local and violent tornadic gyrations, though most tornadoes are thunder-storms. According to Finley, 'of 473 cases in which the atmospheric conditions preceding tornadoes were observed, 410 were reported as violent thunder-storms.' If the air is in the unstable state, and over a given circular area is a little warmer and lighter than that of the surrounding parts, there is set up a vertical circulation, with an ascending current in the interior, and an incoming current from all sides in the lower part of the air, to supply the ascending current. In the interior ascending current the height of incipient condensation and of the base of the cloud depends upon the depression of the dew-point of the air; and the aqueous vapor above that height is condensed, falls as rain, and cools the air through which it falls, until its temperature is lower than that of the surrounding air. This central cooled air, being now heavier than the surrounding air, both on account of its greater density and the amount of falling rain pressing on it, now gradually settles down, and causes an outward current in all directions from the centre. If there were at any one time rain and hail falling with uniform velocity equivalent to a

rainfall of 13.6 millimetres in depth, it would increase the barometric pressure 1 millimetre; and from this alone would arise a squall with a velocity of about 34 miles per hour, making no allowance for friction."

More than two thousand pages have been perused in making these quotations. While no one person, perhaps, could give a perfect *résumé* of such a mass of matter, yet it is hoped that no important theory has been omitted.

Faye's Views.

It is necessary to mention one other theory that has been maintained by M. Faye of Paris. He has made a study of the appearances on the sun around his spots, and has been led to conclude that action in terrestrial storms is analogous in many respects. He thinks that this action originates in the upper atmosphere, and is propagated downward to the earth. A storm is practically a whirl in the swift-moving easterly current, similar to whirls in streams where an obstruction exists. This theory calls for a single remark. There does not seem to be a cause existent in the atmosphere in any degree adequate to set up such a whirl, unless we appeal to some force outside of the motion of the upper current. The transfer of the origin of the storm to the upper current is satisfactory, and we have seen that Professor Ferrel has done the same thing in his later studies. The fatal objection to Faye's view is, that a downrush of air must necessarily cause its heating; and it has been proved that in such a case there can be no condensation of vapor and precipitation, but just the reverse.

CHAPTER V.

OBJECTIONS.

I AM well aware that the position of an objector is an unenviable one, and to be avoided if possible. It seems to me, however, that all modern theories of tornadoes have intrenched themselves behind such a flimsy breastwork of fact that they can be regarded as little more than the "baseless fabric of a dream," and it is very important that the utter valuelessness of these supposed experiments be demonstrated. An attempt has been made to give, as nearly as could be done in so short a space, all the theories that have had their origin in Espy's experiments, and it is my purpose to examine these a little in detail.

Nephelescope.

The earlier form of this apparatus just described was superseded some years later by a double instrument, with which very extensive researches were made. These later experiments were much more complicated than the earlier, but, when properly interpreted, do not seem to lead to any different conclusions. It has already been shown that Espy was entirely misled by his results, and that, if they show any thing at all, they show that moist air did not behave

differently in his apparatus from dry. Somewhat the same line of research, carried on by the writer with the best of modern appliances, has shown conclusively that no different result is had on the condensation of cloud from moist air than from the expansion of air in which no cloud is formed (see *American Meteorological Journal*, September, 1889).

Summation of Theories.

In tornado-generation there must be (1) a primitive impulse or an unstable equilibrium, brought about (*a*) by a local diminution of density, or (*b*) by an abnormal heating of the air near the earth, or (*c*) by a warm current from the south underrunning a cooler from the north; (2) a constantly acting force furnished by the condensation of vapor in an uprushing column of warm, moist air, which produces rarefaction by means of the caloric given out of the vapor; (3) work performed by the uprushing air in pushing aside the atmosphere into which it expands; (4) gyrations of great velocity from right to left set up in the uprushing air, which, from the centrifugal effect, produce a great diminution of pressure (corks fly from empty bottles, cellar-doors are thrown off, whole houses burst open, etc.); (5) a violent inrush of air into the partial vacuum in the centre, the whole effect being likened to that of heated air rushing into a flue or chimney; (6) an origin of these motions in the cloud region from which they are gradually propagated to the earth by the action through friction of the upper strata upon the lower; (7) a progressive motion of the tornado in the direction of the general drift of the atmosphere from south-west to north-east; (8) frequently a passing from a severe thunder-storm into a tornado.

Let us consider each of these theories in turn.

1. A PRIMITIVE IMPULSE.—It is a mistake to suppose that the sun heats any particular locality, whereby circumscribed ascending currents are set up. The hottest part of the day,

that is, the time during which the heating effect is greatest, is about one hour, so that the heat of the sun acts uniformly upon a circle about a thousand miles in diameter. This heat acts only upon the earth's surface, and that in turn upon a layer of air only a few feet in thickness, as has been proved by experiment. To avoid these difficulties, it has been suggested that warm south wind underruns that which is cooler from the north. This, however, is an impossible condition, for the denser must always be beneath the lighter; moreover, as we have seen before, the clouds are always in the same direction as the lower wind. Finally, by (7) we see, that, if the tornado drifts in the upper current from south-west to north-east, that current certainly cannot be from the north.

2, 3. CONDENSATION OF VAPOR, AND WORK PERFORMED.—There is nothing in the science of meteorology, or possibly in any physical science, that has been developed from such a worthless origin as this theory of the liberation of energy on the condensation of moisture. We have already seen that Espy's own researches contradicted themselves. Ought we not to be allowed to theorize a little on this question? The most important effect of the liberation of latent heat is conceded to be the heating of the air, which produces a marked diminution of density. In cooling any air, we must consider the heating effect upon the surrounding air; that is, if a mass of air is cooled, the heat must be used up either in performing work or in heating other air. Take a cubic foot of saturated air at 80°, and cool it down to 79° by expansion: moisture is condensed, and latent heat becomes sensible. For the sake of the argument, let us suppose that a fraction of this heat is used in performing the work of expansion The remainder of the heat will warm up, let us say, a cubic foot of air near by to above 81°, thereby rendering it no longer saturated. We shall have, then, one cubic foot of air at 79° and saturated, and another at above

81° and unsaturated. If we mix these, we shall have two cubic feet of air at just above 80° and unsaturated, and this must be cooled below 80° to saturate it; so that the air in no wise is heated by the liberation of latent heat.

We may look at this from another standpoint. The liberation of an infinitesimal amount of latent heat from the condensation of moisture would be just sufficient to re-evaporate the condensed moisture, so that no heat could be spared for heating the air. Even if a portion of the heat is used up in performing *work*, it is very plain that that could not be used in heating the air. Surely, no one thinks for a moment that this heat from condensation can be used for two purposes, each of which must take all of it at the same time. This reasoning is so obvious, that it is difficult to see how the force of it can be avoided. We have arrived at precisely the same result both by most careful experiment and by an unanswerable train of reasoning. The proof is overwhelming that this great source of energy amounts to nothing whatever.

The following language, recently used by Professor Davis, seems very remarkable. When the air is warm and saturated, he says (*American Meteorological Journal*, December, 1889), "a given amount of cooling causes a larger amount of condensation than the same cooling of cold saturated air. This is thoroughly in accord with well-tried physical principles; it has been abundantly tested by experiment, both on a small scale in the laboratory, and, as we may say, on a large scale in nature; it is universally accepted by men eminent in physical study, whose original ability and careful, studious work have led them to be regarded as authorities in their science, but who, being authorities, have not thereby become arbitrary and irrational. It is therefore difficult to understand why the question should be so confused by Hazen in the *American Meteorological Journal*, September, 1889."

We have already seen that these so-called authorities have tried no personal experiments,—at least, Ferrel does not allude to any such experiments,—and have been entirely misled by a few crude and contradictory researches. Is it not high time that this appeal to authorities be done away with?

One of the main arguments advanced in support of storm theories is that such men as Ferrel, Hann, Mohn, and a host of others, are agreed,—agreed, however, as we have seen, upon exceedingly unsatisfactory evidence. Professor Davis suggests that these theories rest upon experiments, "as we may say, on a large scale in nature." This certainly is far from the truth. All the reasoning regarding the diminution of temperature in dry and moist air as we ascend in the atmosphere is founded upon purely theoretical considerations. Every experiment, whether in the laboratory or in nature, has proved that these theories, in their sum and substance, are false. But there is no use in arguing this question. I am so confident of my position in this controversy, and have become so deeply interested in my studies regarding it, that I am willing to make the following offer:—

I will give a hundred dollars to the first physicist who will show that Espy's observations and experiments with the nephelescope, as published in his "Philosophy of Storms," giving the effects of expansion in moist and dry air, when properly interpreted, prove his theory.

It will be necessary to show,—

1. That the rise of mercury in the gauge after expansion was entirely due to heat from outside.

2. That the speed of expansion Espy used, or the amount of cooling from expansion, was comparable to the probable speed of expansion in the free air.

3. That by placing water in the bottom of the nephelescope the air would be saturated.

4. That air, under the conditions observed by Espy, will lose its dew-point or become unsaturated to the extent of four or five degrees in twenty hours.

5. That the cloud Espy observed was not largely formed by dust pumped into partly dry air.

6. How, if the heat liberated on condensation of the moisture is used in performing the work of expansion, there can be any heat from that source for expanding the air.

7. Why, if there is any latent heat set free on condensation in saturated air, it would not at once re-evaporate the condensed moisture, or heat the surrounding air to an unsaturated state.

8. That if latent heat is set free on the formation of a cloud in the nephelescope, its effect does not disappear at the moment the cloud disappears, provided none of the moisture settles to the bottom or sides of the nephelescope.

9. By means of delicate thermometers, that there is not practically the same effect upon the air, as regards heat, in expansions like these, whether we use dry or moist air, or, what is the same thing, disprove the experiments and statements made in the *American Meteorological Journal*, September, 1889.

Professor Davis says, further, "It is a mistake to say that the latent heat, when liberated, will warm the air enough to allow the condensed vapor to evaporate again; for the latent heat is completely expended in the work of pushing away the air that surrounds the ascending expanding mass, and therefore cannot be applied to any other task. Espy made this error for a time, but afterwards corrected himself. It is regrettable to see the error now revived by Hazen." I am sure no one could ask for a stronger confirmation of his views than this from an opponent. If the above argument amounts to any thing, it declares that the latent heat of condensation would certainly immediately re-evaporate the moisture, unless it were used up in performing *work*. If it

is used for this purpose, it certainly and most emphatically cannot be used for causing a rarefaction in the cloud, and for increasing the energy of the tornado. Professor Davis is entirely wrong in his allusion to Espy. I am inclined to think that even Espy, with all his disadvantages, was too well informed to adopt such a doubtful and visionary idea as this of effective *work* performed in the free upper air. There is not one scintilla of evidence that he ever considered this question, except, possibly, to deny that any thing of the kind was to be thought of.

It is incumbent on those who hold the opposite view to show by Espy's writings that he disposed of any of his heat on this hypothesis, or that he ever thought that the latent heat would re-evaporate the moisture. He very quickly saw that the liberation of so much latent heat as his theory called for would heat up the air enormously, and was forced to dispose of it by radiation into space. It is probable that the amount of energy made effective by this so-called "work" in the free upper air is infinitesimal as regards the development of force. The explosions that Espy made in his nephelescope caused the air to rush with a velocity of perhaps a thousand feet per second. This enormous velocity caused a sufficient cooling to produce a cloud, which, however, was quickly evaporated. All reliable experiments have shown that the expansion of saturated air at velocities probably at least ten times as great as can ever occur in nature does *not* produce any cloud; and we see the reason for this in the fact that the latent heat made sensible does not permit the formation of cloud, for the condensing moisture is re-evaporated before it becomes visible.

It is a very significant fact, and one that has been borne in upon me with no little force by conversation with others, that Ferrel has introduced a long general discussion of this question of work performed by expanding air in his two latest treatises, but has nowhere made this theory available,

or even discussed it, in connection with the generation of storms or tornadoes. It would seem as though the amount of effective energy ought to be computed very closely, and its proper place given it. It is probable that an ascending cylinder of air a hundred miles in diameter would not produce any effective energy or any expenditure of heat in its centre from this cause. I am inclined to think that the total energy that can ever be developed from an ascending mass of saturated air is no whit greater than what may be called the balloon effect. If a hot-air balloon rises in the air at the rate of ten feet per second, it has carried a certain weight, say three thousand pounds, to twenty thousand feet, and there we have potential energy; but, if the balloon descends at the same rate, there will be no display of extraordinary force. If, instead of the confined mass of enormously heated air, we had a mass of air heated a few degrees above the surrounding air, it would rise; but here the air would spread over a great space, and we would not have the concentrated potential energy that we had in the balloon. To say that this air had any power of producing effective energy, or even to say that it could have arisen at all without the corresponding descent of nearly an equal amount of cooler air, is highly problematical.

4, 5. Gyrations in the Uprushing Air, and a Violent Inrush.—We have already seen that the evidence for these gyrations is exceedingly contradictory, and the weight of evidence is overwhelmingly against them. It would almost seem as though this theory were introduced to avoid a serious difficulty; at all events, we hear nothing of it for nearly forty years after the first studies. It is plain that a partial vacuum, if there were one, would be filled at once by the air rushing from all sides. Has this theory been invented to provide a whirling mass having sufficient consistency to keep out the inflowing air? This theory really proves too much; for, if there is this enormous centrifugal effect producing a

partial vacuum, how is it possible for moist air to flow in against the centrifugal effect? The theoretical explanation that there is friction at the earth's surface, which breaks up the centrifugal effect at that point, is exceedingly unsatisfactory.

It is given as a proof of this vacuum, that "corks fly from empty bottles." I have searched the tornado literature through and through, and have not found a single well-authenticated case of this phenomenon. The questions naturally arise, "Why were corks *put* in *empty* bottles?" also "Why did not the corks fly from the full bottles?" It is probable that corks and empty bottles were found in a cellar, and the theory could have very easily arisen that they had met with a separation. It would be very interesting to have a confirmation of this fact. It is said that whole houses sometimes burst from the passage of this partial vacuum. We have already advanced an explanation of this.

It should be noted that nearly all pictures of tornado-funnels make them exceedingly circumscribed, perhaps not more than ten feet across at the tip (see Fig. 1). The earliest representation of a tornado-cloud is very different from this, and it is probable that the imagination has had altogether too much to do with all these later pictures. It is to be hoped that wherever possible, in future drawings, there will be given some idea of the size of the funnel. If houses are affected, the funnel should be at least from a hundred to two hundred feet across at the earth. A remarkable evidence of the desire for showing a gyration in a tornado-cloud is to be found in the quotation regarding the Gentry County tornado, from Professor Ferrel's last book, at p. 47. This statement was of an observation in which it was claimed that trees on the north side of the track were thrown to the west and south-west. As shown in Fig. 2, this is exactly the way trees ought to be thrown, if this theory of a gyra-

tion is a correct one. This is the only instance, if we grant its authenticity, in which, out of a hundred or a hundred and fifty reports of this phenomenon, trees were ever thrown this way. The evidence of this kind is overwhelmingly in favor of the supposition that there is *no* gyration.

6. ORIGIN IN THE CLOUD REGION.—There can be no doubt that the tornado originates in the cloud region; but to say that this must be from an unstable equilibrium at that point, is a violent assumption. The sun, contrary to theory, undoubtedly heats up a cloud so that there is a steady increase of temperature with height, as shown by balloon observations; but there is no unstable equilibrium, though theory indicates that this should be enormous under these conditions. The tornado frequently arises after sunset, when there is no abnormal heating of the cloud. This transfer of the primitive impulse from the earth to the cloud is very significant, and seems to have been done to avoid a difficulty; which, however, has been increased rather than avoided. The hypothesis that such a disturbance, after starting in the cloud region, is transmitted through friction to the earth's surface, seems a little strained, when we reflect, that, according to computation, it would require more than twenty years for such transmission through a depth of three hundred feet.

7. A PROGRESSIVE MOTION IN THE DRIFT OF THE UPPER CURRENT.—If the general storm motion is in this drift, it certainly seems impossible to ascribe that of the tornado to the same. The tornado moves with a velocity fully double that of the general storm, and it is probable that the centre of its motion is not more than half the height of the former; and, as it is known that the velocity of the current increases rapidly with the height, it is safe to say that the drift at the "power" of the tornado is not more than half that in the case of the general storm. It is also impossible to account for the motion of the tornado for more than a hundred

miles, unless it has its own generating force, through the drift of the upper current. If the cloud is about three thousand feet high (not an underestimate), the motion of the upper part will approximate double that of the lower, and, in spite of the utmost centrifugal action, it would in a few minutes be torn apart. The hypothesis that the upper part breaks off, and re-forms itself in front, and afterward communicates its gyrations to the earth through a frictionless medium, must be regarded as one of the most strained that was ever advanced. This would break up the absolutely necessary continuity of the vertical ascending current, and would be fatal to the whole tornado theory.

