SOMETHING ABOUT TORNADOES.[1]

WHERE atmospheric equilibrium is violently discomposed and the agitation covers but a very limited area, the centripetal force becomes much greater than in the case of cyclones. The gyrations are exceedingly rapid and very near the centre; in fact, the violence is greatest at the centre, and diminishes rapidly to the external parts of the disturbance, where the gyrations cease altogether. This form of disturbance is called a tornado. In order that conditions may become favorable for tornadic development, the atmosphere must assume the unstable state. This state will be engendered whenever the rate of decrease of temperature is greater in the surrounding quiet air than it is in the mass of ascending air. The adverse or counter movement of northerly and southerly winds induces the unstable state, because it makes the rate of decrease of temperature greater in the quiet air than in the column of ascending air; that is, the upper strata of the air will be made colder, and the lower strata warmer.

What are known as local storms, under this class of motions of the atmosphere, are not affected by the rotation of the earth upon its axis, because the area of disturbance is too small. The progressive motion of tornadoes to the north-east arises from the fact, that, as they always form in the south-east quadrant of an area of low barometer, they must come within and under the influence of the general drift of the atmosphere on that side of the "low," which, according to the law of atmospheric circulation about the centre of an area of low pressure, is always to the north-east.

The condition of tornado-formation in regard to heat is simply that of unstable equilibrium for saturated air at the existing temperature, the other condition being that the air shall have a gyratory motion relative to some central point, arising from any cause whatever. In the unstable state, the lower strata of the atmosphere are liable to burst up through the upper layers at any point where there may chance to exist some slight predetermining cause, which is never wanting, arising from local conditions of temperature and moisture.

When an upper motion of the atmosphere is started at any point, the air thus engaged is kept warmer, and therefore rarer, than the region immediately surrounding it. This continues as long as the ascending current is supplied with air nearly or quite saturated, or until, from an inversion of the air in the lower strata, the state of unstable equilibrium is changed. The violent whirling motion of the air which characterizes the tornado is dependent upon a pre-existing disturbed and gyrating state of the atmosphere. The case is somewhat similar to that of water in a shallow basin running out through a hole in the centre. If the initial state of the water is that of perfect rest, it flows directly toward the centre with a very slow velocity; but, if there is the least initial disturbance of a gyratory character when the water first begins to flow, it soon runs into rapid gyrations around that centre.

As we have shown, therefore, there are two principal conditions upon which the occurrence of tornadoes depends, and in the absence of either of which they cannot take place. The one is the state of unstable equilibrium of the air, and the other a circulation motion with reference to any centre of disturbance. It is not imperative that the central area shall be stationary, but simply that the motion of the air around it shall be such that when the latter is drawn in toward the centre it will take a gyration around it. When these two principal conditions are present, there is scarcely ever wanting the secondary condition, which, through the effect of some slight initial disturbance, gives rise to an upward burst of the air through the overlying strata. The places and time most favorable to the development of unstable equilibrium and a gyratory motion of the atmosphere are those in which tornadoes are most likely to occur. Of these two conditions, the unstable equilibrium is the most important, since it more rarely occurs than the other, which is scarcely ever so entirely absent as not to give some slight gyratory motion, which becomes violent very near the centre. The question naturally occurs, Where are the places on the earth's surface, and what is the time when conditions are most favorable for the development of tornadoes?

[1] Portion of a paper read before the National Geographic Society of Washington, Nov. 16, 1888, by J. P. Finley.

First, as to places. These are found where, in the general motions of the atmosphere as affected by continents and mountain-ranges, currents of the air at the earth's surface, which come from a warmer latitude, or at sea from a much warmer continent, are caused to flow under the colder upper strata, where the normal motion is nearly eastward, and where consequently the temperature is the normal one, not affected by such motions as take place in the lower strata: in other words, tornadoes are most likely to occur in regions where warm, moist air flows underneath a colder and dryer upper strata, coming from another direction. Such regions are found particularly in the Mississippi, Missouri, and Ohio valleys, and in Alabama, Georgia, and the Carolinas. The other condition of the atmosphere indispensable to the formation of tornadoes — viz., a relative gyratory motion with regard to any point — is found to an unusual extent in the regions above named, especially in the winter season, which fact accounts for the frequent occurrence of tornadoes in the Southern States during the winter and spring, and occasionally in the Mississippi and the Ohio valleys.

