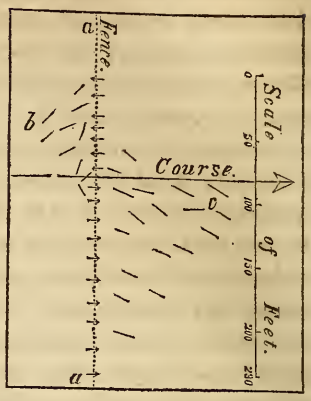
resented in the figure. On the *left* side, however, every post was prostrated *westwardly*, and the rails were likewise blown slightly backward toward *b*, in the same general direction. The scale of feet, which measures across the track, was obtained by estimating twelve feet to each length of the rails. The locality of this sketch was perhaps a mile eastward of the Lyon farm. —The application of the foregoing views of rotation to this case, it can hardly be necessary to point out.

Fig. VI. *Providence Tornado.*



I have noticed many effects of similar kind on fences; but that the *backward* prostration on the left side of the track should have taken full effect in this case, and mainly, perhaps, under the second quadrant, I ascribe to the age and general weakness of the fence.

Additional memorials might here be adduced in evidence, and of similar character to the foregoing; but having already occupied more space than I intended, I must now leave the question of a general whirlwind rotation in this and other tornadoes to the candid consideration of impartial inquirers.

New York, July 12, 1842.

Art. III.—*On a Tornado which passed over Mayfield, Ohio, February 4th*, 1842, *with some notices of other Tornadoes;* by Elias Loomis, Professor of Mathematics and Natural Philosophy in Western Reserve College.

(Communicated to the Conn. Acad. of Arts and Sciences, April 28, 1842.)

On the 4th of February, 1842, between four and five o'clock, P. M., a tornado of destructive violence was experienced in the northeastern part of Ohio. It commenced near the south line of the township of Mayfield, in latitude 41° 31′ N., longitude 81° 27′ W., and pursued a course N. 33½° E. for about twenty four miles; when meeting Lake Erie, it left no further traces of its progress. A more distinct idea of its course may be formed

by inspecting Plate IV, Fig. 5. From this it will be seen that the tornado passed not far from the centre of Mayfield; over a corner of Chester; near the centre of Kirtland; over corners of Mentor and Concord; and directly over the southeast part of the village of Painesville. It is said that no trees are prostrated one hundred and fifty rods south of the south line of Mayfield. Immediately on receiving intelligence of the disaster, Prof. St. John and myself started to survey the ruins, and the subsequent observations were made by us jointly. In measuring the track, each of us carried one end of the chain; and in taking the bearings of prostrate objects, Prof. St. John usually observed the compass, and I recorded the readings. We surveyed the track with special care in Mayfield, Kirtland, and Painesville, and crossed it at other places. Our first observations were made in Mayfield in the vicinity of Chagrin river. Plate IV, Fig. 1, gives a view of this part of the track. This was near the commencement of the tornado, and was also the scene of the greatest violence. The bed of the Chagrin is depressed about three hundred feet below the general level of the surrounding country. A section shewing the undulations of the ground is exhibited in Plate IV, Fig. 2. In Fig. 1, A A A, B B B are trees chiefly of the variety called whitewood. Their average size is from two to four feet diameter, and they were mostly prostrated. The ground descends at first gently, afterwards quite abruptly, to the bed of the river. The forest approaches within about a hundred rods of the river, yet upon this slope the small timber was not greatly injured. The larger trees were mostly prostrated. C represents the house and barn of Chester Ellsworth, not much injured; D, the house of Ezra Carpenter, chimney blown off; E, his barn entirely demolished; F F, woods; G, log house of Mr. Alderman, entirely destroyed; H, house and barn of Anthony Sherman, entirely destroyed; I, Benjamin Wilson's hay barn unroofed; K, another hay barn unroofed; L, Samuel Dean's large framed house, torn entirely to atoms; M, school house, entirely destroyed; N N N, O O O, trees entirely uprooted or broken off; P, a log cabin with north side of roof taken off and a few shingles from the windward side. Beyond P a line was measured with a chain perpendicularly across the track two hundred and thirty rods.

Mr. Halsey Gates, standing near his mills under a shed open to the north, saw the tornado pass, and observed it very atten-

tively. The entire heavens, he says, were covered with dense black clouds moving with great rapidity. No cloud seemed to descend to the earth; yet the progress of the tornado was marked by a huge column of a dull yellow or smoky tinge, a representation of which is given on Plate IV, Fig. 3. The lower half of this column was quite dark, so that objects could not be seen through it; the upper half was lighter, and had several vertical stripes somewhat like the shadows of clouds, or like a cloud at a little distance from which a heavy shower is falling. This column was estimated to be about eighty rods in breadth, was much agitated and moved rapidly forward to the northeast. But little rain fell—in the dialect of our informer, not enough to wet a man's shirt. Some hail fell about the size of buck shot, but not enough to whiten the ground; it was quite soft and porous. It lightened several times quite sharp just before the blow came on, striking a tree at no great distance; 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 sea-shore, or to the Falls of Niagara. The house D was not much injured; The east side was well spattered with mud, and the chimney blown N. 55° W. The house bears from the barn E, N. 62° E. distant sixty six paces. The barn E was lifted entire from its foundation and carried N. 30° W. It contained at the time three tons of hay and four horses. The bottom dropped at a distance of fourteen paces; the other heavy timbers were carried much farther, and lighter objects, such as boards and shingles, were strewn over an area of several acres. Three men were in the barn at the time; they state that the barn was not lifted more than a few inches, but rather slid from its foundations. They made their escape as the barn began to move. A hat belonging to one of the men was carried four miles in the direction of the track. The grass in the vicinity of the barn was beaten down flat upon the ground as by a heavy roller, and all turned N. 48° W. The house G was a log house which had the appearance of having been blown up with powder. The wind first burst open a door—then lifted the building *en masse* from its foundations—the logs opened—the power of the wind upon the building was broken—the logs fell back again nearly upon the foundations—a part of the timbers however being carried some distance N. 27° W. A flock of hens was carried off in the tornado, and they

have not since been seen. One goose near the house had its wings and legs broken, and was almost entirely picked of its feathers; it was carried N. 20° W. The house and barn H were entirely destroyed—mostly carried N. 88° E. Hay from the barn was carried S. 87° E., leaving a perfectly distinct track upon the ground. The chimney of the house was carried S. 50° E. Mr. Peleg Sherman, a half mile distant on the north side of the track, observed the tornado as it passed. Solid hail fell here three quarters of an inch in diameter—not half enough to cover the ground. There was but little rain. An orchard in front of G and H was almost entirely destroyed. Two apple trees were torn up by the roots and carried N. 8° W. fifteen paces, leaving several marks where they struck the ground at intermediate points. Another tree was carried N. 23° E. thirty paces; another sixty paces in the same direction. Several trees had their limbs on the southwest side twisted round the body of the tree by west and north, and left half broken, pointing towards the northeast; while those on the northeast side were wholly uninjured.