8. A SIMILARITY BETWEEN THUNDER-STORMS AND TORNADOES.—This view was advanced prominently in 1884, and in the past few years has become a most important factor in all discussions. It demands a notice by itself, which will be given later.

It will be asked, Is not the foregoing a too severe setting-forth of the general weakness of tornado theories? Is not there some good to be gotten out of such theories, even if there are some points not fully settled? I leave the questions where they stand. I have not tried to overdraw the picture. The essential weakness of such theories is a starting from insufficient data and reasoning regarding most complex motions in a region in which we have hardly a dozen reliable records. It may be put down as an undoubted fact that no great advance can be hoped for in such studies, except the abandonment of these theories, until we investigate carefully the region where all these disturbances are developed.

CHAPTER VI.

ESPY'S EXPERIMENTS.

THESE investigations of Espy upon what actions may be considered as taking place in the upper air, as has been already said, are of the highest importance, and demand a special consideration. A proper interpretation of his results will help us in all our studies and reasonings. One of the most serious difficulties that we shall encounter, however, is in the fact that in the open air we are not dealing with a limited confined space, but we have to do with unlimited space and a well-nigh frictionless medium. The apparatus which he used has been sufficiently described already. The earlier investigation with the nephelescope was made without the use of a condensing syringe; and in this we are able to comprehend clearly just the action which took place, while in the later researches the results were quite complex. Mr. Espy first carried his jar into air the temperature of which was quite low, at freezing or below; and, after it had attained the temperature of its surroundings, the stop-cock was closed, and the jar was taken to a room with high temperature, 70° to 80°. The air inside was expanded by the heat, and the amount of this expansion was measured on the gauge. He then opened the

stop-cock, and closed it at the moment the mercury reached a level in the gauge. The rising of the mercury in the gauge after explosion, he thought was due to the gradual heating of the air which had been cooled by the sudden expansion. In the same way the jar was left in a high temperature for a time; then the stop-cock was closed, and it was carried to a low temperature. In this case, of course, the mercury in the gauge had the opposite motion to that it had before. The same experiments were tried with both moist and dry air.

One of the more important results from these researches, Espy does not seem to have thought of, though it dimly foreshadowed the epoch making experiments of Mayer and Joule, in England, on the mechanical equivalent of heat. It is plain that in this confined space used by Espy there must be a relation between the amount of rise or fall in temperature and the corresponding change in air-pressure under a constant volume, and this will enable us to determine the expansion of air per degree of heat applied. In moist air the average difference of temperature between the cold and warm room was 45°, and the rise of the gauge 2.97 inches; in moist air, going from a warm to a cold room, the fall in temperature was 45°, and the fall in the gauge 2.60 inches: while with dry air these quantities were 57° and 3.34 inches and 63° and 3.30 inches respectively. The amount of change per degree in the four cases was .066, .057, .059, and .052 of an inch, or a mean of .059 of an inch in all the cases. The reading of the barometer is not given; but, if we assume it to be 29.80 inches, we find that the increase of temperature required to double the pressure in the jar was not far from 505°,—a result which is remarkably close to the 490° found by the more careful and extended researches of others. We now see the important bearing of this first work on our studies. If we compress air 5 inches by the gauge, we would heat it 83°; and if 10 inches, 167°;

and so on, provided no heat was lost or dissipated in the operation. We ought also to be able to calculate from the reading of the gauge, after any operation of either condensation or expansion, exactly how much the air was heated or cooled, provided always that no heat was lost or gained.

In the light of this interpretation, let us examine some of Espy's experiments. In one instance he compressed the air 10 inches. We may suppose that he waited long enough to allow the jar to attain the air temperature before explosion. After the explosion the gauge reading was 2.15 inches, which would indicate that the cooling was not far from 36°, provided the only influence on the gauge was through the rise of pressure consequent upon the heating of the air by surroundings. It would appear that the theoretical cooling from such an expansion should be much greater than this; and, in fact, we cannot reason or theorize upon this result in any way, without first learning the probable loss of heat during compression, and its gain during expansion, to and from the environment. Espy's nephelescope was duplicated in its different parts, with the addition of a most delicate thermometer loaned by Professor Russell. This instrument has a bulb .06 of an inch in diameter and 1 inch in length, and would change one degree in from two to three seconds. It is plain, that, in observations with any degree of speed in *change* of temperature, any instrument will be liable to lag behind the existing temperature. This difficulty, however, may be partially avoided by conducting operations at variable rates of speed, because, if we obtain the same result with different rates, we can conclude that the lagging is inappreciable. Again: the amount of this lagging may be approximately computed by using two thermometers with different rates of lagging. Whatever may be this lagging, however, it is plain that it would be exactly the same in moist as in dry air, so that our comparative results will be entirely free from any error due to the instrument. In

saturated air, moisture collects on the bulb; but this can make no difference, since in saturated air the dry and wet thermometers read alike.

Experiments.

On rapidly compressing the air and suddenly releasing it, the amount of rise and fall in temperature was the same, about 7° for 10 inches of compression. We shall be entirely within the limits of error if we assume the lagging to be 1°. Since the air at the side of the jar was at very nearly the air temperature, we can consider that the average heating and cooling of the whole air was not far from 4°. This shows what an enormous loss of heat was sustained by the air in compression to one-third its bulk. The theoretical heating should have been 163°, while the actual heating was one-fortieth of that. But the most important fact in this connection is that Espy, under the same conditions, found the cooling after expansion to be nine times that found above. Espy emphasizes the great necessity that exists in closing the stop-cock at the moment the mercury reaches a level, or at the exact moment when we may suppose the cooling by expansion is greatest. On repeating these experiments, it was a matter of great astonishment to find that the delay of a few seconds only in stopping the expansion, after the columns in the gauge were at the same level, almost entirely obliterated the subsequent rise. This would seem to show that heat from the environment had little or nothing to do with this rise, and this is an exact corroboration of the indication of the thermometer; for a rise of 4°, which was found, would represent less than .25 of an inch on the gauge. Does the mercury in the gauge reach a level before the air inside the jar is in equilibrium with the outside air? Professor Marvin has suggested that the momentum of the mercury in the latter part of the expansion would cause it to reach its level sooner than the air its equilibrium. On performing

the experiment at different speeds of expansion, it was found that a definite relation existed between the rapidity of fall of the mercury and the subsequent rise after arresting the expansion. For example: the air each time was compressed to 400 millimetres, and expanded in 5, 10, and 20 seconds. The amount of rise in these cases was approximately 41, 21, and 12 millimetres respectively. It might be thought that this was due to the greater accession of heat to the air during the slower expansion (that is, the cooling would not become as great), but in all these cases the thermometer indicated the *same* cooling at the end. It must also be plain that this effectually disposes of the question of lagging, as suggested above. The evidence is cumulative and conclusive, that the rise noted by Espy was not due to a heating, from outside, of the air cooled by expansion; and his whole theory regarding the difference in cooling, of dry and moist air, falls to the ground.

As regards the fact that there is only an exceedingly slight rise after waiting a few seconds, Professor Seaman has suggested that the air may be heated in these few seconds, and therefore there is no rise. But it takes time to heat the air under these conditions, and in these few seconds the amount of heating is exceedingly slight: in fact, this one thing is a strong argument against the view that the rise noted after expansion is due to heat; for the rise is very rapid, and is accomplished in a few seconds. Still another point is to be noted: by making the compression to 400 millimetres very rapid (that is, in 10 seconds), and then expanding in 5, 10, or 20 seconds, we have heated and cooled our air by very nearly the same amount, and it has come back to just a degree or two below the outside air temperature; so that the subsequent rise cannot be due to the accession of heat from outside. There is an exceedingly interesting matter right here that I leave for physicists to consider. We are told that the only way in which air can lose its heat is by per-

forming work. Now, is it possible for us to consider that the amount of work done in compressing the air to 400 millimetres is exactly counterbalanced by the work done by the air in forcing aside the outside air as it rushes out of the jar? It would seem as though the former must be a thousand or more times greater than the latter, if we take account of all the circumstances. One more experiment was tried to determine the cause of the rise in the gauge after explosion. If this rise were due to the behavior of the gauge, rather than to outside heat, we ought to be able to obtain it at any moment after expansion, and long before any marked cooling had taken place. When the expansion was arrested after one or two seconds, there was a marked rise in the gauge. This arrest must have been long before the cooling could possibly have brought the air to the outside temperature, for the just previous compression had heated it 4° above the air, and the expansion could not cool it down before 5 seconds had elapsed. Whatever may have been the cause of this rise, there is one point about which there is not the slightest doubt, and this is the principal point that we are to consider. Under all conditions of slow or rapid compression and expansion, the final cooling after explosion was almost identically the same, whether moist or dry air were used. This was determined by the thermometer; and in this experiment it must be admitted that the lagging of the thermometer had no influence, for it would be precisely the same in both moist and dry air. The rise of the gauge after explosion with dry air was slightly greater than with moist air, but this may have been due to a difference in the whirls which the explosion always produced inside the jar. It seems almost incredible that this fatal slip should have occurred at such an extremely critical point in Espy's work; and I am impressed with the conclusion thus reached, not so much by my interpretation of Espy's doubtful results, but far more because the two sets of experiments dovetail into each

other so perfectly, and the one serves as a check on the other.

It is not a little remarkable that we have obtained somewhat the same result as this by another method of reasoning. The condensation of the moisture or the appearanco of the cloud, even in thoroughly saturated air, is exceedingly evanescent in a jar of this kind. It is next to impossible, except with very high compression (15 to 20 inches), to get a particle of mist to settle to the bottom. Under the compressions employed by Espy, the cloud or mist entirely disappears in a few seconds, and not an atom of moisture reaches the bottom of the jar. Suppose, now, that, at the instant of expansion, latent heat were liberated by the formation of the cloud, which would prevent a further cooling. It is very plain that it would be used up immediately in the evaporation of the cloud; and the disappearance of the mist proves that the sensible heat has again become latent, and can have absolutely no effect in expanding the air or in causing a final higher gauge reading, as Espy thought.

A note should be made of the condition of Espy's moist air. The presence of a haze or cloud is no evidence of saturated air, for such cloud has been produced in air having only two per cent of moisture. When air is pumped in from the room, it has an enormous number of dust-particles in it, and these give the semblance of fog on sudden expansion Espy tried to saturate his air by putting a little water into his jar, but it is certain that this expedient would be of little or no effect. Bubbling air through three inches of water will not saturate it, and it was found that nearly all expedients failed to do so. The only satisfactory saturation could be effected by passing the air through a bottle full of small pieces of sponge saturated with water. While we cannot think that Espy's air was saturated, yet it is certain that the experiments in 1889 were with saturated air, and hence must have shown a difference between dry and moist

air, if any could have done so. The delay of several days in some of Espy's experiments after compression before explosion should have served, and probably did serve, to increase the moisture in the air, and not to diminish it, as he thought, and as his researches seemed to indicate. It might be thought essential, in order that this question may be settled beyond all doubt, that there be some explanation of Espy's results showing a slightly greater rise in the gauge after expanding dry air than when moist or partly moist air was used. Undoubtedly, if all the conditions were known, the difference could be easily explained. It is absolutely certain that it was not due to any latent caloric of elasticity that was given out by the moist air.

I think this discussion will enable us to reason more or less effectively as to what are the probable heating and cooling effects in the free atmosphere from descending or ascending currents, and the resultant liberation or production of energy. It is well known that the most perfect locomotive makes use of only five to ten per cent of the total energy developed. We have just seen, that in condensing air to 10 inches, instead of obtaining an increase of temperature of 163°, as theory seems to indicate, we have barely reached 4°, or one-fortieth of the theoretical amount. It is plain that this is due to the loss of heat into the environment of the air. Suppose, now, we take away this confining jar; suppose we make steam in the open air instead of our locomotive boiler; or suppose, instead of trying to compress air in our jar, we had the total horse and steam power of the whole earth engaged in compressing the free air by forcing it through syringes or force-pumps into the atmosphere What would be the result? The utter absurdity of all this is most plainly manifest, but is it any more so than the attempt at developing effective energy in the free air, as has been theoretically accomplished by some? If there is this enormous dissipation of heat under conditions which we can

control, must there not be a very much greater dissipation of heat in all out-doors? Is it not highly probable that many of the theoretical deductions find their only shadow of support in the fact that the assumptions call for a perfect engine without loss of a particle of energy? Has theoretical meteorology ever produced even a single essential effective element or part of this perfect engine? If the considerations herein set forth are borne out by subsequent researches, we must most certainly come to the conclusion that thus far theoretical meteorology has not had a single well-supported fact on which to base its profoundest theories of tornado generation and movement. Professor Wild of St. Petersburg has well said, "Without exact and satisfactory data, meteorology cannot develop as a science, but will be, as heretofore, mainly a tumbling-ground for vague speculations and dilettanti investigations."

CHAPTER VII.

THUNDER-STORMS.

A TYPICAL thunder-storm is first seen as a dense, ragged cloud in the west, extending to a height of over a mile. The sky is entirely clear elsewhere, except sometimes covered by a light fleecy veil of cirrus. The cloud in the west rapidly enlarges, and completely covers the sky except a small portion to the east and south-east. The motion of these clouds is distinctly from the west and quite rapid, while the surface wind is from the south and quite gentle. This wind is blowing toward a general storm situated about five hundred miles to the north-west, and has no connection at all with the thunder-storm which is suddenly interjected, as it were, upon the quiet air. Often there are seen two clouds in the south-west and north-west which seem to meet together and produce the storm, but more often the first appearance is that of a great cloud of dust borne upward about three hundred feet, and advancing with great rapidity from the west (sometimes eighty miles per hour). Some of the clouds sprinkle a little rain as the dust-cloud advances, but this is very light.

When the storm is very severe, a loud roar is sometimes heard like the continuous discharge of electricity which pro-

duces a steady instead of intermittent thunder. During this time, lightning-flashes are seen and distant thunder heard. In a few moments, after the dust cloud has approached nearer and practically with it, the wind suddenly whirls to the west, and blows with great velocity (sometimes eighty miles per hour). Then, in a moment or two more, the lightning and thunder become very intense, and rain falls in torrents. Often the lightning's flash is the signal for a fresh downpour, allowing a few seconds for the fall of the rain from its height. This phenomenon has led to the view, now almost universally accepted, that there is a most intimate relation of cause and effect in this display of electricity and the subsequent rain. Under some circumstances, but invariably in connection with this heavy rain, there fall hail-stones variously measured from the size of a pea to that of hen's eggs, and even larger. In some cases, larger masses, even as great as an elephant, have been reported, but these are due to a mingling or freezing together of many stones in the air or after they reach the earth.

Cold Air.

During the progress of a thunder-storm, and after its front has reached the observer, there is a remarkable cooling of the air. This cooling seems to arise from a downward current in the centre of the storm. It cannot be due to the onrush of a north-westerly wind, for that must come from a warm region, since the thunder-storm has been suddenly interjected into a region of warm southerly winds flowing for hundreds of miles toward the north. This cooling is often very great, and seems to indicate that the air in the centre of the storm is not abnormally heated, as in the case of a general storm, but is very much cooled. The bearing of this upon the generation of the thunder-storm is of great importance, and does not seem to have been sufficiently considered heretofore.

Environment.

When the storm passes to the north or south of the observer, there is quite a brisk breeze from it, showing that the motion of the air is from it on at least three sides. Often it is possible to view the storm, in its onward progress, with clear sky overhead, if its border does not reach the zenith of the observer. Under these circumstances, one sees very distinctly up to the highest clouds a steady motion to the east. The rain is seen falling in great sheets, and its front is very distinctly marked. This rain front seems to be an important phenomenon, and has been seen scores of times advancing with a slight lagging at the earth and in the clouds. The appearance impresses one at once as caused by a rapid motion in the middle cloud region, with a lagging at the earth possibly from friction, and in the upper part of the cloud from a less velocity at that point. In no instance has there ever been observed an uprush of air anywhere in this region. These storms go in parallel lines; and as many as four have been seen running one behind the other, the most northerly one in advance. Often it is reported that a storm has gone slightly north of a station, and then turned and come back directly over it; but this is probably an illusion. The second storm has a motion the same as the first, but goes a little farther south. The motion across the country of these storms is about double that of the attending general storm to the north-west.