Second, as to time. The summer season is the most favorable for tornadoes, when the interior of the continent is warmed up, and the air of the lower strata is drawn from lower latitudes far up into the northern portions of the country on the eastern side of the Rocky Mountains, and the isothermal curve is deflected very decidedly toward the north. From this cause the temperature of the lower strata of this region becomes much higher than that of the superdominant strata; and, if this condition does not of itself induce the unstable state, it is readily accomplished by the addition of any small effect from some other cause, as from extremely warm weather, in which the earth's surface and the lower air strata become abnormally heated.

The great moisture of the air in the southerly winds is also favorable to the induction of the unstable state, since such a change is more readily brought about in air nearly or quite saturated. The southerly currents curving eastward from the Rocky Mountain and Appalachian ranges give rise to a general air movement of considerable force toward the Atlantic Ocean, as the result of which, cold counter currents pass southward to Texas, east of the Rocky Mountains, and to Florida over the Appalachian range, somewhat after the manner of the Arctic currents which flow southward to Florida, between the Gulf Stream and the coast of the United States.

In the summer season this flow of cold air southward is confined to a comparatively narrow belt east of the Rocky Mountains, for at that time the warm, moist currents of the Gulf are drawn very far to the north and west. At this season the northern part of Texas has the same mean temperature as Minnesota, the isotherms being nearly north and south in direction; and the temperature gradient between the warm southerly winds on one side, and the cold northerly currents on the other, is similar to that of the cold wall between the Gulf and Arctic currents.

In the winter and spring the flow of cold air southward from the higher latitudes extends to the Appalachian range, where it overflows the warm, moist southerly currents from the East Gulf and South Atlantic coast. It is this tendency of the air to flow in contrary directions, where the conditions are most favorable to produce the unstable state of the atmosphere, that pronounces the regions here indicated as the "battle-ground of tornadoes." The word "low," as is quite well known, marks upon the weather-map the centre of lowest pressure as indicated by the barometer and direction of the wind. This is practically the centre of the general storm or atmospheric disturbance.

1. The conditions for the development of tornadoes are most favorable in the south-east quadrant of a "low:" in fact, they are not to be looked for in any other portion of the general disturbance. 2. Tornadoes very generally accompany a "low," for the reason that the condition of unstable equilibrium necessary in the formation of a tornado is also required in the "low," at least in the upper cloud-region. 3. The unstable state in a "low" very rarely extends down to the earth's surface, so that tornadoes are not necessarily visible in every general storm. 4. There are frequently secondary whirls, incipient tornadoes, in the cloud-region of a "low," the effects of which do not reach down to the earth's surface, and the only visible effect above is the formation of a local

cloud a little denser and darker than the clouds are generally. 5. A hail-storm is an incipient tornado in the cloud-region of a "low." 6. Tornadoes always occur in the south-east quadrant of a "low," and at distances generally of from 200 to 500 miles from the centre. They are not likely, however, to occur in the south-west and north-west quadrants of a "low," because the currents and counter currents there are nearly east and west; and hence the effect is neutralized, tending neither to produce nor destroy the unstable state. As the "low" progresses eastward, the region of country lying, on the average, about 350 miles to the south and east of the centre of the general storm at any time, is the region within which tornadoes may be expected.

The destructive violence of a tornado is sometimes confined to a path a few yards in width, or it may widen to the extreme limit of eighty rods. The tornado, with hardly an exception, occurs in the afternoon, just after the hottest part of the day. The hours of greatest frequency are 3.30 to 4 P.M., and 4.30 to 5 P.M. The destructive power of the wind increases rapidly from the circumference of the storm to its centre. Observations with a single barometer will not indicate the approach of a tornado, however near the position of the instrument to the path of the storm; and such observations are of value in this connection, only when a number of them are displayed upon the weather-map. The tornado season includes the months of March, April, May, June, July, August, and September. There are, however, cases in a long series of years where tornadoes have been reported every month of the year. The months of greatest frequency, as determined from a record of 206 years, are April, May, June, and July. The month of greatest frequency is May, April coming next on the list. The State in which the greatest number of tornadoes have occurred is Missouri, followed next in order by Kansas and Georgia. The 425 tornadoes and "windfalls" recorded in Wisconsin far exceed the number from any other State; but little weight can be given this fact, owing to the want of a similar investigation of the subject of "windfalls" in other States. The violence of tornadoes expressed relatively by States places Missouri first, succeeded by Iowa and Alabama. By "violence" in this sense is meant the most completely developed storms with perfect conditions longest sustained.

