from southerly to northwest it is possible that they may have been caused by the strong convectional currents over the fire being given a rotational motion by the northwest wind.

Property to the value of $15,000,000 was destroyed by fire and wind.

Supplementary note.—Mr. Hissong has sent to the editor five photographs of whirls that accompanied the oil fire. Since these probably constitute a unique record of a phenomenon which is rarely developed to the degree of intensity here met with, the photographs are reproduced, without retouching, and in the same size as the originals. They are arranged in what appears to have been the order in which they were taken.

Following, is an extract from Mr. Hissong's letter which accompanied the photographs:

It will be noted that the funnels were photographed after leaving the smoke pall that lay over the fire, the faint outlines of distant hills being visible in the background. Also that the funnels appear black in the prints although all accounts of eyewitnesses were to to the effect that they were white, or light colored. This is probably due to the fact that the funnels were between the camera and the sun * * *. The camera was pointing due south. The pictures were taken just after noon on the 8th.

Regarding the distance traveled by the whirls: Some dèbris was found on the slopes of the Santa Lucia range about 3 miles northeast of the fire. This range rises rather abruptly to a height of about 2,500 feet above the floor of the valley and undoubtedly some of the whirls were broken up by this range during the night of the 7–8th. No whirls were seen more than a mile from the fire during daylight hours.

Since writing the report I have learned that a house about 4½ miles south of the tank farm was unroofed about 7 a. m. on the 7th by a violent wind. This was probably the same storm that caused the fire. No lightning was noted in that vicinity, however, and no funnel-shaped cloud was seen.

551.515 (492)

AEROLOGICAL EVIDENCE AS TO THE CAUSES OF TORNADOES

[Based on Dr. E. van Everdingen's "The Cyclone-like Whirlwinds of August 10, 1925," which was published in English in Proc. Koninklijke Akademie van Wetenschappen te Amsterdam, vol. 28, No. 10. Abstract and note by B. M. Varney]

It is remarkable that in the United States, more afflicted with tornadoes than any other area of equal size on the globe, the literature of tornadoes since Ferrel is confined almost exclusively to compilations of statistics on distribution, frequencies of occurrence, descriptions of resulting damage, and so on. We are therefore fortunate in being able to present excerpts from an aerological study by Doctor van Everdingen, of an extensive series of whirlwinds which caused widespread destruction in southern, central, and eastern Holland on August 10, 1925.

The paper opens with a brief statistical survey of whirlwinds of destructive violence in Holland. A total of 82 such has been recorded during the period 1882–1925. The monthly frequency was as follows:

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	2	2	3	9	11	20	19	9	2	4	-----

For the great destruction of August 10, 1925, extensive evidence as to the direction of fall of trees and parts of buildings, distribution and shape of damaged areas, etc., leads to the conclusion that many whirls, decending to the earth's surface intermittently, were involved. None of them appears to have caused wreckage over paths of the lengths frequently found in the United States. The whirlwinds occurred in connection with the passage across the region of a trough of low pressure, accompanied by a thunderstorm of no unusual intensity.

Relative to the pressure distributions at the surface over Holland during the afternoon, there is presented a series of charts for 2, 4, 5, 6, 6:30 and 7 p. m. Commenting on these, Doctor van Everdingen says:

Only at the moment of the passing of the whirlwinds extraordinary isobars are displayed, but these are very remarkable indeed, as in the neighborhood of the tracks of the whirlwinds, they indicate pressure gradients up to 55 mm. per degree, which, if occurring over larger areas and longer periods, would cause hurricanes of the most destructive kind.