In crossing Chagrin river, the tornado appears to have elevated considerable water into the air. The general impression among the inhabitants is, that the bed of the river was left entirely dry, although from the previous rain its height was said to be two feet greater than it had been before for four years. The river varies from twelve to sixteen rods in breadth. There are distinct marks of a considerable rush of water on the Eastern banks. A saw log twelve feet long and three feet diameter, known by its mark, and supposed to have been floating in the river at the time, was found after the tornado about twenty rods from the bank on the east side. The house L appears to have been near the seat of greatest violence. First the cheese house was taken, was carried N. 18° W. sixty feet, and striking the ground was dashed in pieces. An old log house near by, was carried N. 35° W. A south door of the dwelling house blew open—a boy about eleven years old attempting to shut the door, was whirled through a *window* just burst open, and carried N. 65° E., a distance of fourteen rods as measured by us with a chain. Here he was deposited, having received no other injury than a slight scratch upon the face. On looking back for the house he found it gone. It was a large two story framed house, quite new, and remarkably well built. It was lifted entire from its foundations, carried N. 46° E. a dis-

tance of forty four paces—where it struck a tree; the bottom fell; the upper timbers were carried various distances, the clapboards were broken to shivers and lie mostly strewed on the hillside, which rises on the northeast, some lying loose upon the ground, and others sticking fast in the soil. Clapboards of the usual size and pieces of flooring with square ends were driven obliquely into the ground from six to twelve and even eighteen inches, and some with sharp ends to the depth of two feet. The soil is chiefly of clay, was at this time drenched with rain and was almost entirely free from frost. The land was not ploughed but covered with the usual turf. Other fragments of clapboards from this building, easily distinguished by their red color, are found strewed through the woods to the north and east, and some are said to have been discovered at a distance of seven or eight miles. The chimney of the house was carried N. 40° E., the ridge N. 30° W. A number of apple trees near by were almost entirely stripped of their bark, probably in consequence of the cudgeling they received from sticks flying in the air. Four geese were found dead in this vicinity without any material loss of feathers. A large barn, containing ten tons of hay and a ton of straw, was unroofed and carried N. 25° E. six feet. A corn house, containing two hundred bushels of wheat and corn and three barrels of salt, was also unroofed and moved from its foundations northward,—the west corner four paces, the east corner two paces. It ploughed into the ground, throwing up earth to the height of a foot or more, particularly at the northwest angle.

The school-house M was lifted entire from its foundations, carried N. 10° W. twelve paces, and dashed upon the ground. The fragments were scattered as usual. The hill towards the northeast was covered with a very heavy growth of timber,—hemlock, beech, oak, &c. of vast size. Scarce a tree of any importance now stands entire. The breadth of the track at this place was measured with a chain, 230 rods. Two waggons were carried off in the tornado, and only one wheel has since been found.

The following data will enable us to estimate the velocity of the tornado's progress. I requested Mr. Gates to follow in imagination the smoky column as he saw it advance from its first appearance to its disappearance; and with a watch in my hand noted the time. The mean of three such trials, which were tolerably consistent with each other, was fifty two seconds. Dis-

tance travelled estimated at three fourths of a mile, which is a velocity of fifty two miles per hour. According to the best testimony I could obtain, the tornado passed Chagrin River at a quarter past four; passed Painesville a quarter before five. Velocity seventeen miles in thirty minutes, or thirty four miles per hour.

I have obtained an independent estimate of the velocity, in the following manner. The tornado accompanied the change of wind from south to west, which was experienced over a large territory. This change of wind was at Hudson cotemporaneous with the barometric minimum, and it is presumed to have advanced with nearly the same velocity. I have therefore sought for barometric observations, and have obtained them for the fourteen following stations. The time of barometric minimum is not in all cases the time of the lowest observation, but is obtained by projecting the observations on paper and comparing the curves at the different stations.

Station.	Time of minimum.	Station.	Time of minimum.
Natchez, Miss.	1842. Feb. 3, 1 P. M.	Uniontown, Pa.	1842. Feb. 4, 7 P. M.
St. Louis, Mo.	" 4, 2 A. M.	Gettysburgh, Pa.	" " 11 "
Cincinnati, O.	" " 0½ P. M.	Rochester, N. Y.	" 5 1 A. M.
Marietta, O.	" " 4 "	New York City,	" " 5 "
Hudson, O.	" " 4½ "	New Haven, Ct.	" " 7 "
Detroit, Mich.	" " 5 "	Providence, R. I.	" " 10 "
Meadville, Pa.	" " 6½ "	Boston, Mass.	" " 10 "

From these data we find the progress of the wave to be in the direction N. 62° 19′ E., and velocity 30.05 statute miles per hour. But the course of the tornado was N. 33° 30′ E., inclined 28° 49′ to the progress of the wave. The velocity of the wave in the direction of the tornado's progress was then 34.3 miles per hour, a result almost identical with the second estimate. The first estimate can only be regarded as a good guess. The tornado then travelled a space equal to its breadth, at Mayfield, in seventy-five seconds.