Considering the entire record of eighty-eight years (years of record from 1682 to 1888), nearly 4,000 persons have been reported killed, and 6,000 injured. This record is very imperfect, owing to the large number of cases in which the killed and wounded were not definitely reported. The States in which tornadoes have proved the most destructive to life are in relative order as follows: Missouri, Mississippi, Iowa, Illinois, Minnesota, Wisconsin, and Ohio.

Considering the reported valuation of property destroyed, the following States have experienced the most destructive storms, and in the order named: Missouri, $94,325,000 in forty-seven years; Ohio, $87,737,500 in eighty-four years; New York, $67,000,000 in on hundred years; Kansas, $64,000,000 in twenty-nine years; Georgia, $56,500,000, in ninety-three years; Minnesota, $50,750,000 in thirty-three years; Iowa, $49,575,000 in forty-five years; South Carolina, $46,875,000 in one hundred and twenty-seven years. These values are necessarily approximate, owing to the imperfect reports, and it is believed that they fall considerably short of the actual amount of loss.

It is a difficult matter to obtain reliable estimates of the actual value of property destroyed by tornadoes in the United States, since the date of the earliest records; viz., June, 1682. Although the average yearly occurrence of these storms has probably remained unchanged, and will continue so, yet the value of the property subject to destruction by them has increased enormously, and the amount is constantly enlarging as the country advances in wealth and population. Where fifty years ago the tornado swept a barren plain or trackless forest, it now crushes and overwhelms prosperous cities, and devastates rich and populous agricultural districts.

The approximate aggregate loss to property by tornadoes, considering the number of storms reported, is nearly one billion of dollars. Considering the number of years embraced in the period of observations and the average yearly number of tornadoes, the amount is nearly ten billions of dollars. This estimate is probably in excess of the actual loss, because no allowance is made for the many storms which have occurred since 1682 without appreciable waste. Taking the past thirty years as affording more satisfactory information, and considering the average yearly occurrence of tornadoes as 146, the approximate aggregate property loss foots up about two billions of dollars.

A comparison of yearly values, as obtained from carefully prepared tables showing the number and geographical distribution of tornadoes, might lead one to the conclusion that these storms were on the increase. Such a deduction would certainly be erroneous, and for the following reasons. First, From a careful investigation of the origin of tornadoes and their geographical distribution, there is every reason to believe that these storms were as frequent and violent two hundred years ago as now. Moreover, there appears to be no cause for any unusual change in the annual frequency of tornadoes for a like period to come. Second, It must be considered that during the past ten years the Signal Service has had great facilities for collecting reports; and the rapid growth of the country, with a greater zeal of the press, has brought to light the occurrence of many storms which otherwise would not have been reported. Third, The statistical tables are not sufficiently complete, especially prior to 1875 (without which period it would not be safe to make deductions), to permit of reliable conclusions as to periods of maximum and minimum occurrence. It is not unlikely that such variations exist, and that they depend upon the relation of heat and moisture to the general condition of the atmosphere. The more frequently the unstable state of the atmosphere is produced, together with a relative gyratory motion, the more favorable are the conditions for the occurrence of tornadoes, and *vice versa*. Fourth, In the region between the 95th and 107th meridians, tornadoes still occur without causing much damage, because of their passage over thinly settled portions of the country. Owing to this fact, little attention is given to these storms; but this indifference will soon disappear, as the country rapidly settles up and every appearance of the cloud-monster is marked by death and destruction. Fifth, The years (118) that are missing in the period of 206 years from 1682 to 1887 inclusive are not to be considered as years in which no tornadoes occurred, but as years in which records are wanting owing to failure of observations.

Considering the past ten years (1878 to 1887 inclusive) as furnishing reliable and exhaustive records of tornadoes, and that the period prior to 1878 (196 years, 1682 to 1877 inclusive) is deficient owing to want of facilities in collecting reports, we may give an interpolated value for each of these latter years, as determined from the complete ten-year record. This value is found to be 146, which means, that, on the average, 146 tornadoes will occur in the United States.