With isobars of curvature as here occurs, however, by far the greater part of the gradient is required for change of direction, and moreover it is evident that this pressure distribution did not persist long enough to develop its full wind force. There are no indications of the occurrence of similar gradients farther southwest before the whirlwinds appeared. Therefore though we don't exclude the possibility, that in the first place northwesterly gales and whirlwinds with a southerly track may be explained by these pressure gradients, we are of opinion, that on the whole these phenomena are to be regarded rather as sequences of than as causes for the formation of the whirlwinds. * * *

We turn to the aerological side of the study:

In consequence of the constantly increasing application of the investigation of the upper air to the daily forecasts of the weather, we have at our disposal rather complete material of temperatures and velocities of the air in the lower kilometers. By means of aeroplanes the temperature was determined up to a considerable height at Duxford in England, Uccle in Belgium, Helder and Soesterberg in our country, by means of kites or cable balloons at Lindenberg and Friedrichshafen in Germany. Moreover, observations from mountain stations were available in Germany, Switzerland, and France. Numerous observations of pilot balloons give the wind directions in the higher strata at various times of the day.

The morning observations showed large differences of temperature between England and Central Europe at the 1,000 and 2,000 m. levels. Above the Puy de Dome in south central France the temperature was 68° F. at 1,500 m., and it is assumed that this temperature was characteristic of central France and that the southerly and southwesterly winds at that level later brought the warm air over Holland. The morning observation at Friedrichshafen on the Lake of Constance showed a steep lapse rate of temperature above 2,000 m. The assumption is made that this condition overspread Holland in the afternoon *above the warm air from the southwest*, accompanied by a temperature inversion at about 2,000 m., thus bringing about a condition which awaited only the lifting of the warm, moist air by underrunning of the much colder air from the west, to produce thunderstorms.

As first demonstrated by Margules, the gravitational force accomplishes a considerable amount of work when cold masses of air, which first were found beside the warmer masses, spread out under these. With a vertical extension of the layers of 3,000 m. and a difference of temperature of 5° C. the whole mass of air may obtain a velocity of 12 m. p. s. The sudden outbreak of stormy winds during a thunderstorm may completely be explained in this way; but velocities of 50 m. p. s. are not easily reached in this manner; for these we want the cooperation of a heavy thunderstorm squall with a whirlwind.

We now come to the observations which in our view contain the key for the explanation of the whirlwinds. The older theories, which for instance connected the whirlwinds with a rapidly rising current of air, which was said to cause vortices, or which ascribed them to the encounter of two strong wind currents of different directions in the same level, have been found to be failing in most cases. Rapidly rising currents often show no rotation at all. Air currents of very different direction and velocity occur in the same level generally only at distances, very large as compared with the diameter of a whirlwind. On the other hand it is shown daily that very different velocities may occur one *over* the other and that in that case, especially when inversions limit the turbulence, very sharp discontinuities may be found. Gradually it has become probable, that these discontinuities of the wind are necessary for the formation of vortices, and that these vortices therefore will rotate in the first instance about a horizontal axis, the higher parts showing the largest velocity in the direction of propagation. According to hydrodynamics, if friction is not considered, a vortex-thread can end only at the boundary of the fluid. Wegener and Krebs have made the supposition, that waterspouts and whirlwinds constitute the bent-down ends of the horizontal vortices in the

higher strata. If both ends are bent toward the earth, the end on the right of the horizontal vortex will show a cyclonic rotation (anticlockwise), the end on the left an anticyclonic rotation or right-hand rotation. The effect of the earth's rotation on the masses of air streaming towards the vortex will however favor the cyclonic rotation; moreover the other end may bend upwards and terminate at the inversion layer. As a matter of fact observation points to a preponderance of left-handed rotating whirlwinds. Of course the friction near to the surface will cause all kinds of complications—for instance it appears that often a division into a number of whirlwinds occurs.

If this view is correct, the formation of a whirlwind requires a discontinuity of the wind in the vertical and a strongly rising current, in which the discontinuity causes a horizontal vortex.* * *. If the whirlwind constitutes the vertical prolongation of a horizontal vortex, connected with the rising thundercloud, situated to the left of the whirlwind when looking in the direction of propagation, then the maximum precipitation must fall on the left side of the track. This is confirmed by [the distribution of precipitation which fell in connection with the storm]. To the right of the track are even places where no precipitation at all has fallen.