The velocity of the wind's motion however at points of the most destructive violence, was far greater than this. A tolerable idea of its velocity may be gained from the distance to which light objects were driven into the ground. Small pieces of clap-boards with square ends were driven into turf land eighteen inches, and with sharp ends two feet. What charge of powder is capable of producing the same effect? According to the experiments of Dr. Hutton, (Tracts, Vol. 3, p. 214,) a pound ball of cast iron fired

from a gun of two inches calibre into solid blocks of elm wood, in the direction of the fibres, penetrated the following distances:

With a charge of 2 oz. powder,	velocity	800	feet per second,	penetration	7 inches.
" 4	"	1200	"	15	"
" 8	"	1600	"	20	"

Dr. Hutton estimates the resistance of elm timber 7⅓ times more than that of firm earth. A pound ball with a velocity of 800 feet should then penetrate the earth 51 inches. The depth penetrated being assumed to be as the square of the velocity, a pound ball fired with the velocity of 550 feet would penetrate 24 inches. The space penetrated is said to be as the specific gravity of the ball. A wooden ball two inches in diameter, specific gravity .75, fired with a velocity of 550 feet should then penetrate firm earth 2.4 inches. As this last result is a deduction from principles somewhat doubtful, I desired to verify it by experiments of my own. A six pounder was accordingly charged with 1¼ pounds of powder. Two or three short pieces of oak board, three inches wide and one inch thick, were added, and the gun pointed towards a steep hill distant about a rod. The boards penetrated the ground a few inches, were badly shivered and bounded some distance up the hill. A second experiment was tried with nearly the same result. The hill was of usually firm earth but not stony. The greatest penetration did not exceed six inches. Velocity computed 1000 feet per second. According to the former data, the penetration should have been nearly eight inches. But the ground at Mayfield was saturated with water. I have no precise data for estimating the allowance required by this circumstance. I judge however that it would not increase the penetration more than threefold. We arrive then at the conclusion that the clap-boards at Mayfield were driven into the earth with a velocity of 1000 feet per second or 682 miles per hour.

I do not by any means suppose that the velocity was the same throughout the entire track. On the southeast half, probably the velocity did not exceed three times the progressive motion of the tornado.

Let us now determine the directions of the wind. For this purpose we measured the bearings of about seventy prostrate trees extending across the track in the direction N O. We did not attempt to measure the bearings of all indiscriminately, for this would have been a hopeless task. The prostrate trees are only

to be counted by thousands. We searched particularly for trees *crossing* each other. We found but one such case on the south-east half of the track, and this was near the middle. The bottom tree fell N. 20° E.; a second upon it N. 56° E; a third upon the second N. 84° E. We measured a number of single trees on the side N N, the bearings of which were N. 3° E., N. 3° E., N. 3° E., N. 14° E., N. 19° E., N. 25° E., N. 27° E., N. 30° E., N. 30° E., N. 55° E., N. 55° E., N. 55° E., N. 60° E., N. 60° E. The trees were not arranged in the order I have here given them, but lay scattered about indiscriminately. There did not appear any very decided mean difference in the bearings of the trees throughout the entire space N N N. We endeavored to obtain the greatest range of bearings. This appears to be 81°. From the case of the trees which crossed, it may be inferred that the most northerly trees are those which fell first. The mean of the most northerly half is N. 14° E., of the others N. 57° E.

On the other side of the track the phenomena were exceedingly different. Here we had no difficulty in finding trees which lay across each other, and accordingly we measured few others. The following observations were made, commencing near the centre of the track and proceeding towards the northwest border. Fifteen groups were measured in which the trees crossed at a considerable angle. The first mentioned tree in each group lay at the bottom, the others above it in the order named. Five layers were recorded in several instances. This was by no means the whole number which lay on top of each other. Frequently several trees lay nearly parallel with the one observed. The observations are intended to include the whole range of directions.

1. N. 70° W. N. 10 E. N. 82 E.
2. N. 2 W. N. 85 E.
3. N. 28 W. N. 20 W. N. 85 E.* N. 55 E.
4. N. 55 W. N. 32 E. N. 32 E. N. 55 E. N. 68 E.
5. N. 35° W. N. 35 E.
6. N. 40 W. N. 17 W. N. 55 W.* N. 25 E.
7. N. 80 W. N. 85 E.
8. West. N. 28° W. S. 40 E.* N. 75 E.
9. N. 35° W. N. 20 W. N. 85 E.
10. S. 5 W. S. 80 W. N. 80 E. S. 70 E. S. 60 E.
11. N. 25 W. N. 25 E. N. 60 E. N. 68 E. S. 83 E.
12. N. 25° W. N. 26 E.
13. N. 60 W. N. 20 E.
14. N. 60 W. N. 20 W. N. 15 E. N. 65 W.* N. 17 E.
15. N. 40 W. N. 35 W. N. 10 E. N. 62 E.

Mean of the bottom trees N. 55° W.; top trees N. 62° E.; intermediate trees N. 16° E. Here is a remarkable uniformity which cannot be ascribed to accident. The bottom tree points invariably westerly, and the top tree easterly. To this there is *no exception.* The directions of the intervening trees are intermediate between the extremes, passing round in the order west, north, east. To this rule there are only four exceptions marked with an asterisk. The direction of the third tree in the third group differs 30° from that of the fourth; the third tree in the sixth group differs 38° from the second; the third tree in the eighth group differs 65° from the fourth; the fourth tree in the fourteenth group differs 80° from the third. These are the anomalies 30°, 38°, 65°, 80°. How are they to be explained? Do they invalidate the inference which naturally follows from the other bearings, that the wind on this part of the track revolved in the direction west, north, east? I think not. For first, the exceptions are but four to fifty two, or one to thirteen cases. Second, it is not to be supposed that the rotation of the wind was absolutely uniform like the motion of a clock. In the case of what passes for a rectilinear current, the wind often veers by jerks back and forth from its mean direction through an arc varying from 50° to 90° in five minutes. The *mean* variableness at Hudson for an interval of five minutes is 42°; so that it could not be deemed surprising if objects prostrated by what is called a rectilinear current should often differ in their directions by this amount. But thirdly, the direction of the principal roots of a tree will somewhat influence its fall; and finally where thousands of trees are falling at the same instant, as in the present case, in a dense forest, their tops must frequently interfere, and a tree be turned greatly from the position it would otherwise occupy. The force of this last remark will be perceived when it is considered that the tornado had entirely passed in seventy five seconds, and its most destructive violence probably did not exceed fifteen seconds. It should however in candor be admitted that some of the disturbing causes here named would have less influence, from the extreme violence of the wind.

If the motion of the air were merely centripetal, that is, directed in right lines from the circumference of the tornado to the centre, then the phenomena on the two sides of the track should be perfectly *symmetrical*, and a diagram of the directions of prostrate

objects upon one side, if revolved about the central line, should answer equally well for the other side of the track. How far this is conformable to observation has already been seen. The entire range of prostrate trees on the right side is 90°, on the left 360°. Such a supposition then in the present instance is wholly inadmissible.