Applying this constant to existing records, we have a grand total of storms from 1682 to 1887 inclusive (206 years) of 30,076 tornadoes, instead of 2,435 actually observed and reported. This would indicate a failure to report the occurrence of about 27,641 tornadoes which have probably passed over portions of this country since 1682. In that year a very destructive tornado, with distinct funnel-shaped cloud, visited New Haven, Conn., at 2.30 P.M. on the 10th of June. It is the very long interval of 118 years, during which records are entirely missing, that makes the discrepancy so great in the grand totals.

No well-authenticated case of a tornado has been reported from the region of country lying west of the 105th meridian, and it may be generally stated that these storms do not occur in the United States west of the 100th meridian. The cause for this is found in the lack of favorable conditions, on account of the dryness and the lower temperature of the air, and the want of uniformity in the direction and force of surface currents. Violent straight winds, attended with considerable destruction to property, have been reported several times in the past fifteen years, from southern and central California, Arizona, New Mexico, and Montana.

Much has been said and published concerning the influence of forests upon the occurrence and destructiveness of tornadoes, and many people believe that where timber grows in great abundance, tornadoes cannot occur. By comparing the number of tornadoes in each State with the acreage of forests, as estimated in the last census report, it is found that the latter appear to have no perceptible influence in preventing the occurrence of tornadoes, or in assuaging their violence.

In this connection, it should not be forgotten that the conditions which give rise to the development of tornadoes exist in the cloud-regions of the atmosphere, and not at the surface of the earth. Forests would prevent the occurrence of whirlwinds, because these phenomena depend upon the unstable state of the atmosphere at the earth's surface, where the conditions are favorable for the sun's heat to accumulate in the surface strata of the soil, and thus super-heat the air resting upon it. A heavy growth of timber or rank vegetation will prevent this action of the sun's rays.

Whenever a tornado-cloud encounters a forest, the destruction is complete and terrible. The forces of the tornado-cloud are quickly brought into operation, and maintained continuously while the phenomenon exists. They are not affected by having to meet in rapid succession totally different objects, different in size, strength, shape, materials, composition, structure, relative position, etc.

The width of the path of destruction, as determined from the records of 88 years, varies from 10 to 10,560 feet, the average being 1,369 feet. The length of the tornado-track varies from 300 yards to about 200 miles, the average being 24.79 miles. The velocity of progression of the tornado-cloud varies from 7 to 100 miles per hour, the average being 44.11 miles. These extremes may often occur in different portions of the track of a single tornado. The shortest time occupied by the tornado-cloud in passing a given point varies from "an instant" to about 20 minutes, the average being about 74 seconds.

The month of greatest frequency, that is, the month embracing the largest number of days in which tornadoes occurred, is May. The prevailing direction of the progressive movement of the tornado-cloud is north-east. The vortex wind velocities of the tornado-cloud vary from 100 to 500 miles per hour, as deduced from actual measurements. Velocities of from 800 to 1,000 miles per hour are extremes that have been reported, but may not be altogether reliable. Theoretical velocities of 2,000 miles and over per hour, based upon certain assumed atmospheric conditions, have been deduced. Such velocities are mathematically possible, but not meteorologically probable.

The concomitants of the tornado are, an oppressive condition of the air; the gradual setting-in and prolonged opposition of northerly currents and southerly currents over a considerable area; a high temperature, and the presence of considerable moisture; a gradual but continual fall of the thermometer with the prevalence of northerly currents, and a rise with the predominance of southerly; a rapid decrease of temperature with increase of altitude; a decided gradient of temperature across the line of progressive movement; huge masses of dark and portentous clouds in the north-west and south-west, possessing a remarkable intensity of color, usually a deep green; a remarkable rolling and tumbling of the clouds, scuds darting from all points of the compass towards a common centre; hail and rain accompanying the tornado, the former either in unusual size, form, or quantity, and the latter either remarkable in quantity or size of drops; the presence of ozone in the wake of the tornado; a remarkable roaring noise, like the passage of many railroad-trains through a tunnel.