It remains to prove the existence of a considerable discontinuity of the wind. Indeed, in the afternoon of August 10 such a considerable increase of the wind upwards was observed as well at de Bilt as at Uccle, that at first an error was suspected. * * * The observation at de Bilt at 1:35 p. m. yielded the following results:

Height	500	1,000	1,500	2,000 m.
Velocity	5	13	20	31 m. p. s.
Direction from	190	200	220	220 degrees of azimuth

The observation at Uccle was made even later, 4:44–4:54, Amsterdam S. T., hence nearer to the disaster:

Height	500	1,000	1,500	1,800	2,000 m.
Velocity	16	24	36	41	36 m. p. s.
Direction from	218	222	226	224	223 degrees.

Lastly it appeared that in the morning in East-England, at Orleans and Brussels at heights from 2,000 to 2,400 m. velocities of 20 m. p. s. occurred between masses of air, moving slower as well further W. as further East. Hence there is no doubt, that a very important discontinuity of the wind occurred at a height of 2,000 m. leading to velocities of perhaps 40 m. p. s. about the time of the disaster. Such velocities are very rare, especially with a pressure distribution without large gradients at the surface—therefore we may ascribe the serious character of the disaster in the first place to this important discontinuity.

The cause of the local occurrence of such high velocities is to be found in the increase of the pressure differences at the level of 2,000 m., in consequence of the distribution of temperature, and in the increase of pressure differences at various levels by the secondary depression which passed over our country in the afternoon. * * * The difference in barometric pressure between S. England and Friedrichshafen, which in the morning amounted to 7 mm. at 2,000 m., to 10 mm. at 5,000 m., occurred probably in the afternoon over a distance shorter by one-third and was augmented by about 2 mm. by the secondary depression which must have had its origin at least partly in much higher strata. In this way we arrive at almost doubling the gradient, which hence reached a value of almost 3 mm. per degree, between Brussels and Friedrichshafen even more. This explains sufficiently velocities of such magnitude; the gradient wind at 2,000 m. was about 13 m. p. s. per mm. of gradient. * * *

It is evident from the foregoing, that for the formation of so heavy whirlwinds over a large region a rare coincidence of circumstances is required. We need not be amazed, therefore, that in order to find in our country a disaster, comparable with that of 1925, we have to go back to the very heavy whirlwinds of August 1, 1674, which made collapse a number of church towers and part of the cathedral at Utrecht.

NOTE.—For a concise summary of the theories which have contributed most to the discussion of tornadoes, the reader should consult Dr. Alfred Wegener's "Wind und Wasserhosen in Europa," especially chapter 15 on "Views as to the origin of whirlwinds." The thermodynamic and the mechanical theories are, naturally, discussed at greatest length. The thermodynamic, apparently first put forward by Benjamin Franklin in 1753 and thereafter elaborated by many meteorologists in Europe and this country, is reviewed largely on the basis of the work of Ferrel and of Sprung. It will therefore be appropriate here to quote the following statements (well known though they are) from Ferrel's "Recent Advances in Meteorology" (Report of the Chief Signal Officer for 1885, Appendix 71, pp. 324–325, and 327.)

It has been shown that there are two principal conditions upon which tornadoes depend, and that in the absence of either one of these they can not take place. The one is the state of unstable equilibrium of the air, and the other a gyratory motion with reference to any assumed center. * * * When we have these two principal conditions, the other, that there shall be some slight initial disturbance to cause the air to burst up at some point through the strata above, can scarcely ever be wanting. The places and times, then, in which these two principal conditions are found are those in which tornadoes are most likely to occur. * * * The unstable state of the air is most liable to be induced where surface winds from a lower latitude or any warmer region prevail while the normal temperature of the air above is not affected or at least increased in the same way. * * * In the southeast octant, within the cylconic part of the surface, 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.

And this unstable state is of course precisely one of the conditions wherein can occur a discontinuity which, in the view of Wegener and Krebs, favors the formation of that horizontal vortex which is potentially a tornado in the making.