For determining the motion of the wind we have the following data. On the southeast half of the track the wind began on an average blowing towards N. 14° E., and ended N. 57° E. On the northwest half, the wind began N. 55° W.; passed through N. 16° E.; and ended N. 62° E. The tornado advanced N. 33½° E. The destruction of timber on the northwest half was estimated to be double of that on the southeast. Perhaps this might be occasioned by a wind blowing with one half greater velocity. The same inequality in the wind's violence is indicated by the buildings. On the southeast half of the track no building suffered any greater damage than the loss of a roof. On the northwest half, every building except Dean's barn and corn-house was totally demolished, and these are supposed to have been saved by the weight of their load. Let the black arrows on Fig. 4, Plate IV, represent the quantity and direction of the forces in question. Each of these forces is the resultant of two others, one the progressive motion of the tornado, and the other its own peculiar motion. The latter was evidently much the greatest. From the extremity of each of the arrows set off in a direction S. 33½° W., a line representing the progressive motion. The dotted arrows will represent the motion peculiar to the tornado. With these for my guide, I have drawn lines representing the supposed circuit of the wind. Near the point of convergence of these directions the wind must have risen with prodigious violence. According to this diagram, the wind on the right side of the track must have begun generally to blow about N., and ended N. 60° E. At no place could the wind have blown more than a few degrees west of north; at no place could it have been quite east. Thus on the right side, the entire range of directions is included within 90°. On the left side of the central line, the directions comprise every point of the compass. On the line A C, the bearings commence N. 55° W., pass through N. 16° E., and end N. 62° E. This corresponds with the mean of the observations on page 285. A little farther to the left, the

bearings would begin from the west, and end northeast or east. Still farther they would begin southwest, and end east or southeast; and upon the extreme margin the wind would blow towards southeast. All this agrees remarkably well with observation. The house and barn H lay strewed between the directions N. 88° E., and S. 50° E.

We may now perhaps explain some of the anomalies noticed in the bearings on page 285. The anomaly in group third may perhaps be due to a more easterly motion of the whirl than at the fall of the fourth tree, or to the fact that being nearest the vortex the proper motion of the whirl was greatest, and the bearing of a tree consequently less influenced by the progressive motion of the tornado. This last cause might perhaps explain the anomalies in groups sixth and eighth. The anomaly in group fourteenth may perhaps require us to admit a slightly undulatory motion of the vortex, such as is frequently seen in small whirlwinds. In group tenth also, although the rotation is uninterrupted, the variety of directions seems most naturally explained by such a supposition. I think it moreover not improbable that the direction of the wind was materially different at different elevations above the earth's surface upon the same vertical line, so that the bearing of a prostrate tree might be influenced by its height.

We also observed the bearings of a good many fallen trees in the vicinity A A, B B, but the trees were here more sparse. Near A A, the bearings were all comprised between N. and N. 28° E. Near B B, the directions were about the same as at O O; but from their distance the trees seldom lay upon each other. Near the northwest border were measured N. 84° E., N. 88° E., N. 89° E., East, S. 82° E. In the vicinity F F the following observations were made.

1.	N. 42°W.	4.	N. 67°W.	5.	N. 64°W.	8.	N. 62°W.
	N. 18 E.		N. 64 W.		N. 24 W.		N. 70 E.
2.	N. 80 W.		N. 62 E.	6.	S. 70 W.		N. 72 E.
	S. 75 W.*		N. 66 E.		S. 87 E.		East.
3.	N. 16 W.*		S. 65 E.	7.	N. 80 E.		
	N. 82 W.				S. 50 E.		

These observations are similar to those made near O O, and present two similar anomalies, which I have marked with an as-

terisk. They may perhaps be due to the increase of velocity of the wind in approaching the vortex, as before remarked.

We next proceeded to the centre of Kirtland, where we undertook a similar investigation of the phenomena of the storm. Considerable rain fell here for about ten minutes—it was mingled with hail not much larger than a pea—broke some panes of glass —not enough to whiten the ground. Had rained about five minutes before the most violent blast came on. The high wind did not last above ten minutes—the most violent blast only three or four seconds. The air was filled with leaves and sticks, which made it quite dark, so that it was impossible to see but a short distance. It lightened three or four times before the blast—the thunder was quite loud. The best idea of the destruction will be gained by inspecting Fig. 6, Plate IV. A, was a log-house blown down; B, log-house demolished; C, barn unroofed; D, barn unroofed; E, barn and shop unroofed, house injured; F, north roof of barn taken, south roof uninjured; G, house uninjured; H, house unroofed, barn injured; I, north roof of one barn taken, entire roof of a second barn, house little injured; J, house shattered, wing entirely destroyed, barn demolished; K, house demolished; L, north roof of shop taken, shingles of barn all flew off at once like a flock of pigeons; M, house unroofed, child two or three years old crushed by the falling of the chimney, the only death occasioned by the tornado; N, Presbyterian meeting-house; east side moved north twenty two feet, the west side, having the cupola, moved twelve feet—about one third of the north roof taken and otherwise badly shattered; O, north roof of house taken, two barns unroofed; P, house unroofed; Q, house unroofed; R, roof injured; S, north roof taken, and chimney blown off. Where the ridge run east and west the north roof only was usually taken; where the ridge run north and south both were generally taken. The fact here stated was found to hold generally true, that the leeward roof was taken in preference to the windward one.

The following bearings of trees were taken in crossing a forest from T to U. At first few trees were found lying upon each other. The bearings were N. 65° W., N. 17° W., N. 12° W., N. 5° E., N. 7° E., N. 8° E., N. 10° E., N. 11° E., N. 15° E., N. 15° E., N. 20° E., N. 62° E., N. 78° E., N. 80° E. The following groups of trees lying upon each other were observed.

1	N. 2°W.	5	N. 32°W.	9	N. 32°W.	13	N. 48°W.
	N. 10 E.		N. 25 E.		N. 18 W.		N. 5 W.
2	N. 38 E.	6	N. 68 W.		N. 22 E.	14	N. 25 W.
	North *		N. 48 E.	10	N. 30 W.		N. 2 W.
3	N. 48 W.	7	N. 52 W.		N. 8 E.	15	N. 78 W.
	N. 22 W.		N. 70 W.*	11	N. 62 W.		N. 17 W.
	N. 18 W.		N. 11 W.		N. 18 W.	16	N. 40 W.
	N. 11 W.	8	N. 32 W.	12	N. 18 W.		S. 65 W.*
4	N. 32 W.		N. 2 E.		N. 8 E.		N. 25 W.
	N. 47 E.						

There is a perceptible difference between the phenomena here and at Mayfield. Upon the southeast side of the track the average direction is about N. 15° E. At Mayfield, it was N. 35° E. On the northwest side of the track, the average direction of the bottom trees is N. 43° W., and of the top trees N. 5° E. The phenomena are of the same kind, but the velocity of the whirl is much reduced. The rotation of the wind is still in the same direction. There are three anomalies here to be noticed, the most remarkable of which is the second tree in group sixteen, but as this was a small one its direction was probably influenced by the interference of other trees.