Probably the most marked characteristic of a thunderstorm, however, is a rise in pressure at its centre. This rise is universally conceded to-day, though its cause is in grave doubt. It has been repeatedly observed in storms where there has been no rain, and hence cannot be due to the cooling of the air by the rain, or to its downward pressure as it falls. How is it possible to account for this rise of pressure in a storm which is itself travelling more than a mile a minute? We have here to consider a phenomenon entirely dis-

tinct from a sand-whirl of the desert, which has only a slight progressive motion. There seems to be no doubt whatever that we are to consider here a cause or a condition which is inherent in the storm itself. There can be no upsetting of the equilibrium, no uprush of air just in front of a thunder storm and nowhere else, which could give such a rise of pressure in so rapidly a moving body of air. We are certainly dealing here with a *plenum* which moves with the storm, and in fact is the storm itself. It may not be that this is due to a downrush of air-particles from some height; but there is no serious difficulty in assuming that, through electrical action, there is an increased pressure in the centre. It is plain that the foregoing description has a most marked parallelism with that already given of the tornado, and it is virtually admitted that a tornado is simply an extreme development of a thunder-storm.

The attempt to show that while these phenomena are alike in most respects, and yet that in one of the more important factors they are entirely distinct, is most remarkable. We are taught that the origin of both is an unstable equilibrium, in both there is an uprush of air, in both there is a cloud of dust, in both there appear to be two clouds meeting from the north-west and south-west, in both there is a loud roar heard oftentimes, and in both there is a pronounced cooling. They are exactly alike, and produced the same way, but the final result of these actions is to develop two entirely dissimilar and almost opposite conditions. We are told that in a thunder-storm the air starts upward in the centre, has its moisture condensed by expansion, and the resulting precipitation cools the air, increases its density, and finally the diminished pressure at starting gives way to an increased pressure from this change in the density. It must be admitted that this is a reasonable conception, and may be true; but would not this at once destroy the ascending current, and bring the whole action to a standstill? Can we for a

moment have both uprushing currents in a storm-centre feeding its energy, side by side with downrushing currents increasing the pressure? It is only necessary to state this contradiction in order to show the absurdity of the hypothesis. This theory strikes at the root of the whole process of liberation of energy in a moist ascending current; but, more than that, if there is such a cooling and subsequent downrush, why should it not act in precisely the same manner in a tornado? How is it possible for this same uprushing current, which starts in exactly the same way in both these conditions, to continue upward in a tornado, to gather energy as it rises, to liberate more and more latent heat, to rush faster and faster, to grow warmer and warmer, and finally to produce the violent tornado with its supposed almost perfect vacuum in the centre, where a half-mile away there is perhaps a thunder-storm causing an increase of pressure? It would seem as though there could hardly be a plainer exposition of the utter futility of all the attempts that modern theorists have made to grapple with this problem than this latest attempt to start the thunder-storm and tornado in the same direction, and finally bring them out, from almost the same conditions, facing in opposite directions, and absolutely dissimilar in their most essential characteristic.

Explosive Effects.

Is it possible for electricity to produce a sudden increase of pressure in a mass of air sufficient to violently rend asunder objects which it strikes? Oftentimes the bark of trees has been driven off; and the usual explanation of this has been, that the heat of the electricity has converted the sap into steam, and this in turn has forced off the bark. This, however, is not satisfactory, for the reason that even a dead and perfectly dry tree has been struck, and scattered over a large field. A remarkable instance of explosive action in a lightning discharge is to be found in *Nature* for May 8,

1890. A tree standing in a rather open field was struck by lightning, and its fragments strewed over two acres of ground. One solid piece weighing five pounds and a half was thrown three hundred and seventy-eight feet. Other *débris* lay two hundred and ten feet in another direction. Small pieces of riven trunk and bark were found thrown in the teeth of the wind and one hundred and eighty feet from the tree. The concussion or increase of pressure smashed six fine glass window-panes in a house not far away. Another very interesting effect was noted in a house that was struck in Washington, D.C., Aug. 23, 1885. In this case the lightning struck the south-west corner of the tin roof on an L built on the south side of the house, and divided. A portion of the flash passed down an eaves-spout; and at its end, which was two or three feet above the ground, it passed through the air to the damp side of the house, knocking off the plastering on the inside. The other portion of the flash passed down between the weather-boarding and the plastering on the east side, shattered one of the upright posts, and appeared to explode off the weather-boarding toward the east, and the plastering toward the west. A woman and her two sons were apparently stunned by the effects.

While such cases have usually been regarded as "freaks" of lightning, yet it would seem that the matter has not been sufficiently studied to enable us to determine just what effect such a discharge would have upon a confined air space. It may be, the apparent bursting of a house in a tornado may be accounted for in this way. An instance has already been given at St. Louis of a rise in pressure, as shown by a barograph, and at the same time a seeming bursting of houses. Hardly a month passes that there is not some discovery regarding this extraordinary force of electricity, and surely we are not in a position to deny that it might not produce a large number of effects now observed in a tornado, such as searing of green leaves, discoloring the trunks of trees, in-

creasing the pressure, exploding houses, depluming fowls, etc. We are told that lightning-flashes are seldom seen in a funnel-cloud. They have been seen there many times. Moreover, it is not at all certain that an ordinary observer would be in a condition to take particular notice of the presence of electricity in a tornado; and, again, the electricity may pass down or up the funnel without a visible flash. The presence of ozone has been often noticed in a tornado where no lightning was seen.

Possibilities of Electric Action.

It has been my purpose for many years to avoid, as much as possible, all speculations in considering air motions and the causes of atmospheric phenomena. This is especially pertinent when we consider electric action in the atmosphere. It is very difficult to believe that electricity has nothing to do with our thunder-storms, and is merely a result, and never a cause. The fact that physicists have never yet been able to account for more than the smallest fraction of atmospheric electricity should lead us to greater diligence in determining its methods. We know from observation that the electric potential is enormously increased as we ascend in the atmosphere. That little or no connection between atmospheric electricity and storms has been observed by our instruments near the earth is not remarkable, since the earth and air just above it may neutralize all electric action for a hundred feet or more. Our thunder-storms seem to show an enormous storehouse of electricity at five thousand or six thousand feet above the earth; at least, electricity seems to be concentrated there over thousands of square miles during thunder-storm action. We are taught that electricity forms a sort of dual condition, or the electric field is a double one. May not this electric field draw on the sun for its energy? It is believed that light, heat, and electricity are all different manifestations of the same radiant energy.

The abundant source of this energy is the sun. Why may not the sun's electricity, oftentimes observed by its direct effect on our magnetic instruments, and more often still indirectly in our auroras, be intercepted by a peculiar condition of the atmosphere or of the earth below, and thus be concentrated in particular localities? Generally this electricity passes through the air to the earth, but must we think that it always does so? May not this electric field or dual condition gradually develop in the atmosphere largely independent of the passage of air-particles through wind or convection currents?

The Electric Field.

For convenience it has been generally considered that particles have a tendency to leave the positive and pass to the negative pole. For example: in the electric arc-light the carbon at the negative pole is built up at the expense of the positive. The velocity of transmission of these carbon particles perhaps cannot be determined, but it must be only a very small fraction of that of electricity, 190,000 miles per second. Is there any inherent improbability in the supposition that in this dual condition in the atmosphere there is a tendency for moisture and possibly dust particles, positively electrified, to pass rather rapidly from the positive pole, or, better, positive portion of the electric field, to the negative portion? We know from observation that during the passage of a high area or clear sky the electric potential, with very few exceptions, becomes markedly positive, while during the fall of rain it is negative. While a thunder-storm is passing, there are most violent fluctuations of the electrometer-needle from negative to positive and back again, as each flash of lightning is noticed. These fluctuations of the needle are perhaps a hundred times as great as under ordinary conditions of rainfall, and take place when the flash is a mile or two away, showing a most extraordinary inductive

action upon the atmosphere, and for enormous distances. We have positive evidence of such transmission of moisture-particles by a force entirely distinct from heat, pressure, or any other commonly recognized meteorologic condition. It is known that the moisture in the air is one of the most constant elements we have to deal with. The temperature may rise and fall thirty or forty degrees during the day, and yet the quantity of vapor is in no wise changed. The wind, either in direction or velocity, does not change this moisture. The hiding of the sun's heat or light in no wise affects it. Changes in air-pressure produce no effect in general. As a storm approaches, however, we find a most marked increase in this moisture over thousands of square miles, and this even in a calm. As a storm passes off, the conditions are sharply reversed. The moisture becomes depleted in a most remarkable manner, as though it were actually drawn out of the atmosphere by an invisible agency.

The most remarkable example of such action was observed on Dec. 22, 1889, from a third-story window of a house in Washington. It will be seen that the conditions were not favorable for observing this effect at its best. At 3.11 P.M. there were 4.09 grains per cubic foot, and for more than twenty-four hours previous there had been an abundance of moisture from a storm passing near by. The air was almost a calm, and continued so till nightfall. At 5.2 P.M., or one hundred and eleven minutes later, there was only 1.04 grain per cubic foot, and this continued as long as observed. To any one who has made determinations of the moisture of the air, and noted its great constancy, frequently for several days, this sudden subtraction must be very extraordinary. If such changes are possible near the earth, and in the centre of a large city with houses for more than a mile on all sides, what may we not expect to take place in the free air, where there are no interferences, and where we know that such forces are acting in far greater intensity than near the earth?

Enormous Fall of Rain.

Just after a thunder-storm or tornado, there are torrents of rain, and in some quarters it is getting to be quite the custom to call such phenomena cloud-bursts. In these cloud-bursts almost an incalculable amount of rain falls, more than a foot having been reported at times. In one case four feet of hail were reported. Just how much territory is covered by such a cloud-burst cannot be told, as the data are not sufficiently numerous, but fifty or sixty square miles may be easily considered. We have already seen that the later theory, which calls for a downrush in the centre of a thunder-storm, effectually disposes of all possibility of this enormous amount of moisture rushing up in the centre and being condensed by expansion. In the case of a tornado, it is incredible that even a thousandth part of this moisture can be carried up in a funnel a few hundred feet in diameter. If we inquire what would be the effect of the ordinary condensation of such a mass of water in the air over such a limited space, we are confronted by an amount of heat set free that is simply appalling. One gallon of rainfall gives out sufficient heat to melt forty-five pounds of cast iron. A very little consideration will show us that it is absolutely impossible, even allowing a current of moist air at any conceivable velocity, for even a small fraction of rain to be precipitated out of such a current. It has already been shown that the latent heat set free would at once re-evaporate the moisture. We seem to be driven to invoke the aid of some other agent than any thus far recognized as cogent in producing our storms. Is it inconceivable that we have to deal here with a negative electric field, which draws to itself with great velocity particles of moisture from regions perhaps for one hundred miles about, when suddenly, upon a discharge of electricity, the potential upon the particles is diminished, and they unite in great abundance and form raindrops? This is a most inviting field for observation. We already

have facts enough to make a plausible hypothesis, and, what is very important, we have here an unlimited amount of energy which may be called upon to produce all the effects ever observed.

It is not a little remarkable that the earlier views all ascribed tornadic action to electricity, and it would seem as though the time were not far distant when we would be forced to return to this agent for explaining the phenomena. What are needed are careful experiments in this most enchanting field of research. An attempt has been already made to test the question of the transmittal of moisture through the air by electric action. A Holtz machine was run for fifteen minutes in a rather large room; and most careful measurements of the amount of moisture at the machine and at a point twenty feet away, before and after the machine was in action, showed an increase at the machine. When we consider that it was impossible to measure the moisture contents just at the plate of the machine, and also what an extremely slight charge could by any possibility enter the air from the machine, we can but be surprised that any effect at all was observed. With improved methods of observation by which the exact hygrometric state of the air can be easily and accurately determined, and with very accurate tables of reduction which we now have, all that is required is an observer for investigating these phenomena. The expense for apparatus need not be great.

CHAPTER VIII.

TORNADO LOSSES.

THE destruction of life and property by a tornado must ever be regarded as the most important fact from a practical standpoint, and in many respects this feature of the subject is involved in greater confusion and uncertainty than any other. As has already been said, such a violent storm ought to be exceedingly well defined, and the amount of loss determined within a small fraction. One reason for this uncertainty has been the lack of persons desirous of obtaining a complete list of property loss and damage by tornadoes. We have an excellent illustration of an opposite state of affairs in the estimates of loss of property by fire. Here there are hundreds interested in obtaining the exact loss; and it is believed that in this country the loss by fire, whether of insured or uninsured property, is known within four per cent of the actual loss. A most serious difficulty in making such estimates has arisen from a vague and indefinite idea of what a tornado is, and how it should be described. We are told, for example, "if we care for the name 'tornado' to define a distinct class of local storms, then the funnel-shaped cloud, as shown by a distinct rotary movement of the wind, or by peculiar destruction of prop-

erty, should be made the condition of classification. Both for the purpose of study and practical results, this manner of distinguishing the tornado is desirable. It leaves no doubt as to where the line should be drawn, and recognizes a peculiar and important class of meteorological phenomena, independent of their effect upon life and property, which it is quite well known that they can destroy if given an opportunity." We must take most serious exception to these views. It is manifestly only by the effects displayed by these storms at the earth that we can classify or discuss them. The most violent commotions, the most surprising shapes and appearances of clouds meeting or rolling over each other, might have a passing interest, but surely they would be practically of no account if they did not reach the earth and there affect life and property.

Descriptions.

We have already seen that in the earlier history of these outbursts they became familiarly known by a definite name. For example: the New Brunswick (New Jersey), the New Haven (Connecticut), the Stow (Ohio), tornadoes are definite phenomena and extremely localized. In later times the most terrible tornado but one that has occurred in this country was that at Grinnell, Io. To call this the Poweshiek County tornado, and to say that it had a path 450 to 600 feet wide, takes from it almost entirely its definiteness and extreme destruction. In another instance a tornado is described as causing a loss of $4,000,000,—the greatest in this country, and, for that matter, in the world. This tornado is given a path 2,640 feet wide, and passing through Rock, Hennepin, Ramsay, and Washington Counties, Minn., and through St. Croix, Polk, Barron, Chippewa, and Price Counties, Wis. It is not intended, of course, to convey the idea that there was a clean sweep a half-mile wide through these nine counties; but, to one familiar with the more ter-

rible storms, such a description would convey an idea of a most appalling disaster. A most careful study of this nine-counties tornado has revealed the most astounding result, that there were only two towns injured. The principal loss was at Clear Lake, Wis., $139,100; and the other town was Marine, Minn., with a loss of about $65,000. The total direct loss by this tornado in all the counties was not over $250,000, or one-sixteenth the published loss. It should be insisted on, by all means, that every tornado should have a definite local application and a name. In some cases where the country is thinly populated, and houses are destroyed here and there through many townships, it will be necessary to group all such hamlets in the name of a county or of the principal town visited, but this should be rarely resorted to.

Indirect Loss.

Much confusion has arisen from grouping together losses by the tornado proper, and by floods and hail which accompanied it; also by considering losses to orchards, crops, fences, stock, etc., in connection with that to houses and buildings. Certainly, in calculating risks for tornado insurance, and in studying the definite losses, we should catalogue only the definite and direct loss to structures. It is not a little remarkable, that, while the descriptions of tornadoes have tended to vagueness and indefiniteness as to extent of path and destructiveness, no such difficulty has been encountered in photographing the effects of a tornado. The most completely destroyed houses and blocks, and scenes exhibiting the severest violence of the storm, have always attracted the photographer. This country has had over two thousand tornadoes since 1873, but we would be very much deceived if we thought that the scenes of desolation depicted in half a hundred photographs were experienced at more than two per cent of these. The worst of these photographs are taken from only two or three tornadoes.

Tornado Lists.

These are being published from time to time, and in the main are very untrustworthy, from a lack of care in collation, and a desire to exhibit some preconceived idea as regards the tornado. A careful sifting of the lists has shown that many of these tornadoes were of very slight account, and many also were straight blows with little violence. Often a whirling cloud does not reach the earth, but it is called a tornado. In one list the Wallingford (Connecticut) tornado of Aug. 9, 1878, is put down as only a heavy thunder-storm, although it ranks among the severest of all, for there were thirty killed, fifty houses destroyed, and $250,000 of damage done. There will be given later a list of all the most severe tornadoes since 1873. No pains have been spared in making this list as complete as possible; and while in a few cases the loss may be slightly overestimated, yet in the main it is believed to be accurate.

Hinrichs's Views.