There seems to be some evidence, however, that a horizontal vortex might be produced under quite different circumstances. In "Wind und Wasserhosen in Europa" is a description of an experiment performed by Vettin in 1857, whereby he produced in a tank containing air *a horizontal vortex*, by first obtaining an *atmospheric discontinuity*, and then causing a *current to burst up through the discontinuity:*

In an oblong glass tank a circulation of the air was induced by placing a large piece of ice in one end. The air, the motions of which were made visible by means of tobacco smoke, then resolved itself into two layers moving in opposite directions. Now, if the bottom of the tank were warmed at point *c*, so that the air over it was elevated in the usual mushroom form, the resulting vortex ring was strongly distorted on the lee side (see *b* in diagram A of the figure) so that its rotation was weakened, while it became contracted on the windward side, at *a*. If now the warming were forced to a condition where the plane of the discontinuity was broken through (diagram B), the vortex ring on what is now the lee side at *a* is likewise distorted, and changed gradually into a surface vortex. In contrast to this, the previously distorted portion *b* contracts, since the motion of its upper part goes contrary to the upper current. Simultaneously its rotation is accelerated by the descent of air at *b*. In this situation, rolls or funnels are formed, which rotate about horizontal axes, and which, if the heating at *c* is slackened, are unwound (*herabgerollt werden*) by the descending air stream (diagram C) and finally dissipated.

The conditions of Vettin's experiment are clearly the reverse of those shown by Ferrel, and others since Ferrel, to favor the formation of tornadoes. In the experiment, the lower stratum is cold and the upper warm, a condition for stability.

Now, if one may draw a parallel between the above and the aerological conditions accompanying the whirlwinds discussed by Dr. van Everdingen, it is seen that corresponding to the convectional upthrust induced directly by Vettin's local heating there occurred over Holland convectional upthrusts induced secondarily by the under-running of cold air from the northwest. Further than this the conditions of Vettin's experiment do not apply, since the discontinuity most important in connection with the occurrence of the whirlwinds over Holland was not that between the underrunning cold surface air and the warm southwesterly air above, but between the warm southwesterly air and the overrunning cold air stream next higher up. Here was the condition

for instability. But a horizontal vortex was produced both in the experiment and in nature (if we assume the hypothesis of Wegener and Krebs to be correct). That is, it occurred regardless of whether the strata producing the discontinuity favored stability or instability.

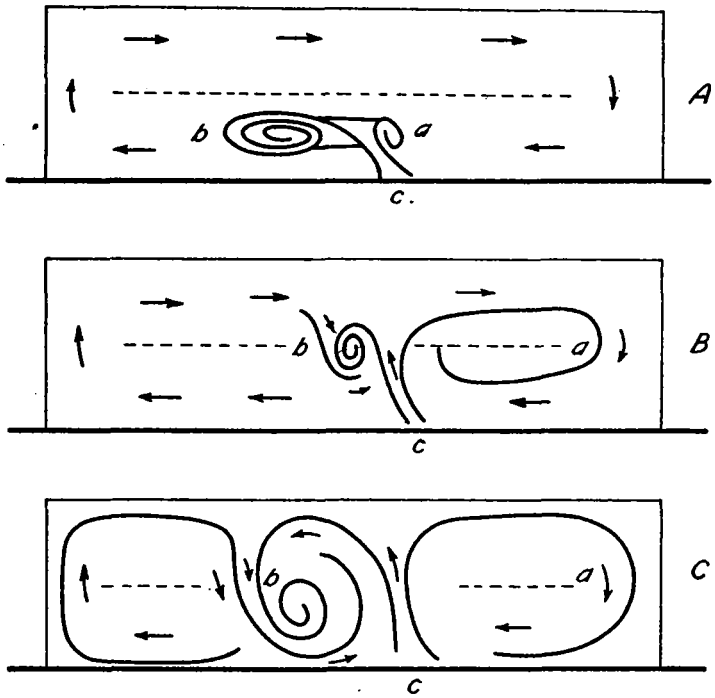

FIG. 1.—The experiment of Vettin: Forming a vortex by breaking through a discontinuity. (After fig. 85 in "*Wind und Wasserhosen in Europa.*")