Our next particular survey was made at Painesville. The tornado passed directly over the southeast part of the village, but its greatest violence does not appear to have reached the earth's surface, as it did but little damage in the town. It blew off the balustrade of the Presbyterian meeting-house; took off a part of the shingles from an old roof, and removed the roofs of some small out-buildings. Hail fell as large as a walnut—quite solid, enough to whiten the ground—and broke a good deal of glass. Enough rain fell to lay the dust in summer—some thunder and lightning. Lasted but a few minutes. In the woods northeast of the village, on the opposite side of Grand River, there was a general prostration of the timber. The following bearings were observed, crossing from the southeast to the northwest side.

1	N. 57°E.	5	N. 30°E.*	9	N. 5°E.	14	N. 17°W.
	N. 72 E.		N. 12 E.		N. 22 E.		N. 7 W.
2	N. 35 E.	6	N. 11 E.	10	N. 4 W.	15	N. 11 E.*
	N. 55 E.		N. 15 E.		N. 35 E.		N. 5 E.
	N. 61 E.	7	N. 20 E.	11	N. 5 E.	16	N. 5 W.
3	N. 48 E.		N. 52 E.		N. 22 E.		N. 18 E.
	N. 62 E.	8	N. 9 W.	12	N. 9 W.	17	N. 15 W.
4	N. 38 E.		N. 7 E.		N. 2 W.		N. 22 E.
	N. 70 E.		N. 18 E.	13	N. 22 W.		N. 47 E.
					N. 12 W.		

Here is the same rotation as at Mayfield and Kirtland, but the whirling motion is well nigh masked by the progressive motion of the tornado. There are but two anomalies, and these are so small as hardly to be entitled to the name. The mean direction upon the southeast side is N. 39° E. which is a little more easterly than at Mayfield. The mean direction of the bottom trees upon the northwest side is N. 7° W.; of the top trees N. 14° E. The phenomena are still of the same kind as at Mayfield and Kirtland, but less distinctly marked.

There have frequently been remarked in tornadoes places of interrupted violence. This was the case in the present instance, though I think this phenomenon may be ascribed in a good degree to inequalities in the surface of the ground. Thus at Mayfield, near A A, B B, the wind was well nigh irresistible. As the ground began to descend towards the river, the tornado seemed to continue nearly on the same level, and only reached the tallest trees. At about half a mile from the river, on the west side, it again struck the ground, and presently exhibited its greatest violence. As it met the hill on the east side of the river, it was forced to rise again, and near the brow of the hill its violence seemed fully equal to the greatest violence in the valley. The upward motion it had received in ascending this hill appears to have continued for some time afterwards; for although the subsequent ground was nearly level, yet at a distance of about a mile from the river, the trees were not generally uprooted, but broken off at an elevation of from twenty to forty feet. Again, at Painesville little damage was done to the town, while in the woods on the opposite side of the river, and nearly on the same level, almost every tree was prostrated.

I do not find, then, a uniform diminished action on the summits of hills, and increased action in the bottoms of valleys, as has been remarked in other cases. There were, however, some facts in the vicinity of the house L at Mayfield quite remarkable. Although the house was swept off by a wind having nearly the velocity of a cannon ball, several apple trees near by were not uprooted, and a row of bee-hives in the open air sustained no great damage. They were blown nearly a rod, and some so much injured that it was thought best to empty them entirely of their honey; but three hives are still in their places filled with bees, and bear no marks of the passage of a tornado. The barn

was about northeast from the hives, and probably offered them considerable protection. Their weight, which was about one hundred and forty pounds each, was probably their greatest security. Dean's wagon stood ten or twelve feet from the corn house towards his dwelling, and was not moved at all, although it might have been pushed along with one hand. The shelter was entirely blown away. So also the house D was but slightly injured, while the barn E, distant sixty six paces, was entirely demolished.

It has been remarked of other tornadoes, that objects did not seem to fall with the ordinary velocity of falling bodies. Some similar instances were observed at Mayfield, as for example the boy who was snatched out the house L and deposited uninjured at a distance of fourteen rods. There were other cases, however, in which bodies plunged into the earth as if shot from a cannon, as for example the clapboards into the side hill.

Another fact well worthy of remark is, that when the ridge of a building was turned towards the wind, both slopes of the roof were usually taken; but when the ridge was at right angles to the wind, if the body of the building was spared, the leeward slope was taken, usually entire, while the windward slope remained uninjured or escaped with the loss of a few shingles. The principle here stated is not peculiar to tornadoes. Many cases have been observed in which a rectilinear current produces the same effect. That the windward slope should stand in preference to the leeward is not strange, for the pressure of the blast holds it in its place. The elevation of the leeward slope has been ascribed to currents of air, which, forcing their way through the crevices of the building, impinge upon the opposite side and roof with sufficient force to burst an opening. That some such effect may take place I will not absolutely deny; yet the cause seems inadequate to explain the phenomena. Currents such as are here supposed should act with greater force against the vertical leeward side than against the roof, which is very oblique to the wind's progress. We ought then to find the leeward side forced off in preference to the roof, particularly as the weight of the roof coöperates with the nails to hold it in its place; and especially should this be true of barns, where the vertical boards are not in general very firmly secured. Not a single instance of this kind has however been observed. Moreover, the meeting-house

at Kirtland had a tight ceiling of plaster, without any opening to the garret; so that currents of air which might find their way into the building might strike upon this ceiling, but would be effectually cut off from the roof. The ceiling was uninjured, but a large hole burst in the roof. The reason then assigned, though admitted to be a *vera causa*, is wholly inadequate to explain the phenomenon. I ascribe it to a rarefaction of the air. A current of air forcibly impelled over an obstacle like the roof of a building, by friction drags along with it the air lying upon the leeward side of the roof, producing a partial rarefaction which might easily be sufficient to lift the roof. The degree of rarefaction requisite to produce the effect is much less than some might imagine. Suppose a barometer above the roof to stand only *one tenth* of an inch lower than within the building, we have an upward force of seven pounds per square foot, a force probably sufficient to throw off a considerable part of the barn roofs of Ohio.