Mr. Hinrichs of Iowa has devoted many years to the study of tornadoes, and has given careful attention to the subject of a classification. A *résumé* of his views has been given in the *American Meteorological Journal* (vol. v. pp. 306, 341, and 385). He would make a careful distinction between a tornado and a squall, or *derecho*, as he would call it. The latter he describes as a straight-line heavy wind, usually advancing from the north-west for many miles across the State. While it is frequently destructive, yet it is of an entirely different type from the tornado. It is barely possible that there has been a slight confusion here, and that the apparent movement of the *derecho* from north-west to south-east is complicated by the occurrence of a series of tornadoes or destructive thunder-storms running in parallel lines from south-west to north-east. It hardly seems probable that we have to deal with a particular class of storm (*derecho*) in Iowa that

is not found east of the Mississippi. What Mr. Hinrichs calls the "front" of the *derecho* may be either a thunder-storm or a tornado, and the universal law controlling these is a movement from south-west to north-east. We have already seen that these violent storms travel in parallel lines, beginning earlier in the afternoon at a point toward the north-west of a tornado region, and gradually working south-east. Each line occurs later and later, and it is also a fact that frequently the later storms have the longer paths. These appearances might also occur in a *derecho*.

Hinrichs's Classification.

The following shows the classification of tornadoes according to Hinrichs's method:—

A. Notable Tornadoes.
- Class I. Multiple.
  - (*a*) Large.
  - (*b*) Small.
- Class II. Single.
  - (*a*) Large.
  - (*b*) Small.

B. Minor and Doubtful Tornadoes.

Finley's Classification.

Lieut. Finley would make no effort at a definite classification according to violence or extent, but would take every funnel-shaped cloud, whether it reaches the earth or is seen in the clouds, and give it a county, date, time of occurrence, direction of motion, shape of cloud, and width of path.

Objections.

Neither of these methods seems satisfactory for our purpose. The first is quite involved, and, moreover, unites two tornadoes under the same head, though they may be twenty miles apart, provided they occurred on the same date. The motion of a tornado is complex; it oftentimes lifts, and

passes a dozen miles before again striking the earth. Again, we have several occurring in parallel paths on the same date. To unite these together under the head of a "multiple tornado" seems very injudicious. It will serve to great definiteness if we consider each descent of a tornado-cloud, and each occurrence of destruction in parallel bands, as a separate tornado. My meaning should be distinctly understood. I would call the tornado of St. Cloud and Sauk Rapids, Minn., a single occurrence, because the cloud did not lift between these two; also the Louisville and Jeffersonville tornado was a single occurrence, for the same reason. I would call the Fayetteville (Arkansas) and Marshfield (Missouri) tornadoes separate occurrences, though having the same date, April 18, 1880. They were a great many miles apart, and, while undoubtedly in the same tornado region, yet they should be kept distinct.

Scale of Violence.

The establishment of a scale of violence is one of the most important steps to be taken at this stage of our studies and information. The question arises at once as to whether this scale should be according to the violence displayed in twisting trees and destroying houses, or according to the property loss. The former would be a very difficult matter to determine, but should certainly be coupled with the extent of region over which the manifestation occurred. It is also true that we should have with every tornado and destructive storm a definite estimate made, as impartially as possible, of the property loss. We may hope ere long that a beginning of interest will occur and develop in this direction, as has already appeared in the study of fire losses. By what precedes, it is plain that our ultimate arrangement of tornadoes according to a scale would place the more violent in a slightly different position from the more destructive; but this difference is exceedingly slight, and, until we make

finer distinctions than are possible now, we can easily place the most violent and destructive in a class by themselves, or on a scale of 3 in class (3). Going to the other end of the scale, we will put the least violent at (1), and (2) will comprise all between these two. Of course, no hard and fast line can be drawn between these different grades, and some would put a few on the border of (2), in (3), and *vice versa*, but this is a very small matter. It is very important that in our lists the dates be arranged chronologically; but, if we wish to make a distinction between tornadoes at the border-lines, we may do so by using the plus and minus signs: for example, (3 —) would be near to (2 +), and (3 +) would be the highest in the scale. This would be a step toward dividing into nine classes instead of three. Another method of classification would be to determine the number of houses destroyed in each tornado, and then arrange the list on this basis. Such a list would not differ materially from the former. The only difficulty would be in assigning the proper number of houses under each scale. For purposes of comparison and in computing risks, we might also arrange a list of towns destroyed, or partly destroyed, according to an arbitrary scale. It matters little what method we adopt, for it is probable that any scheme would give practically the same final comparison, but it is absolutely essential that we adopt some scale.

Authorities.

The most complete general description of tornadoes is to be found in the *Monthly Weather Review*, published by the Signal Service. In addition, we have descriptions of violent storms in our newspapers, and publications by Lieut. Finley. The most complete list of tornadoes has just been finished by Lieut. Finley in the *American Meteorological Journal*. This contains only the date, time of day, width and direction of path, and gives us no idea whatever of the destruc-

tion, which is by far the most important characteristic, and the only one that concerns us here. It has been found impossible to use this list, and the original authorities have been studied in making out a final description of tornadoes for this discussion. The method adopted for this list was to form as clear an idea as possible of the amount of violence and loss that should be given to each division of the scale, and then to put each tornado and violent storm rigidly in its proper place. If any doubt occurred as to whether the storm came, for example, in (3) or (2), it was indicated by a minus or plus sign, as just described. It was found necessary to begin the list with 1873, and it ends with 1888. The total number of tornadoes during these sixteen years was 2,221; or, by scale, 48 (3), 988 (2), and 1,185 (1). In the accompanying table are grouped these tornadoes in the seventeen States in which they are the most frequent. A careful study of this table will reveal most interesting and unexpected results. That Ohio, New York, and Pennsylvania should stand so high in this list is largely due to the fact that tornadoes have been so thoroughly reported in those States. A severe storm in any one of these States is noticed far more than in States where local storms are more abundant. An attempt has been made to determine the total tornado loss in these States. Outside of the forty-eight most destructive, scale (3), it is impossible to get an accurate estimate of the average loss. In two instances where the newspapers had reported great loss by a funnel-cloud, a careful examination revealed the fact that such a funnel-cloud had reached the earth; but the total damage in one case was $200, and in the other $75. Whatever may be the estimated loss, we have here the figures giving the number of tornadoes, and we can easily determine the true loss if at any time we find the average loss. After a careful study of the reports, it has been decided to place the average loss by tornadoes, scale (2), as $20,000 each, and by (1) as $3,000

each. There is no doubt at all that this estimate is at least ten per cent too great. The figures in the last column of

Résumé of Tornadoes, 1873–88.

	Number.					Loss.			
	(3)	(2)	(1)	Total.	Total by Weight.	(3)	(2)	(1)	Total.
Alabama.....	3	55	20	78	139	$380,000	$1,100,000	$60,000	$1,540,000
Arkansas.....	4	35	24	63	106	430,000	700,000	72,000	1,202,000
Georgia.....		77	53	130	207		1,540,000	159,000	1,699,000
Illinois.	6	102	129	237	351	1,250,000	2,040,000	387,000	3,677,000
Indiana.....	2	56	58	116	176	275,000	1,120,000	174,000	1,569,000
Iowa.....	3	61	75	139	206	740,000	1,220,000	225,000	2,185,000
Kansas	3	103	109	215	321	350,000	2,060,000	327,000	2,737,000
Michigan.....		31	48	79	110		620,000	144,000	764,000
Minnesota.....	3	29	45	77	112	1,000,000	580,000	135,000	1,715,000
Mississippi ...	4	25	18	47	80	620,000	500,000	54,000	1,174,000
Missouri.....	7	76	60	143	233	1,185,000	1,520,000	180,000	2,885 000
New York.. ...	1	49	70	120	171	80,000	980,000	210,000	1,270,000
North Carolina		32	30	62	94		640,000	90,000	730,000
Ohio.....	4	84	87	175	267	1,030,000	1,680,000	261,000	2,971,000
Pennsylvania..		45	66	111	156		900,000	198,000	1,098,000
South Carolina	1	29	20	50	81	200,000	580,000	60,000	840,000
Wisconsin.....	3	53	48	101	163	650,000	1,060,000	144,000	1,854,000
Total	44	942	960	1,916	2,976	8,190,000	18,840,000	2,880,000	29,910,000
All States	48	988	1,185	2,221	3,305	9,650,000	19,760 000	3,555,000	32,965,000

this table give the total loss in each State. Taking the total number of tornadoes from 1873 to 1888, or 2,221, and divid-

ing the total loss, $32,965,000, by it, we obtain $14,842 as the average loss by each tornado.

These figures are very significant, and will bear the closest scrutiny. We may make an interesting comparison with the only other list that is at all complete. This contains 2,435 tornadoes as having occurred in this country, with a total loss of $941,282,500, or a loss by each tornado of $386,-564. Taking the forty-eight tornadoes in the above list, scale (3), we find the total loss, as carefully determined, $9,650,000, or a loss of $201,042 for each; that is to say, if the former estimate has any value at all, this country has been visited by 2,435 tornadoes, each of which was nearly twice as destructive as each one of the forty-eight tornadoes known to be most destructive. It is safe to say, that, were our Western States subject to such appalling disaster as this, they would have been depopulated long ago. We have just seen that from 1873 to 1888 the average loss by the 2,221 tornadoes was $14,842, with a margin of at least ten per cent too great an estimate; or, in other words, the actual loss from tornadoes in this country is one twenty-sixth, or only four per cent, of that estimated in the list above.

It will be distinctly understood that there is no desire in all this to make out that there is no danger from tornadoes, or to minimize their effects. It is of the utmost importance that the true facts be established; that the people understand that entirely unnecessary fears have been aroused; and that the extremest exaggeration has occurred from, it is to be feared, an unfortunate desire to influence their actions in regard to tornadoes. The worst is bad enough without exaggeration. Fears have also been engendered from an extreme agitation of this subject in the line of protecting lives from these outbursts. The protection of life is the most important of all, but there is no necessity of going to the expense of having a so-called tornado cave constructed, and, above all, of spending hours in such a cave, as we have frequent reports of

persons doing because of terror inspired by improper reports. It is probable that no tornado ever visited a place without giving ample warning by the great roar (in some cases reported as thirty minutes, and even more, before the outburst) or by the unmistakable funnel-cloud. A cellar under the house is an ample protection, and none other is really needed. Above all, the people of the West should allay their fears at the appearance of every threatening or lurid cloud in the south-west horizon.

Warnings.

As the Western States become more thickly populated, it is probable that some means will be resorted to, to warn the villages of the approach of a veritable tornado. Outposts placed at a mile or two to the south-west or west would have an excellent opportunity to watch for such outbursts, and give the signal for the inhabitants to watch for the cloud. It would be a great advantage to all concerned if people could realize that the tornado proper is an exceedingly definite and unmistakable phenomenon; that it does not come upon a house like a stroke of lightning, unseen and unheralded. Instances are by no means rare where the funnel has been seen advancing directly over a person, and has been easily avoided by running to the north or north-west. On the south side of the path there are indraughts extending to quite a distance; so that it is generally safer, unless the track of the tornado is seen to be quite to the north of the observer, for one to run to the north-west, but never to the north-east or east, as that is in the line of the tornado. Persons have stood within one hundred and fifty feet of the tornado on the north side, and have felt no unusual disturbance. It is admitted, however, that this requires no unusual courage. Let the people of the West look upon this phenomenon more in the light of its great peculiarity and wonderful nature,—a nature which has absolutely no parallel,

and one the study of which must be for years to come of the highest importance. The wisest philosopher has hardly begun to get an inkling of its formation; and those who are so minded can, by a careful observation and record, help in obtaining and formulating the facts regarding this extraordinary appearance.

Can the Tornado Energy be Dissipated?

The time is coming when this question will become exceedingly important. It is very unsafe to theorize without some facts to start from. It is probable that often serious damage will be warded off from a town which has an extensive forest to the south-west and west. If the energy of a tornado is in an electrical action, as it most undoubtedly is, there is no reason why this may not be diminished by a properly arranged network of wires and poles to the south-west. A tornado is exactly the same as a water-spout at sea; and, if ships have broken up such a spout from the concussion produced by the firing of a cannon, there seems no reason why the energy of a tornado may not be largely diminished by the explosion of gunpowder or dynamite. Of course, the great difficulty would be to make the explosion anywhere near the tornado. Further than this, we cannot go without experiments, and, above all, without a better knowledge of the force producing the energy manifested.

CHAPTER IX.

TORNADO INSURANCE.

NEXT to the loss of life and destruction of property by a tornado comes the practical question, "Can I and shall I insure my property against this loss?" Undoubtedly both the public and insurance companies have been misled on this subject, and yet it will be distinctly understood that in whatever is written here there is no censure implied. I have been in correspondence with these companies, and find that they have been groping in the dark; but they are watching tornado risks very carefully, and are prepared to make a change when such is deemed advisable. It is a remarkable fact, that, out of the thousands who have insured their property against tornadoes during the past six years, only two, so far as published, have received any return, and these for $2,000 each. If we should examine the returns for fire insurance, no such state of affairs as this would be found, and the reason for it is not far to seek. Usually tornado insurance is placed in the towns where a tornado has just occurred, and, like lightning, the path of a tornado never runs twice in the same line. When we consider the extremely narrow path of a tornado, this is not to be wondered at. After the recent tornado in Louisville, Ky., we are

told that tornado insurance had a most extraordinary boom, and it was being placed at a rate even greater than that for fire insurance in some cases. This is most extraordinary, and can only be explained on the supposition that all classes had had their attention called to incorrect views, and were not cognizant of, or had not studied, the true relations of the subject. We have already seen that in the nine-counties tornado the actual losses of $250,000 were exaggerated to $4,000,000; but what shall be said when we learn that after the returns from all tornadoes were in, and we must consider that these returns represented far more than the actual loss, it was decided to multiply them by 25, that is, increase the losses by 2,500 per cent, on the plea that all the losses were not reported? It is not to be wondered at that under such manipulations every one has been very much mystified. As to the Louisville tornado, we shall find that Kentucky is not classed as a tornado State even. It is doubtful if another such tornado ever strikes Kentucky, certainly not in a hundred years.

Risk.

This whole matter of insurance depends on the risk. If a company should be organized to insure a house against being knocked down by a meteor, no one would dream of such a thing as noticing it, except in pity. No company was ever organized to place insurance against lightning distinctively; but the risk is so slight, that all or nearly all companies simply add that risk to the regular fire risk. I think it can be shown that the tornado risk is not so vastly different from that of lightning. Suppose a man's life is insured, and he wants to go into a tornado region: not one word is said by the company. But suppose the man goes South during the summer season: he must take his own risk, for the company will not take it. The difference in these cases is very plain: the chance of death in the first instance is perhaps

one in a million or less, while in the second it may be one in a thousand or more. These illustrations will suffice to make this subject clear to those who have given no thought to it. If we can find the relative risk between lightning and tornadoes or between fire and the same, or if we can find the chance that any given house will be struck, we shall have a basis upon which to reckon the importance of this insurance. It is an eminently practical question to be solved by the law of chances, and not an undetermined factor, or a subject to be accounted for on the plea that it is the working of an inscrutable providence; and we must be resigned to our fate if we do not insure against it. The fire hazard has been very accurately computed, and it is known approximately just how many persons will insure their property, and how high it is necessary to put the premium in order to pay the losses and expenses. Whenever a tremendous conflagration like that of Chicago or Boston breaks forth, these estimates are entirely wrong, and many companies are forced to the wall. It is impossible, however, to allow for such calamities; and it is probable, that, excepting some minor changes, no radical change in fire insurance has occurred on account of those fires.

Tornado Risk.

If we knew, approximately even, just the loss from tornadoes, and could place the insurance where the loss of houses blown down and the expense of insurance would not be greater than the gain in premiums, we would have an ideal state of insurance, and we could tell just the amount each householder should pay. Or if we knew just the average loss per year in the tornado States, and could persuade enough people to take up this kind of insurance, it is plain the business could be carried on profitably. One difficulty now encountered is, that people do not ordinarily see that the risk is any thing like that represented (which is true),

and consequently only a small fraction of this kind of insurance is taken as compared with fire insurance. It would take a great many years to determine tornado risks with sufficient accuracy to estimate the amount of premium needed; but we can make a comparison with the risks and losses by fire, and thus arrive at an approximate solution of the question It should be noted, however, that these risks are of very different characters. The fire risk is ever present and a perpetual menace. Moreover, it is one which is in great danger of propagating itself, or becoming enormously great by communication from house to house. A tornado is more like an accident: it happens at the rarest intervals, and there is no spreading. We might compare these risks as those coming to a man's life in going to a fever district and in going to a tornado district respectively, as was done above It may be objected that we cannot compare fire insurance with that for tornadoes, in that fire losses are much greater in large cities, where the population is denser than in the country. The objection is not a serious one, for the reason that the greatest destruction from tornadoes has been in our large cities; and, again, the protection against fire is much more perfect in the city than in the country; in fact, insurance premiums are less in the city than in the country on a great many kinds of property.

