Meteorology. — E. VAN EVERDINGEN: *"The cyclone-like whirlwinds of August 10, 1925."*

(Communicated at the meeting of October 31, 1925).

1. When in the morning of August 11 the papers in this country, from all quarters in the southern and eastern part of the country, received reports of heavy devastations, reminding in their description of the effect of a hurricane or a cyclone, especially in consequence of the reports saying that Borculo had been "entirely destroyed", the Meteorological Institute was asked for information about the cause of the disaster and publication of its observations. In both respects we were obliged to disappoint the applicants. We could say nothing about the cause but that it ought to be connected with the passage of the line squall of a thunderstorm, which had attracted our attention also at De Bilt by the darkness preceding it, no particularly severe phenomena ensuing however. Hence local observations did not give any clue, nor those at the four principal stations from which we get telegraphic reports at regular intervals — at the moment of the disaster at Borculo, about 7 o'clock p.m., the weather map shows a shallow depression-centre over the northern part of our country, with lowest readings just below 755 mm., and the maximum gradient of pressure in the triangles Flushing—De Bilt—Maastricht and De Bilt—Maastricht—Groningen remains short of 2 mm. per degree for very divergent directions. It is in good harmony with this fact that at none of the principal stations windforce of any extraordinary importance occurred, at some even the gale-limit was by far not attained. For these reasons, however severe the destructions may have been locally, it is not right to talk of a hurricane or a cyclone — with those words we indicate in meteorology phenomena of a much greater size, with a diameter of many hundreds and a length of path of thousands of kilometers. For the local whirlwinds which often, albeit usually in a much more modest form, accompany thunderstorms, the real dutch name "windhoos" (wind-spout) is best adapted. In this case, in view of their exceptional severity and extension, we may talk of cyclone-like whirlwinds.

2. It is probably on account of the very local character of whirlwinds that we are inclined to believe them to be more rare than they really are. In this country, in the period 1888—1913 whirlwinds of more or less importance occurred on the average on 8 days per annum. During the years 1882—1925 the Meteor. Institute got notice of 82 cases, in which at one or more places damage was caused, comparable with what occurred this time on a big scale: trees knocked down or snapped, hay-cocks blown

up and scattered, roofs or even houses damaged. Fig. 1 indicates the localities, where these whirlwinds occurred: much haunted are Sealand and Friesland, remarkably spared the N.-E. part of Groningen and Dutch

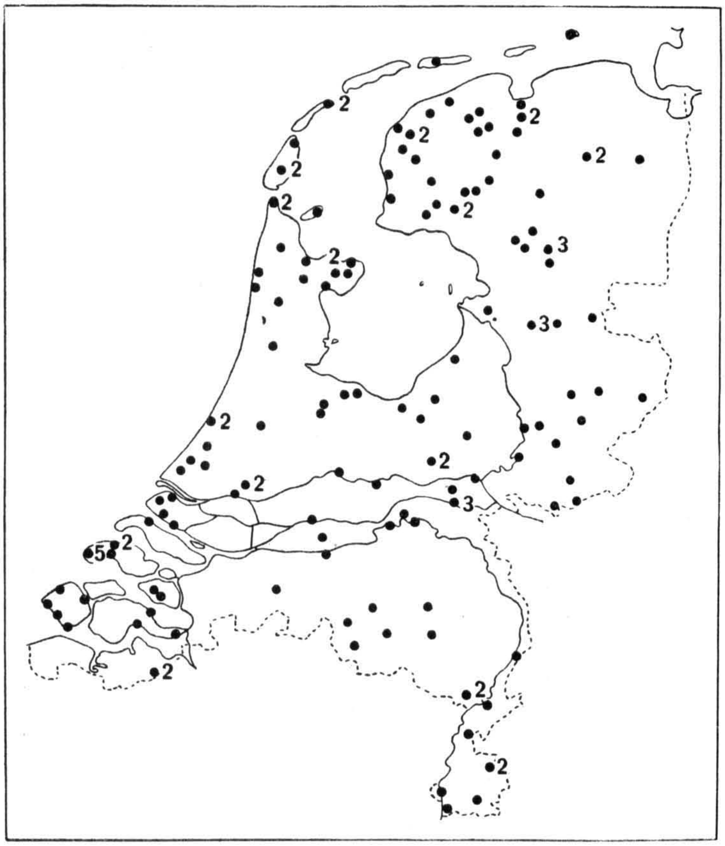

Fig. 1.

Flanders. The total number of cases however is still too small to permit us to draw conclusions, though it seems probable that the proximity of the sea or the influence of heated sands and hills favours the formation of whirlwinds. The distribution of these whirlwinds over the various months was:

Jan.	Febr.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	2	2	3	9	11	20	19	9	2	4	—

and bears much resemblance to that which WEGENER has deduced in his remarkable book "Wind und Wasserhosen in Europa"' — here however June has sensibly less, July more.