In the tornado which occurred at Stow in 1837, a circumstance was remarked which I had never seen noticed before, that several fowls were picked almost clean of their feathers. In the New Haven tornado of 1839, the same fact was noticed. I made particular inquiry on this point at Mayfield. Four geese were found near Mr. Dean's house lying dead among the rubbish, without any perceptible loss of feathers. I heard of one goose so far stripped that its remaining feathers were not considered worth saving: its legs and wings were both broken. A turkey also was found lodged in a tree near Dean's, with the loss of about half of its feathers, and its bones broken. As electricity has been maintained to be the efficient cause of tornadoes, I have inquired whether this loss of feathers could be due to electric repulsion. I think not—Because first, the effect is not uniform; many fowls near the centre of the Mayfield tornado were killed but did not lose their feathers. Secondly, although electricity was manifested in the passage of the tornado, its intensity did not appear to be equal to that of a common summer thunder-shower. Thirdly, the effect may be explained by other causes known to be in operation. The gun mentioned on p. 284, was charged with five ounces of powder, and a chicken just killed added for a ball. As the gun was small, it was necessary to press down the chicken with considerable force, by which means it was probably somewhat bruised. 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 is computed at five hundred feet per second, or three hundred and forty one 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. If I could have the use of a suitable gun I would determine this velocity by experiment. It is presumed to be not far from a hundred miles per hour. But it is said that a fowl carried off in a tornado floats with the same velocity as the current, and suffers no violence. This is only partially true. There is abundant evidence that in the Mayfield tornado the wind, at points but moderately distant from each other, was blowing in opposite directions and with very unequal velocities. A fowl floating in the air would at one instant fall in with a current moving with an accelerated and the next instant a retarded velocity. It might thus experience very sudden changes of velocity, amounting perhaps to a hundred miles per hour. The explanation here given derives confirmation from the fact that the fowls observed at Mayfield had both their legs and wings broken. Mr. Espy states, that he had been informed that fowls thus stripped of their feathers have not been killed outright, but have been seen walking about naked after the tornado passed.* Such was not the case at Stow or Mayfield, so far as I have been able to ascertain; and I have heard of no other instance in which the phenomenon has been observed except at New Haven.† A

* At a subsequent date Mr. Espy communicates the following: "The information which I have received concerning the chickens and turkies remaining alive after being stripped of their feathers in a tornado, is verbal, and I have no doubt of the fact, though I cannot refer you to the authority by name. A gentleman told me that he saw turkies walking about naked after the passage of a tornado which occurred many years ago; but he added that *they soon died.* This was the first intimation I ever had of the fact, and he told it me as a strange phenomenon which came under his own observation."

Prof. C. G. Forshey, in a letter just received, writes thus:—"After the passage of the Natchez tornado in 1840, I saw many birds dead, generally not stripped; but a wild turkey I examined was almost featherless, and lying in a field half a mile from the woods. It did not occur to me to see if the bones were broken."

† I am informed by Mr. Herrick, that the fowls there were said to have run a few rods after being deplumed, but they soon died.

flock of fifteen sheep belonging to Mr. Alderman and near his house, was overtaken by the tornado. Six were killed outright, their legs were broken, and in many cases their entrails torn out; several of the living also escaped with broken legs.

Having thus discovered the true 'experimentum crucis' for analyzing the phenomena of tornadoes by observations of groups of trees lying upon each other, I felt desirous of applying the same test to the Stow hurricane, hoping it might remove the obscurity which still rested upon that subject. I immediately set out to re-examine the track. The traces of the hurricane were almost entirely obliterated, with the exception of those left upon the trees; and upon the north side of the east and west road, these being mostly fruit trees, had long since been righted. But in the front on the south side, particularly in front of the house G, (see this Journal, Vol. xxxiii, p. 369,) the trees remained almost without exception undisturbed, and I had no difficulty in recognizing individuals which I had before observed. The four trees particularly mentioned, p. 373, line 16, are undisturbed, as the track of the tornado is here as distinctly marked as it was the day after its occurrence. The following groups of trees were measured, the first being near the south border, the remainder towards the centre.

1	N. 30°W.	7	N. 46°W.	13	N. 45 W.	20	N. 43°W.
	N. 19 W.		North.		N. 68 E.		N. 22 W.
2	N. 42 W.		N. 46 E.	14	N. 33 W.	21	N. 34 W.
	N. 25 W.	8	N. 45 W.		N. 4 E.		N. 63 E.
	N. 22 W.		S. 43 E.	15	N. 39 W.	22	N. 66 W.
	N. 25 E.	9	N. 60 W.		N. 33 E.		N. 75 W.*
3	N. 40 W.		N. 32 E.	16	N. 63 W.		N. 38 W.
	N. 29 E.	10	N. 62 W.		N. 51 W.	23	N. 6 W.
4	N. 43 W.		N. 25 E.		N. 38 E.		N. 55 E.
	N. 39 W.		N. 54 E.	17	N. 32 W.	24	N. 37 W.
	N. 19 E.	11	N. 73 W.		N. 77 E.		N. 34 E.
5	N. 22 E.*		N. 30 W.	18	N. 40 W.	25	N. 43 W.
	N. 9 E.		N. 26 W.		N. 1 E.		N. 20 E.
6	N. 32 W.	12	N. 52 E.	19	S. 75 W.		
	N. 82 E.		N. 66 E.		N. 19 E.		

Here we have a well marked rotation of the wind, and only two anomalies, amounting to 9° and 13°. Mean of the bottom trees, N. 43° W.; top trees, N. 32° E.; remaining trees, N. 17° W. These are all upon the south side of the central line, or very near the centre. On the north side of the track I have no new

observations. Those recorded in my former article range between S. 54° W.; South; and S. 68° E. Near the centre were two trees, S. 82° W., N. 86° W. These trees, it will be observed, lie parallel with the track and almost directly in the centre. (See this Journal, Vol. XLII, p. 12.) This southwest wind on the north side of the track probably preceded the southeast, as the westerly wind preceded the easterly on the south side. We may then proceed to construct a diagram of the wind's motions as at Mayfield. The result is shown, Plate IV, Fig. 7. The motion is decidedly centripetal, with a slight tendency to revolve *with* the sun.