The cloud generated by the vortex assumes the form of a funnel, with the smallest end towards the earth. This explains the remarkable contraction of the storm's path. Upon reaching the earth's surface, the vortex has four motions: viz., first, the whirling or gyratory motion, always from right to left; second, the progressive motion, generally from some point in the south-west quadrant to some point in the north-east quadrant; third, the curvilinear motion; fourth, oscillatory motion.

The characteristic effects of a tornado are, objects are drawn towards the vortex from every point of the compass; objects passing into the vortex are thrown upwards and outwards by the vortical action of the engaged air; structures are literally torn to pieces by the vortical action of the air, evidence of which is afforded by the fineness of the *débris*, and also its disposition in the storm's path; the *débris* is thrown inward from each side of the storm's path; light objects are carried to great heights and also to great distances; objects are carried inward and upward by the centripetal, and outward by the centrifugal, forces of the vortex; weight and size are conditions which generally present immaterial values to the power of the tornado; persons are stripped of clothing; fowls and birds are denuded of feathers and killed; trees are whipped to bare poles; heavy objects are carried for miles in the air; long and heavy timbers are driven to considerable depths in the solid earth; the vortex is completely filled with flying *débris*; timbers are driven through the sides of buildings; sand and gravel are driven into wood; the strongest trees are uprooted, or twisted off near the roots; men and animals are terribly mangled by contact with flying *débris* and by being rolled over the ground for a considerable distance; in the path of the storm all vegetation is destroyed; railroad-trains are thrown from the track; iron bridges are completely dismantled and carried from their foundations; heavy bowlders, weighing tons, are rolled along the earth; the largest railroad-engines are lifted from the tracks on which they rest; all objects, whether metal or non-metallic, magnetic or non-magnetic, simple or compound, animate or inanimate, are acted upon in a similar manner.

THE SITUATION IN SAMOA.

THE continuous disturbances on the Samoa Islands, and their bearing upon questions of great political importance, give to these islands a special interest. The group consists of thirteen islands, only three of which are of commercial interest, — Savaii, Upolu, and Tutuila. Savaii is the largest island of the three, measuring some 40 miles from east to west by 20 miles from north to south, and having an area of 700 square miles. It has no harbor of any importance, and in this respect it contrasts strongly with Upolu and Tutuila. The little bay of Mataatu, in the extreme north of the island, is the only place where large vessels can anchor; but even it is not safe from November to February. The interior of the island is occupied by two mountain-ranges of volcanic origin. It has no rivers or streams, the water filtering away through the porous soil. Where the mountains approach the coast, the latter is very steep and inaccessible, while in other places a well-wooded strip of alluvial land is found, on which numerous villages are situated. The sterility of the interior of this island has always been a barrier to all settlement or cultivation, and even to the visits of travellers and explorers.

Upolu, which covers an area of 550 square miles, is also mountainous, but it is well wooded and fertile, and possesses several considerable streams, although they are, of course, not navigable. On the northern coast of this island lies Apia, the chief town of the whole Samoan group. It is prettily situated, having a background of mountains thickly wooded, and a foreground of harbor and coral reefs. The harbor consists of two portions, the most westerly being the best for vessels that intend to remain for any length of time, especially during the rainy season. For sailing-craft, a steady breeze is absolutely necessary on entering or leaving the harbor, as a strong current sets along its entrance.

Passing down the coast east of Apia, a succession of beautiful bays are met with. At the distance of from half a mile to two miles from the shore a coral reef protects this portion of the island for nearly twenty miles. At high tide canoes and boats can pass between this and the mainland, and thus a great deal of the insular traffic is carried on.

As seen from the sea, there are not many islands in the Pacific that present a more beautiful or picturesque appearance than Upolu. It shows a bold and majestic front, the central range being not less than 3,000 feet high, and wooded almost to its summit. It is throughout a very fertile island, and fully equal to the best portions of the Fiji group.

Tutuila is about 17 miles long and 5 broad. On its southern side is the deep bay of Pagopago, which almost cuts the island in two. This harbor, which is one of the best in the whole South Pacific, is surrounded by hills from 2,000 to 3,000 feet high. Surrounding the harbor at their base is a small strip of level land. The harbor is half a mile wide at its entrance, and runs north and south for a distance of a mile, when it turns in a westerly direction, and opens out into a fine sheet of water. It is somewhat difficult for sailing-vessels to leave, in consequence of the trade-winds blowing directly into it; but for steamboats it is unsurpassed by