Constancy of Tornadoes.

It is an exceedingly important question to determine, if possible, whether tornadoes are on the increase, or whether we may reason from their occurrence in the past as to their probable action in the future. The tendency is to take serious alarm when a tornado has happened near a community, and to conclude at once that the risk has suddenly become very much greater than before, and is likely to continue. We may cite as an instance the alarm in a good many minds after the occurrence of the recent Louisville

tornado. Notwithstanding the fact that this was the first serious tornado in Kentucky, and that in all probability another such would never occur there, certainly not in Louisville, yet many seem to have thought that a change had come in the climate, and we were now to have more of these outbursts. A careful study has shown that such fears are groundless, and that our climate is practically constant. We may strike an average of tornadoes in the past, and reason that there will be no more than that average in the future. In fact, if we include 1883 and 1884 in our average, we know that it will be too great, for a very large number of tornadoes occurred in those years. It is to be noted that the reports of tornadoes must necessarily increase as houses increase in the tornado States, but this will be balanced by the fact that fire losses will also increase. It is perfectly safe for us to compare fire and tornado losses, and to determine approximately what the comparative premium should be.

The accompanying table (p. 98) shows for the years 1876–84, in the seventeen tornado States, the total loss by tornadoes of scale (3), (2), (1); the loss by fire during the same years; and the relative loss by the two.

The tornado loss in this table has been rigidly computed from the actual estimated loss for scale (3), and allowing $20,000 each for (2), and $3,000 each for (1). There is no doubt that this loss is more than ten per cent too great. It should also be remembered that during the two years 1883 and 1884 there were as many tornadoes as in the remaining seven, and in the sixteen years thus far studied this is very nearly the relation. There are several most astonishing facts brought out in this table, and such as are very difficult to understand. Perhaps the most surprising result is that in Kansas the tornado loss is one-third of that by fire. I have gone over the data, and can find no flaw. All the tornado reports from the different States were treated exactly alike, and the result for any one State may be compared di-

rectly with that for any other. In Nebraska, a neighboring State, the tornado loss is insignificant, not more than one-twentieth of that by fire; and in Missouri it is one-twelfth

Tornado and Fire Losses in Seventeen States, 1876–84.

	Number.			Loss.		
	(3)	(2)	(1)	Tornado.	Fire.	Tornado / Fire.
Alabama	1	30	8	$704,000	$6,169,000	1-9
Arkansas	3	21	18	754,000	6,419,000	1-9
Georgia		54	32	1,176,000	14,083,000	1-12
Illinois	4	77	87	2,601,000	38,060,000	1-15
Indiana	1	42	30	1,005,000	22,981,000	1-23
Iowa	3	42	50	1,730,000	14,821,000	1-9
Kansas	2	77	68	1,944,000	6,108,000	1-3
Michigan		24	18	534,000	30,583,000	1-57
Minnesota	2	20	23	1,069,000	18,752,000	1-18
Mississippi	4	21	15	1,085,000	5,479,000	1-5
Missouri	7	61	45	3,250,000	27,129,000	1-12
New York	1	34	33	859,000	124,767,000	1-145
North Carolina		18	11	393,000	6,486,000	1-17
Ohio	2	42	35	1,225,000	41,496,000	1 34
Pennsylvania		22	22	506,000	69,869,000	1-138
South Carolina	1	24	12	716,000	7,747,000	1-11
Wisconsin	3	39	33	1,529,000	21,375,000	1-14
Total	34	648	540	20,080,000	462,324,000	1-23
Total, omitting Pennsylvania & New York	33	592	485	18,715,000	267,688,000	1-14

of the fire loss. Of course, where no estimate of the loss is given, as is the case in more than half the occurrences, the

position in the scale is dependent on the reported violence of the tornado. I am inclined to think that Kansas has had its severe storms multiplied by reporters to too great an extent. It seems necessary to give these figures exactly as they came out; and I shall be very much gratified if the citizens or professional men of any State, feeling that their State has not been given a fair show, should make for themselves a careful canvass of the State for tornado losses. I shall be pleased to send to any such State a list of the dates of all the tornadoes reported from that State, for the authorities or those interested to verify the losses sustained. I have attempted, by correspondence and in other ways, to get more complete returns, but there seems to be great apathy on this question. Possibly many have been very much discouraged at the palpable exaggerations that have been published. It seems to me that this matter is of the greatest importance, and now is the time to establish an accurate estimate of tornado losses which will be of permanent value for comparison with future years. Certainly more harm will come from vague reports of doubtful tornadoes and exaggerated statements of losses than can ever come from an exact knowledge of the truth. There is no doubt that there is a tornado evil. Let us learn its exact proportions, and then people will know just what to prepare for.

I do not think that in this table the States of New York and Pennsylvania can be regarded as full-fledged tornado States. Moreover, the comparative loss between fire and tornadoes is not the same as in the other States, owing to the relatively greater loss by fire in the cities in these two States. I have therefore taken out these two States in the final summing-up of the table. Kansas has been left in, however. We find that in the fifteen remaining States the relative loss was one-fourteenth; that is to say, the loss by tornadoes is seven per cent of that by fire. I think we may safely say that any fire insurance company would be entirely

secure if they increased their premium by eight per cent or ten per cent, and assured the householder against loss from tornadoes as well as fire, provided such insurance could be placed through all the fifteen States, and for a term of four or five years. As will be shown later, there seems to be good evidence for believing that once in eleven years the risk from tornadoes is somewhat increased for two or three years. When we see that insurance companies, computing from imperfect tornado losses multiplied by 25, have charged the same for both fire and tornado insurance, it is not to be wondered at that so few have taken the latter. Every one has the evidence of his senses that tornado losses in his community in fifteen to twenty years, excepting a few of the more disastrous tornadoes, have not equalled the average fire loss in a single year. It is said that such matters generally adjust themselves through a competition and rivalry between different companies, but it is very unfortunate for a few who have to suffer while this adjustment is taking place. Will it not be far more satisfactory to insured and insurers if this subject be thoroughly ventilated, and a good idea of the comparative risk between fire and tornadoes be arrived at? It should not be forgotten that it is only by uniform action and support of both fire and tornado insurance by the people in the fifteen States, that any thing like an average result can be obtained; or, at least, this must be the case in any one State, for there are a few lines of action in the State which seem to be more favorable for the development of tornadoes than the whole area of the State.

CHAPTER X.

THE MOST DESTRUCTIVE TORNADOES SINCE 1872.

A GOOD many rather imperfect lists have been published from time to time, which have not had sufficient care manifested in their collation. There are several peculiar difficulties which one meets in this work. For example: each of three different men at three towns makes a report of a tornado, presumably in the town. One makes the property loss $25,000, and the number of killed, 8; while the second makes these $100,000 and 9, and the third $200,000 and 12, respectively. Fortunately a request was made for the names of the persons killed, and it was found that 8 of them were the same in all three reports, showing that the same tornado had been described. It would have been a very easy matter to have considered the loss of life 29, and of property $325,000, if these had been regarded as different. In another case there were found four tornado lists, two of them containing over 2,000 in each list. One of these was given as occurring near Erie, Penn., on July 26, 1875, in the afternoon. The condition before the storm was "very sultry," and after it, "chilly;" the destructive winds had a motion first from "south-west," then "north-west, west, and north;" while the rain was given as falling "after" the tornado. One hundred

and thirty-four lives were lost, and property valued at $500,000 was destroyed. This whole account was so circumstantial and straightforward, that it was very remarkable to find no mention of such a destructive storm in the *Weather Review*. After a search of a good many days, it was at last found that this loss of life and property occurred from a flood near Pittsburgh, Penn., on July 26, 1874.

The *Weather Review* has been appealed to in determining what storms should go into the list below, as it does not appear probable that any notable tornado would be overlooked in that. The criterion for destructiveness has been not entirely the loss to structures, but the violence of the storm, the loss of life, etc., have entered into the estimate. It is not expected that this list will prove entirely satisfactory: in fact, it has already been changed slightly since its first preparation in June, 1889. The utmost pains have been taken to make it reliable, and, if there has been any error, it has been in the line of allowing too much loss rather than too little in any individual case.

(1) Nov. 22, 1874. Tuscumbia, Colbert County, Ala. (scale 3).—Struck the town at 6 P.M.; nearly half the town of 1,400 inhabitants destroyed; 10 persons killed, and 30 wounded; 100 buildings damaged or destroyed; loss, $100,000 (estimated).

(2) May 6, 1876. Chicago, Cook County, Ill. (scale 3).—Moved from south-west to north east, accompanied by rain, thunder, and lightning; bounding like a ball, it apparently reached the ground but two or three times; loss, $250,000.

(3) June 4, 1877. Mount Carmel, Wabash County, Ill. (scale 3+).—200 to 400 feet wide; great destruction of property; 16 killed, 100 wounded; loss, $400,000.

(4) July 7, 1877. Pensaukee, Oconto County, Wis. (scale

3).—Moved from north-west to south-east, lasting about 2 minutes; 8 killed, many wounded; loss, $300,000.

(5) June 1, 1878. Richmond, Ray County, Mo. (scale 3).—Entered the town at 4.5 P.M. from the south, sweeping every thing clean; heavy sills 18 inches square and 16 feet long were swept away; path through the city 750 feet wide and 1 mile long, in which space not a single house was left; 13 killed, 70 wounded; 100 buildings damaged or destroyed; loss, $100,000 (estimated).

(6) Aug. 9, 1878. Wallingford, New Haven County, Conn. (scale 3+).—At 5.45 P.M. a dark cloud approached from the west; "electricity of the most terrific kind filled the air;" "straight rods of fire came down from the sides of the cloud to the earth; the *débris* of houses was scattered along in parallel lines, as though a mighty river had passed; the greatest destruction occurred in a path 400 feet wide and half a mile long; 34 killed, 70 wounded; 40 dwellings, 50 barns, 1 church, and 1 schoolhouse were destroyed or badly damaged; loss, $200,000.

(7) April 14, 1879. Collinsville, Madison County, Ill. (scale 3—).—Struck town at 2.45 P.M.; nearly every gravestone in cemetery was levelled; 1 killed, several wounded; 60 buildings destroyed; loss, $50,000.

(8) April 16, 1879. Walterboro, Colleton County, S.C. (scale 3).—Rainfall after tornado, which struck at 3.45 P.M., was unprecedented; wind on north side had a downward crushing tendency, on the south side an upward lifting action; 4 people saw balls of lightning running along the ground; 16 killed; 50 buildings destroyed; loss, $200,000.

(9) March 4, 1880. Indianapolis, Marion County, Ind. (scale 3—).—Moved from south-west to north-east with a zigzag course through the city; loss, $100,000.

(10) April 18, 1880. Fayetteville, Washington County, Ark. (scale 3).—Struck town at 8.30 P.M.; not a building escaped in its path, 90 feet wide, through the town; 2 killed, 20 to 30 injured; 100 buildings destroyed; loss, $100,000.

(11) April 18, 1880. Marshfield, Webster County, Mo. (scale 3).—Struck at 5 P.M.; near town, trees 3 feet in diameter, for a space several hundred yards wide, were lifted entirely out of the ground; every house in the town of 2,000 people was destroyed or badly damaged; 65 killed, 200 wounded; loss, $110,000.

(12) April 18, 1880. Licking, Texas County, Mo. (scale 3—). —Struck at 8.15 P.M.; entire town, of 388 people, destroyed except 3 houses; 300 left homeless; 1 killed, 17 wounded; 65 houses destroyed; loss, $50,000.

(13) April 18, 1880. Beloit, Rock County, Wis. (scale 3—). —Struck at 5 P.M.; moved from south-west to north-east; several killed, many injured; many houses destroyed; loss, $75,000.

(14) April 24, 1880. Taylorville, Christian County, Ill. (scale 3—).—Struck at 7 P.M.; 6 killed; 25 houses destroyed; loss, $60,000.

(15) April 25, 1880. Macon, Noxubee County, Miss. (scale 3).—Struck at 8.30 P.M.; 22 killed, 72 injured; 55 buildings destroyed; loss, $100,000.

(16) May 10, 1880. Arrowsmith, McLean County, Ill. (scale 3—).—Loss, $100,000.

(17) May 28, 1880. Savoy, Fannin County, Tex. (scale 3—).—Time, 10 P.M.; town almost destroyed; 15 killed, 60 wounded; 48 buildings razed; loss, $50,000.

(18) June 14, 1880. Glendale, Hamilton County, O. (scale 3—).—Time, 8 P.M.; loss, $80,000.

(19) April 12, 1881. Hernando, De Soto County, Miss. (scale 3—).—In some spots hail-stones as large as hen's eggs fell; electricity and thunder not observed; 10 killed; 25 buildings demolished; loss, $50,000 (estimated).

(20) June 12, 1881. Jackson, Andrew County, Mo. (scale 3).—A great deal of destruction occurred at King City, De Kalb County; in county and vicinity, 5 killed; 80 buildings razed; loss, $250,000.

(21) July 15, 1881. New Ulm, Brown County, Minn. (scale 3+).—11 killed, 53 wounded; nearly 300 buildings destroyed or seriously damaged; loss in town, $400,000.

(22) Sept. 24, 1881. Quincy, Adams County, Ill. (scale 3).—Time, 5 P.M.; storm accompanied by terrific lightning and thunder; 9 killed; 21 buildings razed; loss, $100,000.

(23) April 18, 1882. Brownsville, Sabine County, Mo. (scale 3).—Time, 4 20 P.M.; 8 killed; 10 brick houses, 40 others, and 1 school razed; loss, $150,000.

(24) May 8, 1882. McKinney, Cleveland County, Ark. (scale 3—).—50 buildings destroyed; loss, $30,000.

(25) May 8, 1882. Mount Ida, Montgomery County, Ark. (scale 3—).—Time, 5.30 P.M.; 2 killed; 100 buildings demolished; loss, $50,000.

(26) June 17, 1882. Grinnell, Poweshiek County, Io. (scale 3+).—Time, 8.45 P.M.; 60 killed, 150 injured; 140 houses reduced to ruins in 5 minutes; loss, $600,000.

(27) April 22, 1883. Beauregard, Copiah County, Miss. (scale 3+).—Time, 3 P.M.; every house and store destroyed in the town of 600 people; solid iron screw of

a cotton-press weighing 675 pounds was carried 900 feet; 29 killed, 40 wounded; loss, $450,000.

(28) April 22, 1883. Wesson, Copiah County, Miss. (scale 3 —).—13 killed, 60 injured; 27 houses destroyed; loss, $20,000.

(29) May 13, 1883. Kansas City, Jackson County, Mo. (scale 3).—Time, 8.30 P.M.; 200 houses destroyed; loss in town and vicinity, $300,000.

(30) May 13, 1883. Macon City, Macon County, Mo. (scale 3 —).—Time, 8.30 P.M.; 5 killed; 107 buildings razed; loss, $150,000. This destruction and loss may include the whole county.

(31) May 18, 1883. Oronogo, Jasper County, Mo. (scale 3 —).—6 killed, 33 injured; nearly all houses destroyed; loss, $75,000.

(32) May 18, 1883. Racine, Racine County, Wis. (scale 3 —).—Time, 7 P.M.; 16 killed, 100 injured; loss, $75,000.

(33) June 2, 1883. Greenville, Hunt County, Tex. (scale 3 —).—Time, 7.15 P.M.; 1 killed, several wounded; 40 houses razed; loss, $70,000.

(34) June 11, 1883. Brush Creek, Fayette County, Io. (scale 3 —).—Town one-third destroyed; loss, $40,000.

(35) Aug. 21, 1883. Rochester, Olmstead County, Minn. (scale 3).—Time, 6.36 P.M.; large part of town destroyed; 26 killed; 135 houses destroyed; loss in county, $200,000.

(36) Feb. 19, 1884. Leeds, Jefferson County, Ala. (scale 3 —).—Time, 1.20 P.M; hail of unusual size; 11 killed, 31 wounded; 27 houses and many barns destroyed; loss, $80,000 (estimated).

(37) April 27, 1884. Jamestown, Greene County, O. (scale 3).—Time, 5 P.M.; 6 killed; two-thirds of buildings destroyed; loss, $200,000.

(38) July 21, 1884. Dell Rapids, Minnehaha County, Dak. (scale 3).—Time, 3.5 P.M.; 7 killed; many buildings destroyed; loss, $100,000.