In order to obtain further light on the subject of tornadoes, I have paid some attention to those small whirls which are not uncommon in warm days, which last but a few seconds, and elevate light objects, such as leaves, dust, etc. March 31, 1838, about $11\frac{3}{4}$ A. M., I was walking alone in Hudson about half a mile west of the college. My attention was attracted by a roaring noise in a neighboring wood. I presently perceived a small whirlwind advancing into a cleared field, and marking its course by dead leaves which were elevated into the air to the height of pretty tall trees, and which revolved spirally upward *in the direction of the sun's motion.* The whirl advanced from S. 30° E. to N. 30° W., which was the direction of the wind at that time in this place, being somewhat of a ravine, although upon the hill at the college soon after, the wind was northwest. I followed it without any difficulty for several rods, until it came to a wood, where its force was very much broken, and it soon disappeared. I stood in the middle of the whirl and near its centre, and the wind blew with such force that I was obliged to hold my hat on, although the whirl advanced not more than three or four miles per hour. It crossed a small brook about five feet wide quite slowly, throwing up spray and a considerable quantity of water about a foot high, and for a diameter about the same. It lasted but a second or two, for the whirl passed nearly perpendicularly across it.

Aug. 22, 1838, 2 P. M. A whirl formed in the road directly in front of the college. It moved a rod or two from north to south, whirling *in the direction of the sun.* The motion was quite rapid, and the whirl increased in dimensions from below upwards. Dec. 29, 1838, 10 A. M., a snow whirl revolved *with* the sun. July 11, 1839, 10 A. M., a small sand whirl revolved in a direction

contrary to the sun's motion; moved towards the northeast. Aug. 3, 1839, several sand whirls formed in the road, moved but a short distance, yet all revolved in the *same* direction with the sun's motion. Aug. 4, 1839, another revolved in the *same* direction. May 8, 1840, a whirl revolved in the *opposite* direction. Having satisfied myself that these small whirls revolve indifferently with or against the sun, I took no further pains to record particular dates, but have since often observed them revolve in *each* direction.

In all the preceding cases, including those of Stow and Mayfield, there are two distinct motions—first the progressive motion of the meteor, and secondly its own peculiar motion; and this last may be resolved into three others, viz. a vertical motion, and two horizontal, one in the direction of a radius, and the other at right angles to it. These four motions appear to bear a variable ratio to each other. The upward and centripetal motions no where disappear, yet they are seen in very unequal strength at Mayfield and Painesville; while the motion at right angles to a radius is strongly marked at Mayfield, but barely distinguishable at Stow. By pursuing the method of investigation exemplified in this article, it is believed that the peculiarities of a well marked tornado can hardly escape detection. May we not then indulge the hope that the much vexed question, whether tornadoes are whirlwinds, will soon be settled? That some tornadoes are whirlwinds certainly cannot be denied. That the motion at right angles to a radius is sometimes quite small compared with the centripetal motion, seems equally clear. That this motion in a tornado should ever become mathematically nothing, appears infinitely improbable.

I have collected below, in a tabular form, all the tornadoes in this country with respect to which I have been able to obtain any important information, and have introduced some of which I could only furnish the dates. It is hoped that those who have the means will contribute to filling these blanks.

TORNADOES IN THE

	Date.	Hour.	Temp.	Attendant phenomena.		Course
Natchez, Miss.,	1823 May					
Morgan, Ohio,	1823 June 19	9 1-2 P. M.	unusual heat	lightn'g	rain	East
Natchez, Miss.,	1824 May					
Maury Co., Tenn.,	1830 Mar. 30					
Shelbyville, Tenn.,	1830 May 31	midnight	sultry	lightn'g	rain in torrents, but *no* hail	East
Kingston, Miss.,	1832 May 7					
Springfield, Ohio,	1833 April 11					
N. C.,	1833 Oct. 12					
Utica, N. Y.,	1834 Aug. 14	4–5 P. M.	hot	lightn'g	rain and hail	East
Kinderhook, N. Y.,	1835 June 19	4 P. M.	84°	lightn'g	rain	N. E.
N. Brunswick, N.J.	1835 June 19	5 1-2 P. M.	82	lightn'g	rain and hail	N. 80° E.
Pine Plains, N. Y.,	1837 June 3	6 P. M.	sultry	lightn'g	rain	East
Stow, Ohio,	1837 Oct. 20	3 A. M.	75° 2 P.M. on 19th	lightn'g	rain	East
Belfast, N. Y.,	1838 July 25	P. M.	hot	lightn'g		S. of E.
Providence, R. I.,	1838 Aug. 30	4 P. M.		lightn'g	rain	E. S. E.
Maumee, Ohio,	1839 May 23			lightn'g	rain	N. E.
New Haven, Ct.,	1839 July 31	noon	76°	lightn'g	rain and hail	N. 50 E.
Mobile, Ala.,	1840 Mar. 24	7 P. M.	sultry	lightn'g	rain and hail 1 inch	S. 80 E.
Natchez, Miss.,	1840 May 7	2 P. M.	80°	lightn'g	rain 8 2-3in.: very large hailstones	N. 60 E.
Mayfield, Ohio,	1842 Feb. 4	4 1-2 P. M.	60	lightn'g	rain and hail	N. 33 E.
Tuscaloosa, Ala.,	1842 Mar. 4	6 A. M.			copious rain	N. of E.

From the preceding table it may be inferred, 1. That no season of the year is exempt from tornadoes, but that they occur most frequently in May and June. 2. That they occur chiefly between noon and sunset. Only three out of fourteen occurred during the night; and 3. That the temperature at the time is unusually elevated. This is a generalization of considerable importance, that tornadoes are to be expected only at high temperatures, and if they occur in cold months, the temperature is unusually high for the season. 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 about twelve degrees north of east. 6. Their average breadth is about one hundred and twenty rods; length fifteen miles; velocity of progress when violent about thirty miles per hour; duration of destructive violence forty five seconds. The duration of destructive violence may be computed from the breadth and velocity of the tornado, on the supposition that its base is circular; and probably this result is more to be depended upon than the estimates of observers, which are generally made under the influence of fear and likely to be exaggerated. 7. Light objects are frequently transported by the wind a distance of from three to twenty miles. 8. Very few human lives are lost by tornadoes. With the exception of the Natchez tornado, the average is but about one to a tor-

UNITED STATES.