The particularity of the whirlwinds of August 10 does not in the first instance consist in the character of the destructions, which has been formerly equalled at various places. We mention f.i. August 29, 1916 when in Limburg hundreds of trees were smashed ; by chance also August 29, 1919, when near Voorthuizen once more hundreds of trees fell ; July 17, 1920, when a similar case happened in Twente, finally July 11, 1924, when Delft and Alphen on the Rhine were visited. Moreover it is possible that local circumstances have played their part, and hence a comparison is difficult. Extraordinary without doubt was however the extension of the region, where the destruction took place. Immediately after the disaster the Meteorological Institute has asked all its voluntary observers in the southerly, central and easterly part of the country to make a sketch of the extension of the damage in their vicinity, and also the principal papers printed such a request. Many persons have answered to this request with much diligence : moreover we were favoured by the cooperation of Dr. H. K. DE HAAS from Rotterdam, who passed his summer-holidays at Barchem and from there recorded the direction in which trees had fallen at many spots over a large area — we will treat of this afterwards. The writer, together with Dr. C. SCHOUTE, adjunct-Director, and Mr. W. WOLTHERS, secretary of the Institute, who likewise passed his holidays at Barchem, visited a large portion of the damaged district in Gelderland and Overijssel by means of a motor car, put kindly at our disposition by the municipality of Borculo. Also Messrs. K. ZWART, retired head-teacher, and J. TH. A. BOTH, functionary of the El. Cy. "de Berkel", earned great merit by surveying and charting the direction of fall of trees in the municipality of Ruurlo. Finally we received a map of the whole region visited on two motor car trips in N.-Brabant and Gelderland and Overijssel by Mr. J. G. LEPPER, engineer at Aerdenhout.

The whole of these data enabled us to draw a concise map of the devastated regions. Whereas for some whirlwinds and tornado's, occurred abroad, it has been possible to find out a track, along which within a certain width almost everything is destructed, so much so that f.i. in Scandinavia people speak of an "Asgardsroad" through a wood, in this case one is struck rather by the great lack of regularity and the saltatory character of the destructive action. In the midst of an otherwise uninjured wood we find spots, where all trees have been felled ; along a road of more than 10 km. we find at irregular distances portions, where everything has been devastated by forces across the road, next to large regions almost uninjured — at other places the devastation is limited to a single narrow strip. Therefore it was impossible to map completely the extension of the damage; hence we have only indicated in fig. 2 the devastated regions by a scale of three degrees : narrow horizontal shadings for the regions, where heavy damage was caused to trees, crossed shadings where also buildings were damaged, black where buildings were entirely destructed. A wide horizontal shading indicates damage at few isolated spots.

On investigation it appeared that no reports of damage in Belgium had reached the Meteorological Observatory at Uccle. On the contrary in Germany damage was caused at a rather large number of places. Though we did not yet receive complete information [1]), we could conclude from reports in the papers that in the N.-E. part the spots devastated are much further apart in the transverse direction than in our country, as may appear