(39) Sept. 9, 1884. Clear Lake, Polk County, Wis. (scale 3). —Time, 5 P.M.; greater part of town in ruins; 3 killed; 40 buildings destroyed; loss, $150,000.

(40) Aug. 3, 1885. Camden, Camden County, N.J. (scale 3+).—Time, 3.20 P.M.; path from one to two squares wide; 6 killed, 100 injured; 500 houses razed or unroofed; loss, $500,000.

(41) Sept. 8, 1885. Washington Court House, Fayette County, O. (scale 3+).—Time, 7.30 P.M.; width of path, 250 feet; town almost destroyed; 6 killed, 100 injured; 40 business-houses and 200 residences razed; loss, $500,000.

(42) April 14, 1886. Coon Rapids, Carroll County, Io. (scale 3 —).—Time, 5.5 P.M.; 1 killed; 32 buildings razed; loss, $55,000.

(43) April 14, 1886. St. Cloud, Stearns County, and Sauk Rapids, Benton County, Minn. (scale 3+).—74 killed, 136 wounded; 138 buildings destroyed; loss, $400,000.

(44) May 12, 1886. Attica, Fountain County, Ind. (scale 3).—Time, 10 P.M.; in vicinity, 9 killed; 200 houses razed; loss, $200,000.

(45) April 15, 1887. St. Clairsville and Martin's Ferry, Belmont County, O. (scale 3). Time, 3.20 P.M.; none killed; about 200 buildings of all kinds demolished; loss, $250,000.

(46) April 21, 1887. Prescott, Linn County, Kan. (scale 3).

—Time, 5.30 P.M.; 20 killed, 237 wounded; 330 buildings razed in vicinity; loss, $150,000.

(47) April 22, 1887. Mount Carmel (near), Wabash County, Ill. (scale 3 —).—Time, 6 P.M.; 2 killed, several wounded; every thing in path destroyed; loss, $50,000.

(48) April 22, 1887. Clarksville (near), Johnson County, Ark. (scale 3).—Time, 6.30 A.M.; 20 killed, 75 to 100 injured in vicinity; loss, $150,000.

(49) June 16, 1887. Grand Forks, Grand Forks County, Dak. (scale 3).—Time, 3.22 P.M.; 4 killed; 50 or more houses, besides hundreds of barns, etc., razed; loss, $150,000.

(50) Feb. 19, 1888. Mount Vernon, Jefferson County, Ill. (scale 3+).—18 killed, 54 wounded; 100 buildings razed; loss, $400,000.

(51) May 27, 1888. Hillsboro, Hill County, Tex. (scale 3 —).—Many buildings razed; loss, $100,000.

(52) Aug. 21, 1888. Wilmington, New Castle County, Del. (scale 3).—1 killed, 20 wounded; loss $100,000 to $200,000.

(53) Jan. 9, 1889. Brooklyn, Kings County, N.Y. (scale 3).—Time, 7.40 P.M. (Eastern); width, 500-600 feet; length, 2 miles; whirl from right to left; roar heard 10 or 15 minutes before; loss, $300,000.

(54) Jan. 9, 1889. Reading, Berks County, Penn. (scale 3). —Time, 5.40 P.M.; swept from west to east in a path 60 to 100 feet wide; wind often seemed to crush from above; 40 killed; loss, $200,000 (estimated).

(55) Jan. 12, 1890. St. Louis, St. Louis County, Mo. (scale 3).—Time, 4 P.M.; moved to north-east in a path 500 to 2,000 feet wide; heavy rain for 3 minutes; greatest damage where path was narrowest; 3 killed; 100 houses razed; loss, $250,000.

(56) March 27, 1890, Metropolis, Massac County, Ill. (scale 3 —).—1 killed, 50 injured; loss, $150,000.

(57) March 27, 1890. Louisville, Jefferson County, Ky. (scale 3+).—Time, 7.57 P.M.; path at beginning 600 feet, as it left the city 1,500 feet; cloud did not quite reach the earth; great damage to property; 76 killed, 200 injured; loss, $2,250,000.

This list comprises all the most destructive storms that have been reported, as far as a definite locality was mentioned. It has been found exceedingly difficult to determine the loss in many cases, because an estimate has evidently been made of the loss to crops, orchards, etc., from the rain, hail, and floods that accompanied the tornado, and not from the wind itself. Again, the loss reported evidently referred to a large region in the county, and not to any specific town. Some of these may be enumerated as follows:—

DATE.	COUNTY.	STATE.	LOSS.
June 12, 1881	DeKalb and others.	Missouri.	$200,000
Nov. 5, 1883	Greene and others.	Missouri.	150,000
Nov. 21, 1883	Izard.	Arkansas.	300,000
April 14, 1886	Cass.	Iowa.	160,000
May 11, 1886	Pettis and others.	Missouri.	500,000
May 12, 1886	Greene and others.	Ohio.	1,000,000
May 14, 1886	Hardin and others.	Ohio.	720,000
May 14, 1886	Huron.	Ohio.	500,000
May 14, 1886	Seneca.	Ohio.	300,000
May 14, 1886	Mercer.	Ohio.	250,000

It is highly probable that in some of these cases the losses from one county have been estimated in another, though this has been avoided as much as possible. It is very much

to be hoped that more definite estimates will be made in the future. The loss to structures by the wind should be carefully distinguished from the loss of every other kind, by hail or flood, and to crops, stock, or orchards. I shall be very grateful to any who will send me corrections to this list, or add other tornadoes.

CHAPTER XI.

SUN-SPOTS.

ATTEMPTS are continually being made to connect terrestrial weather and storms with the motions and positions of the moon, the planets, and the sun. It has been fairly well shown that at the time of full moon there is a tendency, in some parts of the world, toward a diminution of clouds. One computation has shown a slightly greater rainfall during new moon on the Atlantic coast, but precisely the contrary on the Pacific coast. There has also been a very slight evidence of the increase of thunder-storms at the new moon. The influence of the planets must be absolutely inappreciable. When we consider the sun, however, we see at once the intimate connection between its radiant energy and all activities upon the earth. The growth and well-being of every living thing are absolutely dependent upon the sun's light and heat. It is believed by many that the sun's heat is the only agent to be considered in seeking for an explanation of our storms and all our weather changes. It is undoubtedly true that some form of solar energy is concerned in our storms, but it would be quite hazardous to say that electric influences from the sun are not far more potent for producing storms than even its heat. As the sun's heat is the most prominent energy

recognized by our senses, every attempt has been put forth to determine whether this is constant as regards our climate, or whether there are fluctuations at long intervals. It is plain that these changes, if they exist, cannot be appreciable to our thermometers for centuries. The difficulty of measuring the intensity of solar rays by direct observation has been practically insuperable; and we may say that the total amount of heat which we receive is so great, as compared with its fluctuation from the greatest to the least, that we cannot hope for any definite solution of that question for years to come.

Coincidences.

In seeking any relation between the sun's light, heat, rotation, or appearances, and terrestrial phenomena, it is unsafe to trust to mere coincidences; but some connection of cause and effect should be established. For example: on Aug. 3, 1872, while Professor C. A. Young was examining the solar prominences with a telescope, he saw a most violent outburst upon the sun, and noted the exact instant when it occurred. Afterwards he found that his assistant at that very moment had observed a violent agitation of his magnetic needle; and an examination of the records at Kew, England, revealed exactly the same disturbance of the needle there. This may safely be regarded as more than a mere coincidence, and proves, in connection with other observations of a like nature, the intimate relation between solar disturbance and terrestrial magnetism.

It is well known that the sun is periodically spotted; that is, once in about eleven years spots gradually appear, and increase near the sun's equator. A remarkable fact about these spots is that their motion very near the sun's equator appears to be faster than in higher latitudes. They revolve or come in sight in a little over twenty-five days in the former position, and in about twenty-seven days in the latter.

This single fact should lead a great many of those who believe that our tornadoes are produced just as the spots appear by rotation, or about twenty-six days apart, to doubt the sufficiency of the explanation, because any such periodicity would be entirely broken up from the variable rotation period of the spots. The cause of these spots has not been well established, but it is probable that they are the result of increased electric activity on the sun. The attempt to connect this eleven-year period with our weather has proved intensely fascinating, and volumes of researches have been published. Such comparisons have proved, in the main, very illusory. While an apparent connection would be found in a few periods, yet, as the number of observations increased, the supposed connection was disproved. A single illustration will suffice. The attempt has been made repeatedly to connect the sun-spot period with fluctuations in temperature. In the nature of the case, it is impossible, perhaps, to prove whether the spots show the sun to be hotter or cooler during their existence. The fluctuations of temperature on the earth certainly do not show a preponderance either way, when compared with the appearance of sun-spots. This does not necessarily prove, however, that the spots do not influence our temperature, or that they do not show increased heat in the sun; for this increased heat would tend to produce clouds from a greater evaporation, and these in turn would prevent the sun's rays reaching the earth, and this would result in a cooling rather than a heating, which would mask the spot influence (see *Monthly Weather Review*, January, 1888).

Auroras.

Research has shown conclusively that our auroras and magnetic storms have an eleven-year period, and this is coincident with spot fluctuations; that is, as activity in spots increases, our auroras increase, and *vice versa*. It has also

been definitely settled that the aurora is an electric phenomenon, and is intimately connected with magnetic storms on the earth. Here we have practically a number of coincidences which may be said to prove a definite connection between these phenomena without a positive knowledge that they are both produced by a common force, or that the spots produce the effect upon the earth. The coincidences here, however, are very marked, and there are practically no discordances. These points should be most carefully borne in mind in all our studies in this line.

Sun-Spots and Storms.

Meldrum of Mauritius was one of the first to study the relation between cyclones and sun-spots, and found that during the three maximum periods of the spots between 1848 and 1871 there were nearly twice as many cyclones as during the minimum periods. The evidence in 1871, however, was far less than in 1848, and the more recent spot maximum of 1884 showed no increase in cyclones; so that this proof, which has been *the* one that has been relied upon above all others, has gradually dwindled down to practically nothing. It should be noted, however, that we have no absolute proof one way or the other; for during the spot maxima of 1871 and 1884 there may have been other forces acting which tended to diminish the activity of cyclones, or to divert them from the track of ships whose records Meldrum examined. Poey examined the West India cyclones, going back to 1750, and he thought that there were more cyclones during spot maxima. This record is so long that I have deemed it worth while to give it a careful study. The spot curve is remarkably well defined, with very few irregularities. The maximum and minimum points are very easy to find, and one can have no doubt as to the exact year of each period. The cyclone curve, on the other hand, is exceedingly irregular, and fluctuates back and forth across the spot curve. Com-

paring the cyclone and spot curves, I find that in the twenty-four maximum and minimum periods there are eight coincidences, ten positive discordances, and six doubtful cases (that is, cases which showed a flat curve for cyclones at the time of either maximum or minimum spots). This is a very poor showing, and certainly proves no intimate relation. No one can compare these curves and consider that the relation is proved by them.

If it could be shown that our cyclones were due to special heat or electric action, and that sun-spots tended in the same direction, there might be some hope in establishing a relation between them. Under the circumstances, however, it is necessary either to obtain accordance or else to explain away the discordances. Coincidences for a few periods are very probable, and prove nothing. The weakness of this cyclone research lies in the fact that only very limited portions of the earth have been considered. The only proper way would be to determine the extent of storm activity over the whole globe each day of the year, and then to compare this with sun-spot action. The reasons that many sun-spotists have met with so much encouragement in their researches have been two: 1. A "coaxing," as Professor Young puts it, of the critical point of a sun-spot period (that is, if the cyclone maximum came two or three years earlier or later than the spot maximum, it has been regarded as a coincidence); 2. A consideration of all manner of terrestrial disturbances as fulfilling the prediction or establishing the coincidence. All manner of tornadoes, storms, blizzards, hot waves, cold waves, floods, frosts, earthquakes, etc., have been drawn into their nets. It would seem that this practice should be regarded as very unreliable. If a spot produces a cold wave one week or at one time, it can never produce a hot wave at any other time. The determination of such a relation, if there be one, is one of the simplest mathematical processes that can be imagined, after the data

are at hand, and yet the sun-spotists are very anxious to make their own computations. One of them writes, "I am very much afraid you will coax the data to disprove my view." It is very plain that no accurate research of this kind can ever be made by any one that cannot be repeated by any other person, and the fear of sun-spotists to have the verification of their theories taken out of their hands is well grounded.

Tornadoes and Sun-Spots.

If we take such a very great territory as that of the United States, and have stations at every sixty or a hundred miles, then count the number of stations each day at which the wind velocity reached twenty miles or more per hour, we would have a partial view of the average storm activity each day of the year. Again: if we could get a record of every violent storm in this region, and give it a proper weight, we would have a fair idea of storm activity, and could compare it directly with the known and easily measured spot activity. This has been done with the 2,221 tornadoes that have visited this country. The table below shows the relative intensity of tornadoes by weight, and the relative sun-spot intensity:—

Year.	Tornadoes.	Sun-Spots.	Year.	Tornadoes.	Sun-Spots.
1873.....	8	701	1881.....	169	730
1874.....	15	601	1882.....	286	1002
1875.....	69	272	1883.....	589	1155
1876.....	68	122	1884.....	461	1079
1877	111	92	1885.....	374	811
1878.....	108	24	1886.....	243	527
1879.....	92	49	1887.....	183	[300]
1880.....	269	416	1888.....	259	[100]

In this table, numbers in the sun-spot column are taken from the Greenwich photographs, and show the relative area

covered by spots in millionths of the sun's surface. The earlier tornado records are in some doubt, as they are quite meagre. The enormous increase in both tornadoes and sun-spots during 1883 and 1884 is very striking, and seems to be a fact, though it will require several more eleven-year periods to establish the coincidence. There was an increased activity in collecting tornado data in 1882, but this continued through till 1887; so that the great increase in the two years above cannot be ascribed to this cause. Moreover, the list of 2,221 tornadoes was made up chiefly from the same source throughout all the years. There is a quite strong proof that the sun-spots are due to the action of electricity. Now, it has been shown that our tornadoes have an abundance of electric action, so that there is no inherent improbability in the supposition of a relation between these phenomena, aside from a mere coincidence in their phases.

Specific Influence of Spots.

If such a relation exists, some have thought that there ought to be a synchronism between the appearance of spots and resulting storms. The view has been strenuously supported, that within two or three days after the appearance of a spot on the eastern limb of the sun, or by the rotation of the sun, storms break forth or greatly increase in violence on the earth, and that it would be possible to use this fact in making predictions of violent storms. It will be easily seen that this view, if true, is of the extremest importance. No attempt is made to explain why it is that after two or three days this spot influence dies down, while the spots are still in full view of the earth for ten days. Since electric energy is transmitted at once from the sun, why should it not begin its action at once upon the earth? We must remember that *this action is not a direct one, but electricity must act first* upon the clouds or atmosphere, and possibly these upon the earth in turn, before the storm is produced or influenced; so

that there need not be a direct connection between the two. The reason that this hypothesis has gained in favor has been already explained, and lies in ignoring discordances and emphasizing coincidences. Our curve of tornado activity furnishes a most extraordinary means of determining this specific effect of spots, if there be such.

The Greenwich, India, and Mauritius photographs of spots show exactly the appearance of each spot by solar rotation, and its area, or, as we may say, its relative intensity. We can easily determine, then, the activity of spots on the eastern limb of the sun during any day. It will be seen that this process is very dissimilar to the one adopted in obtaining the annual intensity; for that used the spotted area over the whole sun each day, while this method uses the area of a spot for three days only, and immediately after its first appearance by rotation. The years 1874 to 1886 were used, and the tornado months March to September. Curves were constructed showing both the spot and tornado activity for each day of the above period. An examination of the curves showed, (1) 46 tornadoes coincident with spots, (2) 156 spots without tornadoes, and (3) 393 tornadoes without spots: 46:593, or 8 per cent, which is insignificant. Next there were compared three successive days of spots, and the same days of tornadoes, during the extremely abundant tornado years 1882 to 1885 and the months April to August. It will be seen that in this comparison every thing was in favor of the tornado and spot-rotation hypothesis. There were 43 coincidences, 30 spot groups without tornadoes, and 79 tornado groups without spots: 43:109, or 28 per cent. It is plain that this hypothesis breaks down completely under this investigation.

General Influence of Spots.