Breadth in rods.	Length in miles	Velocity in miles p'r hour	Duration in seconds.	Light objects carried miles.	Persons killed.	Other effects.
80–100	2			board 2 1-2		cloud of the color of a glowing [oven.
not ov'r 320			15	shingles 3 book 7	5	cloud permanently luminous, and of the color of red hot iron.
30–80				1-4 mile		
40–80	17 1-2	27	25 computed	reticle 7 letter 20		leeward roofs taken, Raritan [dried.
70–320	about 30			23	0	
40–80	3			sheet 3 frock 5	4	leeward roofs taken, fowls deplumed.
240–480	20				0	Genesee dried.
20–25	7	8–10	25 computed		0	leeward roofs taken, water raised.
60	8	40	30 estimated 17 computed	cape 3	0	fowls deplumed.
10–40	3–4				1	
160	25	30	few	sheet tin 20 window 30	48 in city 269 on riv'r	leeward roofs taken, fowls deplumed, water raised.
100–265	24	34	75 computed	clapb'rds 8	1 1	leeward roofs taken, fowls deplumed, Chagrin dried.

nado. This result is quite remarkable considered as a philosophical fact. At Natchez the loss of life was very great, but the circumstances were peculiar. Those on the river were chiefly travellers, and perished mostly, if not all, by drowning. The population of the city is 4800, that is, $\frac{1}{100}$th of the permanent population included within the limits of the track were killed. This is probably not greatly above the average, and it is certainly remarkable that ninety nine in a hundred of those on dry land should survive. 9. Leeward roofs are generally taken in preference to windward. 10. Fowls are frequently picked of most of their feathers. 11. In passing over ponds or rivers, water is invariably raised in considerable quantity. This last remark is sufficient to show that water-spouts and tornadoes are essentially the same.

The tornado at Morgan in 1823, is thus described by Deacon Beach. About eight o'clock, the sky became overcast with a dark cloud, attended with plentiful rain and some lightning. The rain suddenly ceased, but the cloud remained, covering the whole heavens and producing intense darkness. The air was perfectly still after the rain for about an hour, and the heat unusually great. At half past nine he heard a roaring as of very 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 unbroken above, apparently within two or three miles, and moving rapidly in the direction of his house. The brightness of the cloud made the face of things light above the brightness of a full moon. Having turned into the house, he was engaged in securing it, when the tornado passed, taking the roof and chamber floor, and many articles from below. It was a log house. 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. The passage of the tornado seemed instantaneous, but the light of the cloud continued for more than a quarter of an hour. Dea. B. was able to read in his Bible, which he found many rods from his house, at least *ten minutes* after the storm had passed.

Judge Griswold saw the same phenomenon. The cloud appeared to him funnel-shaped, apex downward, from which a stream of fire apparently issued.

The appearance of the cloud, as here described, corresponds very well with the account of the Shelbyville tornado, as given in this Journal, Vol. xxxi, p. 258. The cloud is said to have been permanently luminous, and of the color of red hot iron. This seems to indicate a continued flow of electricity from the clouds to the earth. The Stow hurricane is the only remaining one in the preceding list which occurred in the night, and I have not been able to learn that any one observed the appearance of the cloud.

In this article I have indulged in no speculations on the origin of the Mayfield tornado. This would require an investigation of the general phenomena of the storm which accompanied the tornado. I am collecting materials for such an investigation, as also of the storm of the 16th of the same month. I wish observations from the 1st to 6th inclusive, and also from the 14th to the 18th inclusive, for February, 1842. If any one has barometric observations for this period and will forward them to me by mail, accompanied with a complete copy of all his other meteorological observations for the same interval, they will be most gratefully received. I propose to give not only my own analysis of these storms, but also to publish the observations in such detail that any one may draw his own conclusions from them.


Fig. 5
LAKE ERIE
Painesville
Mentor
Concord
Willoughby
Kirtland
Chardon
Euclid
Mayfield
Chester
Munson
Chagrin R.
Gates'o
Fig 4
Fig. 7.
East

Starky column which accompanied the tornado

ILLUSTRATIONS to PROF. LOOMIS'S PAPER on the MAYFIELD TORNADO.


LAKE ERIE
Fig. 5
Mentor
Concord
Painesville
Grand R.
Willoughby
Kirtland
Chardon
Chagrin R.
Track of the tornado
Euclid
Mayfield
Chester
Munson
Gates
leveland

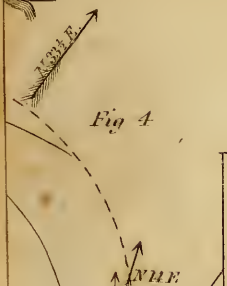
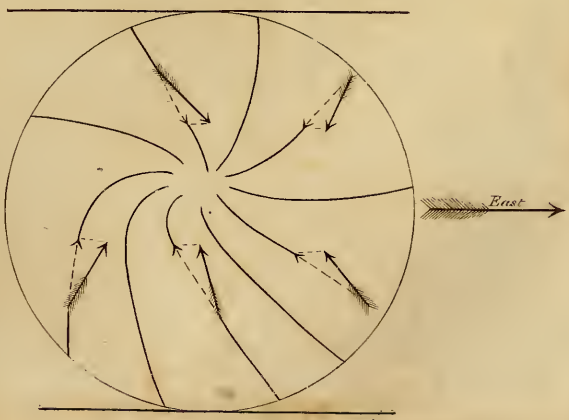

LAKE ERIE
Fig 4
NUE

Fig. 7.


East

Smoky column which accompanied the tornado

Fig. 3

Fig. 1

Fig. 6

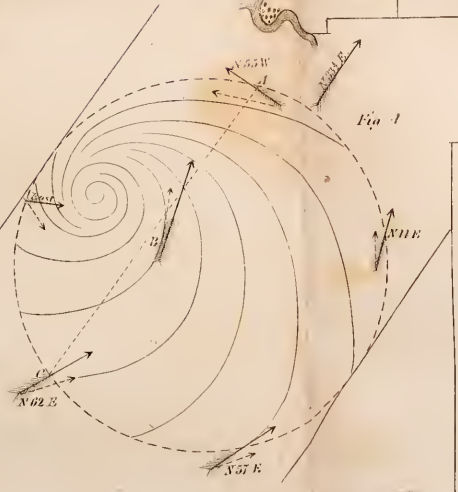


Fig. 4

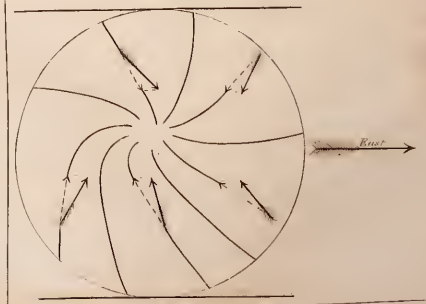


Fig. 7.

Fig. 2

Profile of the Chagrin Valley where it was crossed by the Tornado

ILLUSTRATIONS TO PROF. LOOMIS'S PAPER ON THE MAYFIELD TORNADO.