In the phenomena discussed above, there seems to be a basis for believing that neither the thermodynamic hypothesis nor the mechanical, alone, adequately accounts for the inception of a tornado. Certainly the puncturing of a discontinuity, above and below which are winds of greatly contrasted velocity, by a convectional upthrust, suggests a query as to whether we may not expect further aerological investigation to show that both thermodynamical and mechanical principles must be invoked to solve the riddle. If such be the case, the view of Ferrel and others, according to which the thermodynamic principles play the major part, and the view of Wegener and Krebs with its emphasis on the mechanical, must share the honors of the middle ground. The example of Dr. van Everdingen's study of a special case may well be followed by other investigators.

Supplementary note.—Since the above material was prepared, Mr. J. E. Hissong's report on the tornadolike whirlwinds at the San Luis Obispo oil fire (see p. 161) has been received. The reader will note in the last paragraph of that report a statement concerning the apparent relation between the occurrence of the whirlwinds and the passage of a windshift line, a relation which, if one may judge from the necessarily scanty data, seems to have been closely similar to that discussed by Dr. van Everdingen. The oil fire certainly furnished no mean convectional upthrust. That the passage of the windshift furnished a discontinuity is probably almost certain. Mr. Hissong says: "In view of the fact that the tornadoes were first noted just after the wind changed from southerly to northwest it is possible that they may have been caused by the strong convectional currents over the fire being given a rotational motion by the northwest wind."—*B. M. V.*

THE NATIONAL ELIMINATION BALLOON RACE FROM LITTLE ROCK, ARK., APRIL 29, 1926

629.132.1 (73)

By JOHN A. RILEY

[Aerological Station, Broken Arrow, Okla.]

On the 28th, meteorological conditions ideal for the race began to be indicated and so it proved at Little Rock on the 29th, which was a warm, sunshiny day, with light southwesterly winds. Fair weather also prevailed quite generally over the Central and Eastern States, an unusually favorable condition considering that the region is normally visited by frequent rains and thundershowers at this season. With a bright moon throughout the night the pilots were able to recognize towns, rivers, and mountains and thus to know their positions at all times both night and day.

The meteorological controls in effect on the 29th were first to be recognized on the weather map of the 26th; a HIGH had appeared on the North Pacific coast and a LOW was moving eastward across Manitoba. Surface conditions on the day of the race were dominated by this HIGH, which had moved southeastward and now overlay most of the Southern and Eastern States, with a crest over the Ohio and lower Mississippi Valleys. Sea level isobars extended nearly straight NE–SW. Meanwhile the northern LOW had moved eastward across the lake region and was located over New Brunswick on the 29th. It had brought considerable cold air over the Northeastern States, while the Southwest was enjoying the mild tem peratures of early summer. The resulting temperature differences in the free air caused, above 1,500 meters, a cyclonic system of winds centered over New England and covering the country from the Mississippi Valley eastward.

Northwesterly winds therefore prevailed in the upper levels while below 1,000 meters the winds conformed nearly to the sea level isobars, i. e., they were SW. to WSW. over Arkansas and nearly west farther north and east. An observation at Little Rock at noon showed typically light winds to 2,000 meters, from west to southwest below 1,000 meters, and northwest above.

The balloonists could have chosen a course variously from northeast to southeast depending on the altitude, but the northwesterly wind could be ruled out of consideration not only because its speed was decreasing but because even had strong winds persisted a record breaking distance could not have been made in that direction before reaching the Gulf coast. Southerly component winds were greatly to be preferred.

The race was therefore necessarily a low altitude one at least at the beginning; to gain the greatest final distance it was desirable to make as much northing as possible the first night, as it was strongly indicated that westerly winds then prevailing over the Ohio Valley would continue for some time, and that little or no further progress northward could be made after reaching that region or during the second night. Thus, other conditions being favorable, the Atlantic might be the limiting factor for distance. This proved to be true for Mr. Van Orman, the winner, who decided to land when he sighted the lighthouse of James Bay shortly after midnight, May 1.