On observing the sun-spots carefully, we find that there are marked periods during which the spot activity increases

and diminishes. In order to compare such periods with tornado activity, curves of both were drawn; and it was found that while a rise in the tornado curve occurred during the greatest activity of spots, yet the converse of this proposition was not true, for there might be a rise in the spot curve without a response from the tornado curve. This may have been due, as has already been suggested, by the masking of the spot effect at the earth's surface. The evidence, while showing a tendency to increased tornado action during an abundance of spots in at least one eleven-year period, does not show any marked specific action or relation between any definite spot phenomenon and a corresponding response by storms on the earth. The subject is exceedingly complex, and merits further study, especially in the line of a removal of any outside influences which would tend to mask the influence of spots at the earth.

CHAPTER XII.

PREDICTIONS.

It has been said that one of the best tests of the advancement of a science is its power to make predictions. Unfortunately, weather science has easily lent itself to all classes of wise or simple persons, and has suffered by their ignorant attempts at foisting upon it crude and imperfect forecasts of the future weather. An interest attends some of these efforts, however, from their curious and incongruous medley. Witness, for example, the famous lines of Dr. Jenner, beginning

> "The ass begins to bray,
> We shall have rain to-day,"

now so universally quoted. Many of these signs have a real significance: for example, the very old saying, "When it is evening, ye say, 'It will be fair weather, for the heaven is red;' and in the morning, 'It will be foul weather to-day, for the heaven is red and lowering.'" It has been suggested already that much may be learned from cloud appearances to assist in determining the probability of a tornado. A peculiar livid and greenish color is often seen, or ragged and angry-looking clouds in the west announce the greater

disturbance. The appearance of lightning and heavy thunder usually precedes the tornado, though of course both these may be followed by an ordinary thunder-storm. The loud indescribable roar is unmistakable as a precursor of the funnel-cloud.

The question is often asked, however, "Can there be a prediction of a tornado a day, week, year, or even a century, in advance?" This problem has been most exhaustively studied by so-called weather prophets, and the public have been not a little mystified by the varying claims put forth by each prophet, and especially by the extraordinary success in such predictions that these men insist they have had. The scope of this paper will not permit more than an outline of these theories; but we may lay down certain rules that should guide us in estimating the value of such predictions, and in putting our faith in them. The moon, the planets, and the sun have been the most potent factors in these theories of storm-formation.

The Moon's Influence.

The comparative nearness of this body, and the fact that its phases occur in about seven days, which is approximately the interval for the occurrence of storms, have made it one of the most popular influences for weather changes. Soon after the death of the elder Herschel there appeared a singular set of weather tables ascribed to him, and purporting to give weather predictions according to the age of the moon. These tables have been scattered broadcast over this country. It is needless to remark that Herschel had nothing to do with them, as has been shown by his son. The moon is an inert mass, and can have no influence on our weather, except, as we have just seen, it has a very slight tendency to drive away clouds. Observations have shown that the tide produced by the moon in our atmosphere is only four-thousandths of an inch of mercury.

Planetary Hypotheses.

If the moon, only 250,000 miles away, has no marked influence on our weather, what must we think of the effect of the planets, millions of miles away? It is no wonder that at least one of these prophets, after giving the whole subject careful study, was forced to abandon the planetary hypothesis for the lunar theory. There is nothing which shows the utter absurdity of these planetary theories more forcibly than the introduction of the hypothetical planet Vulcan. This is needed in order to have a body revolving around the sun frequently enough to make his position relative to the earth coincident with our numerous storms. One of these prophets, an American, thought he saw Vulcan passing across the sun, and published a careful computation indicating, that, according to Le Verrier's orbit, the planet should have been exactly at that point; but, unfortunately for this hypothesis, it was shown by Professor Proctor, that, owing to a slight inaccuracy, this computation was wrong, and that this prophet, if he saw Vulcan at all, must have seen it directly *through the sun*, on the opposite side from the earth. Granting that there is a planet only 8,000,000 miles from the sun, and about 85,000,000 from us, is it not perfectly plain that its influence on terrestrial weather would be most completely overshadowed by the all-powerful sun behind it?

It is not a little remarkable that these prophets are entirely disagreed as to how this planetary effect is produced. One would have our storms and tornadoes coincident with the equinoxes of the planets, another with their oppositions and conjunctions; and so on. It is easy to see, that, under these circumstances, no two of these prophets agree on the dates of storms, but they are distributed quite uniformly for about half the days in the year. How does it happen, that, though these dates disagree, all these prophets are perfectly satisfied as to the exact fulfilment of their predictions? This is very

simple to explain; for the man who predicts a storm on the 1st of the month, for example, verifies by a storm, say, in Illinois, while the one who has put his storm on the 3d of the month verifies by the same storm, which has now moved to Maine. There is just one crucial test by which we may satisfy ourselves of the worthlessness of these theories. It has been outlined in the last chapter. Let these prophets make a careful study of all the influences they can muster, and put down, no matter whether for the past or the future, the dates when they would expect the worst storms, and also the dates of fewest disturbances, then take the whole extent of this country, and establish the dates of most and least atmospheric disturbance. A comparison of these dates would quickly prove the value of such predictions. It is needless to add, that frequent and continued attempts to obtain these dates from at least four of these prophets, and to get any one of them to agree to this comparison, have lamentably failed.

There are not a few people who put great faith in such predictions, though a moment's thought would show how preposterous the claim is. For example: the Louisville tornado, on March 27 of the present year, was heralded as a perfect verification of a prediction for storms from March 28 to 30, and pains were taken to spread this fact from Maine to California. Suppose some one in the tornado district had read this prediction on March 27, and put faith in it: would he not have been misled? Again: if some one in Maine had read the prediction, would a storm in Kentucky apply to his locality? It is so easy to make a storm prediction, and so easy to verify it if one is allowed his own way, that there is no immediate prospect of silencing these prophets; but it is to be hoped that our citizens will study this matter for themselves, and before long obtain right views. It is plain that such a prediction made years beforehand can have no influence on right-thinking persons, for we know that it is im-

possible to predict the weather with certainty for even twenty-four hours.

Since 1872 it has been known that tornadoes and severe storms occur in the south-east quadrant of a depression system as it traverses the country, and in the history of the Signal Service frequent predictions of such storms have been made. A great deal of discussion has arisen as to the possibility of extending this system, and of giving ample warning of these outbursts. The most that can be said at present is, that the occurrence of such a storm is exceedingly rare; and in a very small space, while we may be able to indicate a region of several thousand square miles where such local outbursts may be expected, yet little more than this can be hoped for. People living in such districts, when they hear of the prediction, should not be disturbed, but simply take it as a probable occurrence at possibly one or two places, and in any particular locality should be guided by the appearance of clouds and other threatening signs which have become familiar. In fact, the question frequently arises as to whether it would not be better to omit such a prediction entirely; but if the right view be taken of it, that it is a warning to look out, and not a positive statement, no one should be unduly disturbed.

There are times when there seems to be an unusual amount of electricity present in the atmosphere, and when these severe storms occur without presenting any indication whatever on our maps or in our reports. It is impossible, from our present telegrams and knowledge of these storms, to make any predictions in such cases, though we may hope that in the future we may have a clearer idea of disturbed conditions at one or two thousand feet above the earth, which will enable better predictions. Such storms are not very severe as a general thing. A storm region like that in Kentucky on March 27, 1890, is plainly indicated on our maps, and predictions of severe local storms were sent from

the Signal Office all through that region nearly twelve hours in advance.

There has been a gradual development in these predictions as the conditions have become more familiar. One of the later attempts was made in 1884, and in this case the whole country east of the 102d meridian was divided into eighteen districts, and private predictions were made each day during the tornado season as to whether or not a tornado would occur in any district. The claim was made that in this case 97 per cent of the predictions were successful, but a serious fallacy in these attempts was soon pointed out. To say that on any day in New England, for example, there would be no tornado, was no prediction at all; for only under most extraordinary conditions, occurring once in three or four years, are any tornadoes experienced there. Several verifications of these predictions according to mathematical principles gave from 13 to 20 per cent of success. This does not indicate, however, the measure of skill that has been attained in tornado prediction, but was due primarily to an injudicious system of predicting, and secondarily to an improper estimate of the nature of the problem. It would be impossible, of course, to say that such a tornado as that at Grinnell in 1882, and the recent one at Louisville, would occur in any district. All that we can do is to predict a disturbed region. In verification, it would hardly be fair to adopt principles which could be used in determining the skill of a marksman shooting at a target, for example; but we must take into account the knowledge we have already gained of the relative violence and the manner of occurrence of such storms. We must determine, on a scale, the number of violent storms occurring in any district where such storms were predicted, and not confine attention to the most violent alone. To draw an imaginary line, and say that if a storm occurs within five miles of that line, in a district where it was predicted, it shall count fully as a success, but

if it occurs five miles on the other side of that line it shall count as a total failure, is to impose restrictions upon the problem which seem entirely unreasonable.

In a study of tornado predictions made by Mr. Finley for June, 1885, the present writer assumed "that violent storms occurring, in any district predicted for, half way between the centre and edge, shall have weight 1; in the rest of the district, $\frac{3}{4}$; to the centre of the next outlying district, $\frac{1}{2}$; to the edge of that district, $\frac{1}{4}$; all outside of these, 0" (see *American Journal of Science*, August, 1887, p. 129). The percentage of skill attained as thus measured was 49. Mr. Curtis, taking the same predictions and discussing them mathematically, found 14 per cent. Mr. Curtis has more recently (1887) adopted somewhat the method suggested above, and obtained 40 per cent. These percentages, however, mean very little as to showing a real knowledge of the probable occurrence of tornadoes, for it is necessary to radically change the system of predicting. It would seem wiser to determine as nearly as possible the central point of any probable disturbance, three hundred or four hundred miles to the south-east of a general storm, and then give boundaries more or less definite to the violence of the storms. This we are able to do from what is known of the behavior of such storms. In verifying, we should consider all the storms that occurred, and give weights corresponding to their distance from the centre of the disturbed region, and to their intensity.

Tornado Photographs.

One of the most recent developments in tornado studies has been a strong desire to photograph this extraordinary appearance. It is very unfortunate that this desire has become so strong that unscrupulous persons have resorted to photographing sketches of tornadoes, and selling them for the real article. It is also unfortunate that all these alleged

photographs have been made at distances of from ten to twenty miles. It is a great desideratum that we have many photographs taken at much closer quarters, and this is not so impossible as *might at first sight* appear. It would be useless for any one to attempt a photograph on the south side of a tornado within a thousand or fifteen hundred feet; but on the north side we have repeated authentic observations of persons who stood within one hundred and fifty feet, and did not feel any violent wind. It is much to be hoped that a photographer will catch, by his instantaneous flash, one of these monsters as it passes just south of his position. It will require more than the usual amount of bravery to do this, however, as is very plain.

Alleged Photograph.

While nearly all these photographs show quite plainly their origin, yet there is a single exception in a picture representing an alleged tornado near Jamestown, Dak., on June 6, 1887, recently published in a prominent magazine. There is no doubt that this is a genuine photograph. There exist most serious difficulties in regarding it a tornado-cloud, however. The picture shows a dense mass of cloud extending from the trees at the earth up to the uniform veil of cloud above, with clear sky on either side. This mass has a thickening on the right-hand side, and this is supposed to be the tornado. The appearance is exactly that of a cloud-burst, as has been often witnessed, and not at all of a tornado. The dimensions of the camera and the distance of the cloud give the height between two and three miles. The distance of the cloud was variously estimated from eighteen to twenty miles. There was no destruction, and no one saw it, at the spot where the tornado was supposed to be. The only way it could be located was by following two lines of sight of persons from ten to fifteen miles away until they crossed. Drawings of a sand-whirl, not far from the alleged

tornado, showed a funnel-cloud, and nothing at all like this indefinite mass in the picture. The evidence is quite conclusive that on this day there were in this region several appearances simulating cloud bursts, tornadoes, and sand-whirls. It is very probable that this photograph was that of a cloud-burst within two or three miles of Jamestown. It is highly improbable that either a cloud-burst or a tornado ever had a height exceeding two or three thousand feet. A photograph of a funnel-cloud showing details, and especially two or three photographs taken as the cloud comes up and passes by, would be of the highest interest, and invaluable at this stage of our studies.

CHAPTER XIII.

THE LOUISVILLE TORNADO.

ONCE in a great while the whole world is startled by such an appalling catastrophe as the Chicago fire of 1871 or the Boston conflagration of 1872. Such disasters are entirely outside of the usual experience, and thus make a most profound impression. Of such a character are to be regarded the Grinnell (Iowa) tornado of April 17, 1882, and the more recent one at Louisville on March 27, 1890, in which 76 people were killed and $2,250,000 of property were destroyed. It might be thought that every tornado has exactly the same power, but does not show it because it does not happen to strike where it can do the most damage. To a certain extent we might argue in precisely the same way about a fire. Every fire, under such environments as mentioned above, would reproduce the terrible effects, but we find that the ordinary result of a fire is far different; and this is exactly the truth in regard to tornadoes. No two tornadoes are alike in their diameter or force. We may argue, however, that if two thousand tornadoes have produced one such as that at Grinnell, then we need not expect such a one again in about the same number, excepting as an increase in the size and frequency of towns in the tornado regions gives a more fre-

quent opportunity for such accidents. This may also be said as true regarding the most serious fires.

Just preceding this tornado the atmospheric disturbance to the west and north-west of its development was unusually marked; so much so, that all the region in which the violent storms occurred were warned of their probable occurrence nearly twelve hours in advance by the Signal Office at Washington. The centre of the general storm at 7 A.M. (Central time), or twelve hours before the tornado, was in eastern Kansas, at which point the air-pressure was below 29.1 inches. At 7 P.M. this storm had moved rapidly to central Illinois, and just fifty-seven minutes later Louisville was struck and partly destroyed. This fact, that we have a chart of the meteorological conditions within an hour of this outburst, is very important. We find that the winds throughout the tornado region were from the south and south-east; and this current existed even up to the clouds, as we have determined in so many cases before. In fact, the whole circulation of the atmosphere was no whit different from that noted again and again in such general storms. The tornadoes were suddenly thrown into this atmospheric circulation almost without warning. The velocity of the general storm, moving nearly due east, was 38 miles per hour from 7 to 11 A.M. of March 27, 39 miles per hour in the next four hours, and 37 miles per hour in the four hours just preceding the tornadoes. It is a little difficult to obtain the exact velocity of the tornadoes, as the times are in most cases very indefinite; but the best authenticated times in the Louisville outburst would make it a little more than 80 miles per hour, the path being directed nearly north-east. There was a most remarkable series of tornadoes in this region, including southern Illinois and Indiana, western Kentucky, and just the northern border of Tennessee. The paths were all in a north-east direction, the earlier being 200 miles nearer the centre of the general storm, and much shorter than the later.

The first definite notice of a violent rush of air was at Mill Creek, Ill., at 4.30 P.M. This track (I) was very short, and is not traced outside of the town. Track II runs a short distance near Olney, Ill., and the time was 5.30 P.M. Track III was much the longest, and most destructive of all. It was first noted at 5.30 P.M., at Metropolis, Ill., and passed through or near the following towns (all in Kentucky), dipping now and then as it rushed onward at 80 miles per hour,— Hampton at 5.40; Marion at 6; Clay at 6; Dixon, Sebree, West Louisville, Delaware, Owensboro, at 6.17; Enterprise, Knottsville, Hawesville, Louisville, at 7.57,— and is last heard of in Jeffersonville, Ind., just across the river from Louisville. Track IV first appears at Farmington, Ky., and passes near Kuttawa, Eddyville at 6.30, Bremen, and Hartford, all in Kentucky. Track V is traced near Belleview, Caledonia, and Sinking Fork, in Kentucky. Track VI may possibly be connected with III, and is traceable near Eminence, Pleasureville at 8.30, La Grange at 8.50, Campbellburg, and Carrollton, all in Kentucky. Track VII passes near Rogana, Tenn., at 8.30; Eulia, Tenn.; Coatstown, Tenn., at 8.50; Dixon's Springs, Tenn. (probably); Butlersville, Ky.; and Glasgow, Ky., at 9 Track VIII is traced near Fayetteville, Fosterville at 9.15, Millersburg at 9.15, all in Tennessee. Track IX is near Rockcastle Springs, Ky., at 11. The last violent wind, or track X, is found at Marshall, Ky., at 8.30.

It will be understood, that, though all this region felt these violent wind-rushes, yet these paths are by no means continuous from town to town, and in most cases there was no serious damage. Louisville suffered the worst, as just noted. Outside of Louisville there were 59 killed and a property loss of $1,000,000. At Metropolis, Ill., 1 person was killed, 50 injured, and the property loss was $150,000. The most exaggerated reports of losses were circulated by the newspapers. One prominent Western paper, whose statement was widely copied by others, a whole month afterward

placed the loss in Webster County, Ky., alone at 111, while the true loss was 8. In Barren County the loss was placed at 30, though no one was killed there. In Lyons County 23 killed were given, though but 2 died there. This same paper made no mention of loss of life in Livingston County, where 9 were killed, and in 6 other counties where an aggregate of 40 were killed. Of course, there was no intention of distorting facts in this case: it is given as a simple illustration of the great difficulty which inheres in studies of this kind, and the great danger there is in taking descriptions by two or more observers of the same destruction, and applying them to several places, and not to a single spot. The utmost care should be exercised in giving the exact place of the catastrophe, either as in a town or village, or so many miles in any direction, as the case may be.

While the names of a large number of towns have been given above as visited on this date, yet there were many others that could not be enumerated for lack of space: in fact, a thorough research would seek to establish exactly the spots where destruction was least, as well as where it was greatest. It is quite remarkable that though this whole region was in a disturbed condition, meteorologically speaking, yet there were enormous areas not seriously touched. A careful research would have developed some valuable facts; but, so far as known, the only outburst given a careful study was at Louisville. It is to be deplored that such a fine opportunity to add to our knowledge of these storms was lost. We may hope that in the near future such occasions will be seized upon as of the greatest importance. It is probable that the weather service of each State would be best suited to take up this study, and it is noted that the Ohio Weather Service has exhibited commendable zeal in this regard.

There has been published in the *Weather Review* a good description by Sergeant Frank Burke of the tornado at Louis-

ville, Ky., and this will be freely quoted from. The times given are all reduced to Central. "At 7.30 P.M., although intense darkness precluded careful observation, the clouds in the south-west exhibited evidence of a most violent commotion. It appeared as though north-west and south-west clouds, in coming into contact, had been shattered to pieces, and their fragments, intermingling, had been thrown upward and laterally by the force of the shock. These movements occurred at a considerable elevation, the space between the clouds and the earth having a misty or fog-like condition. Heavy rain began almost at the moment of this commotion. At the same time the lightning-flashes, which had occurred hitherto only at long intervals, increased tenfold in frequency and intensity, the south-west quarter of the heavens being the centre from which the almost incessant flashes radiated. A peculiar feature of this display was the almost entire absence of thunder. The wind had been blowing a moderate breeze from the south-east during the afternoon. At 7.34 it shifted suddenly to the south-west, and increased in force. At 7.50 the rain had almost ceased. A few moments later, scattering hail fell, average diameter half an inch; then came a momentary lull in the wind, and a peculiar, indescribable oppressiveness of the atmosphere. The darkness was intensified at this moment by the sudden diminution of the gas-jets, which in many cases were extinguished. It may be important to state in this connection that the lights were not blown out, but failed through lack of pressure in the reservoir. The approach of the tornado was heralded by a tremendous roaring sound, mingled with the crash of falling buildings. The noise has been likened to that produced by the passage of a heavy train of cars over a bridge, a thousand times intensified. The storm struck the city at 18th Street and Broadway, crossed it in an almost due north-east direction, and at 7.57 left it at 7th and Water Streets. This time is verified by the telegraph officials, who

noted it as the moment when their wires, which cross the tornado's track, ceased to work. Persons who saw the cloud coincide in stating that it was of a balloon or turnip shape, though the darkness and confusion precluded accurate observations of its movements. It was accompanied by a most terrific electric display, and several reliable persons assert that balls of fire were playing about it. The highest wind recorded at the Signal Office, less than 1,800 feet from the path, was 36 miles per hour. After it had passed, the wind shifted suddenly to the west, and continued to blow from that point for twenty-four hours, and with increasing velocity, the record showing 42 miles per hour at 9 P.M. The sky was perfectly clear at 9.30 P.M., except a streak of very high and apparently motionless cirrus in the west. Shortly after this time the atmosphere became obscured by a peculiar haze or smoke, through which the moon shone with a reddish light.

"Where the tornado entered the city, the width of the path was a little more than 600 feet. As the cloud progressed, the width of its path increased to 1,500. There is no evidence that the tornado-cloud touched the ground at any point in Louisville. In nearly every case the destruction was confined to the upper floors of the demolished buildings, but comparatively few houses being totally ruined; and also a large proportion of the one-story structures in its path were uninjured. Churches, halls, warehouses, and other structures having but little interior support, suffered the most. To this fact is attributed the principal loss of life. At the Falls City Hall alone, where a large number had congregated, 44 were killed. Frame buildings invariably withstood the shock much better than those constructed of masonry. But few of the destroyed buildings bear evidence of being actually blown down by the whirl of the tornado-cloud itself, but their destruction was apparently caused rather by a lateral or vertical rush of air-currents centring

toward it. The ruins and the disposition of the *débris* give ample evidence of this. The right [south] side of the storm-track, and in a less marked degree the left side, afforded numerous examples of the intensity of this lateral force. In both cases [i.e., on either side of the track] the sides of the buildings facing the storm were pulled out, the *débris* falling towards it [the track]. In many cases fragile articles, such as glassware, remained undisturbed. In the centre of the track the destruction was mainly due to a vertical force which lifted the roofs of the buildings. The roof of the Union Depot was lifted bodily, and deposited intact on the floor, immediately beneath its original location.

"The destroyed buildings were, as a rule, of a very unsubstantial character, being mainly ordinary brick dwellings, small stores, and warehouses. The Fort Nelson building, at 7th and Main Streets, is the most notable exception to the general destruction in the tornado path. This is a well-constructed six-story building, and, by its greater height than those surrounding it, was more exposed to the storm's fury. Despite the fact that it was directly in the storm's track, and that all other houses on either side were wrecked, it escaped with the loss of its windows. The gyratory motion of the tornado is well illustrated in the disposition of the prostrated trees in the parks, and the timber outside the city. In the centre the trees were piled in promiscuous heaps, denoting a tremendous wrenching or twisting force. On the right side the tree-tops point almost north-east; those on the left side, nearer due east. Throughout the path of the storm the zone of destruction on the right [south] side is more than twice as wide as that on the left side, and shows a much greater intensity of force."

I have quoted almost the whole of Mr. Burke's most excellent report, which may be regarded as a model in its terseness and statement of valuable facts. One or two comments are added. The heavy rain preceding the tornado

seems to have been independent of it, and not necessarily due to any action in it. The presence of lightning, and absence of thunder, are noteworthy, and may explain the fact that oftentimes no electric action is reported in a tornado. Thunder is always regarded as the most prominent characteristic in a thunder-storm. The sudden shifting of the wind to a direction from the tornado is very significant. How could this have been if there were a partial vacuum in the storm? The failure of the gaslights is very interesting, and at first sight appears to show a marked diminution in pressure. Diligent inquiry at a gas-office, however, shows that no reasonable diminution in the pressure of the atmosphere could affect a gaslight; moreover, this same phenomenon was noted at Cleveland, O, at a time when there was a very high wind, but no tornado. Investigation has shown that a high wind forces the immense gas-holder against the vertical posts, and this causes the failure in the pressure. This explanation is now accepted by those familiar with the subject. It seems also probable that such a high wind, when blowing near the earth, would have a tendency to an upward thrust; and this has been shown repeatedly by the uplift of dust, leaves, and small branches in front of a sudden gust. The increasing wind after the tornado was not connected in any way with that, but was simply the high wind in the rear of a storm, and in this case it was intensified by the steep barometric gradient. The preservation of the Fort Nelson building was probably due to a diminution in, or a lifting-up of, the storm just at that point, and not to its construction. There are innumerable instances in which the frailest structures have been left undisturbed in the centre of a tornado-track. The evidence from the prostrated trees does not bear out the gyratory theory, but is rather strongly against it. If there were any gyration, say, from right to left, the trees on the left (north) side ought to face west, and not east as they were reported.

Mr. Burke, in a private correspondence, states that he made a most diligent search for evidence of corks being blown from bottles, but did not find a single case, although there were several apothecary-shops and bottling-establishments in the centre of the track. He also states that the diminution in the gaslights was quite sudden, and passed away quickly. It would be interesting if some one would determine the velocity of the wind needed to produce this effect. This report must be regarded as corroborative, and not as absolutely establishing points now in doubt. The statements in the report show only very slight evidence of bias or leaning toward any theory; and this is just what is needed now, if we are to make any headway in our studies. The report is worthy of commendation.

Incidentally one of the more interesting facts brought out by the tornadoes on this date are barograph traces made by the passage of the tornado at Owensboro, Ky., and Cincinnati, O. These are given in the accompanying plate, Figs. 6 and 7. Unfortunately the original trace for Fig. 6 was carried by the owner to Scotland, and given to Mr. Buchan, who rightly regarded it as a most valuable acquisition. It is to be regretted that the original was not kept in this country, where it belongs, and a copy taken abroad. The copy I have, however, is a fair representation of the original. I have enlarged Figs. 5, 6, and 7 from the Richard barograph to make them directly comparable with the barograph sheet at Washington, given in Fig. 8. The barograph at Owensboro was a mile and a half from the nearest point of the tornado. It has been supposed all along that a tornado could not produce any effect on pressure more than a few hundred feet from its centre, but here seems to be good evidence of an effect over 7,000 feet away. The first sudden drop of the curve with an immediate return is a little singular, and appears like the sudden drop found by others, and explained by the effect of the wind. Whatever may

have caused this drop, there is no doubt of the rise after it; and this rise is far more striking at Cincinnati, where the storm crossed 59 minutes after leaving Louisville. Fig. 5 is

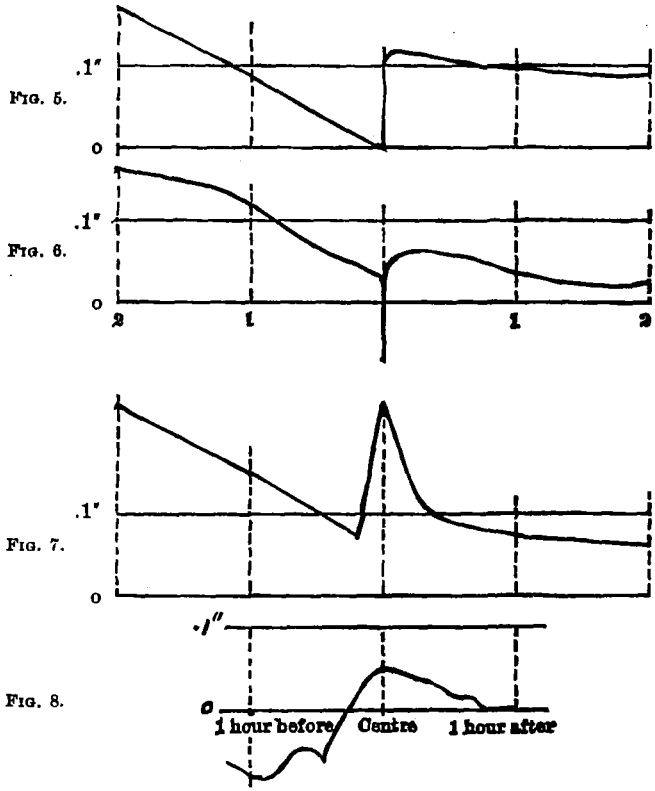

Fig. 5, tornado St. Louis, Mo. (Jan. 12, 1890, 5.16 P.M.); Fig. 6, tornado Owensboro, Ky. (March 27, 1890, 6.17 P.M.); Fig. 7, tornado Cincinnati, O. (March 27, 1890, 8.20 P.M.); Fig. 8, thunder-storm Washington, D.C. (June 22, 1890. 9.8 P.M.).

also given from the barograph at St. Louis during the tornado of Jan. 12 of this year. This has already been referred

to. There is no doubt of a marked rise here. Fig. 8 is a portion of the pressure-curve made at Washington, D.C., during the prevalence of one of the most severe thunderstorms that has visited the station. There was a steady rise for an hour, and a less rapid fall after the centre had passed. This storm came up and passed off very slowly, and was attended by most brilliant lightning and a terrific wind. The general similarity in these curves, excepting Fig. 6, is very striking. We may hope to get more of such curves on both sides, and possibly in the centre of tornado-tracks.

CHAPTER XIV.

INSTRUCTIONS FOR OBSERVING TORNADOES.

If any one thing has been emphasized in these pages, it has been the extreme need of more light on this whole question. The earlier investigators of the phenomenon were untrammelled, to a large extent, by preconceived opinions, and it must strike every one that few substantial facts unknown to them have been brought out since their time. It is to be hoped that the number of those willing to aid in establishing the facts and ferreting out the mysteries will be largely increased, and it is for such these instructions are given.

1. It is very essential that one divests himself of every preconceived notion about the whirling, sucking, or any other action of a tornado. There is the utmost danger of seeing the tornado do what we think it ought to do. It would be far safer, if one has an inclination to such views, to deny that such a view is correct, and only to accept it after most incontestable proof.

2. Note the time of day carefully, and specify whether the time used is Eastern, Central, Mountain, or some city time.

3. The side of the track on which the observer stood should be given.

4. Note the appearance of the clouds in the distance,—

whether they roll upward, come together from the north and south,— or any other phenomenon connected with them.

5. Special note should be made of a cloud of dust and its general appearance.

6. See whether the funnel-cloud is visible at a distance, or suddenly breaks into view on the approach of the tornado. If possible, locate the first appearance of the funnel by a tree, house, or object close by, and, after the tornado has passed, measure the distance from the observer's position to that of the tornado when first seen.

7. If the observer is a thousand feet or more away from the funnel, or cannot see distinctly trees or objects in it or near it, he should not try to make detailed observations of the whirl, or any thing else at the tornado. Fix the attention on the motion of detached clouds. Make every effort, by comparison with trees and houses between the tornado and the observer, to get its height, width, and speed: these can be much better found out at a little distance than close to the cloud.

8. Make careful observations of all electric displays, the appearance of balls of fire, the sound of thunder, the roar of the tornado, etc.

9. If the observer is within a hundred feet of the tornado on the north side, he need have no fear, and may carefully examine all objects flying just above the ground. He should note carefully the foot, the middle, and the top of the funnel, to see whether any tree or object is carried to his right as he faces the funnel.

10. Note also whether any object is carried up straight in the funnel, or whether it is borne along in the swift wind. If there is an uprush in the tornado, it ought to be easily told; and the appearance will be very different from that if the object or house is borne along by the wind, and afterward inclined upward. If there is a sort of explosive effect, the upward motion will be more or less jerky, and not steady

as in a stream. On the whole, the evidence seems to show something like an uprush, though it seems conclusive that this is not due to a vacuum in the tornado, as many think. It is very plain that nothing can be sucked into the tornado, because of a partial vacuum there; but if it rushes in or up, it must be borne or propelled by a stream of electricity, so to speak, or by a rush of air. One of the best illustrations of this has just come to hand from the storm at Bradshaw, Neb. This tornado passed over a tank ten feet long, three feet wide, and twenty inches deep, full of water. This tank was air-tight, and had an opening in the top one foot square. The observer reports that the tornado sucked all the water out of this tank. A moment's reflection will show that this could have been done only by the insertion of the funnel into the opening one foot square. Of course this is absurd, and we must resort to some other explanation of the phenomenon.

11. After the tornado has passed, note the appearance of the houses for explosive effects.

12. Pay particular attention to the direction of the trees, making a separate observation on the south side, in the centre, and on the north side. See if any *débris* or objects have been carried in any case toward the west or south-west on the north side of the track, and measure the distance.

13. A note should be made of the width of the greatest destruction, not including houses unroofed on the borders; also the length of the path where it was most destructive, and the distance from the point at which it first struck the earth to the point at which it left the earth during the time of the greatest destruction.

14. Give the names of persons killed, if any.

15. Give an estimate of the loss to buildings, also specifying the number of buildings destroyed and their characters as to strength, etc.

16. A note should be made of the rainfall,— whether it

To C. Frankenfield.

was most abundant before, during, or after the tornado; also, if possible, the amount of rain at the centre of the track and at some point two thousand or three thousand feet on either side.

17. Careful note should be made of hail, size of stones, width of track, situation with respect to the main track, etc.

18. After the tornado the direction of the path should be most carefully determined.

19. All evidences of corks flying from bottles should be carefully looked for.

20. If one has a barograph, its record will be of the utmost value. If one has a barometer, an observation should be made by some one every minute till the tornado has passed. If the barometer is an aneroid, the face should be gently tapped before each observation. A steady watch of the needle may show any sudden fluctuation too rapid to be caught by reading the barometer. This instrument may be read in a dug-out or a cellar as well as in a house.

Of course, every one will keep eyes and ears open for any and all phenomena to be noted in this remarkable outburst.

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