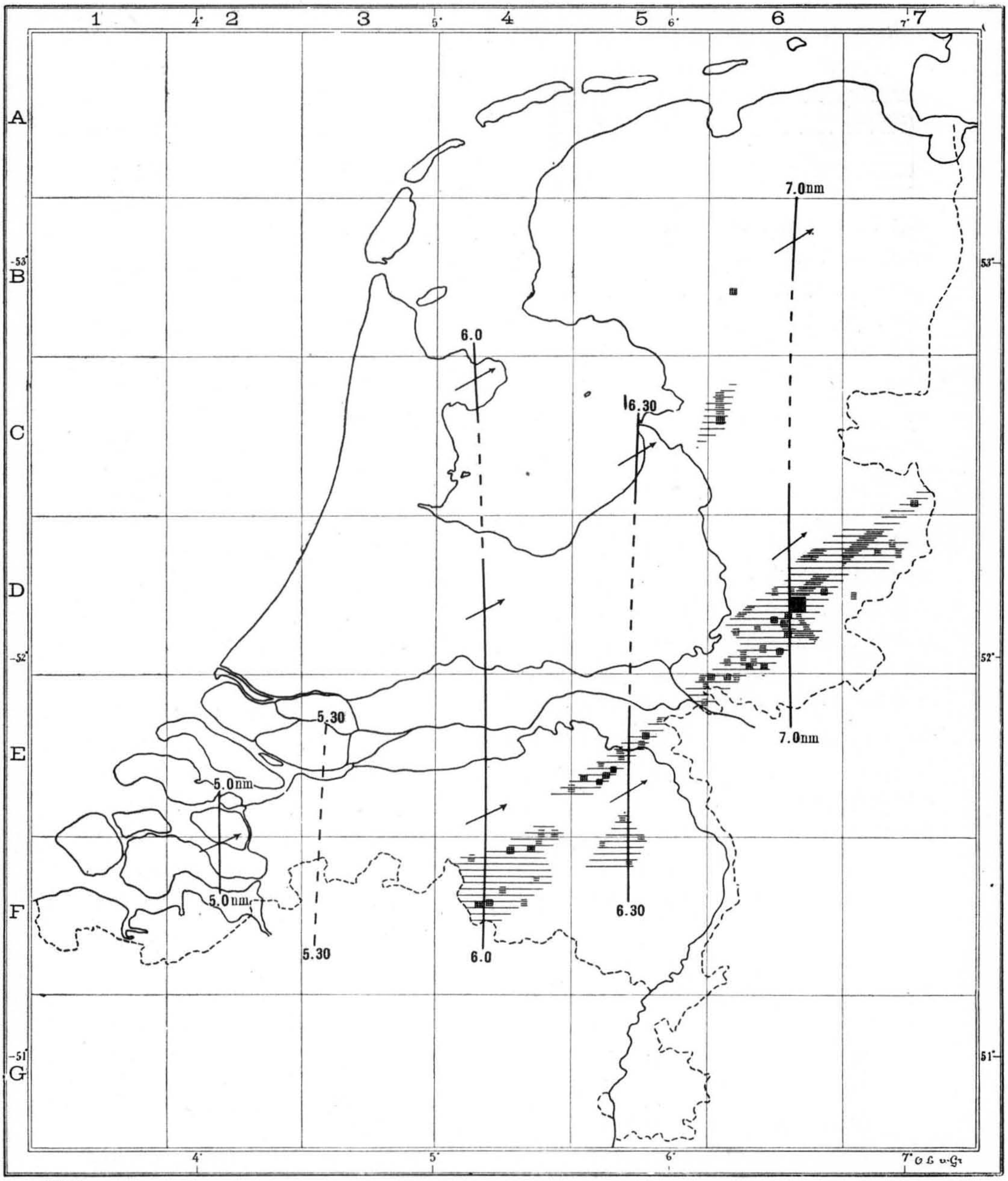

Fig. 2.

[1]) While correcting the proofprint we received a map from the „Deutsche Seewarte" at Hamburg, from which it appears that the squall-lines of the thunderstorm may be followed up to Kiel, and windforce 9—12 of the Beaufort scale was reported largely from three parallel tracks, the prolongation of which to our country contains all the regions devastated there.

from fig. 3. Taking everything together it appears that the length of the track is of the same order as the 4 longest tracks mentioned by WEGENER.

3. It is in the first place the capricious character of the destructions which forces us to ascribe them to whirlwinds. If the effects ought to be ascribed to nothing else but a gale, then the force of a hurricane of such strength would be required, that over a wide area *everything* would have been destructed. In whirlwinds indeed exceptionally high windforces occur locally and temporarily; even 100 m. p. s. has been mentioned, though nobody can tell with certainty that such velocities have been reached. Indeed, all calculations of the force of the wind from the pressure of the wind, estimated from its destructive effect, yield too high values because it is certain, that other forces of the same order of magnitude must have been present at the same time. These are the differences in atmospheric pressure, which in the rare cases where a whirlwind came across a barograph have proved to be able to reach 20 to 30 mm. The mean diameter of a whirlwind is something of the order of 100 m. Hence mean pressure gradients of the order of 1 mm of mercury in 5 to 3 meters play a part, locally and near the axis perhaps 10 times bigger. This causes forces of the order of 25 to 40 kg. per m^2 of an object of 1 m. thickness, hence forces, already equal to the windforces experienced in heavy gales, but differing from these in this respect, that they increase with the thickness of the object on which they are displayed. If such a whirlwind progresses with a big velocity — in this case there is reason to estimate that velocity at 20 to 30 m. p. s. — then there is certainly no time to develop everywhere, an equal distribution of pressure, and we may expect quasi-explosive effects of the not expanded air, which is present inside buildings.

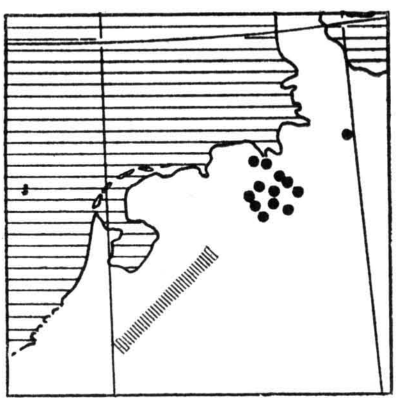

Fig. 3.

That is why roofconstructions are tilted up, roofcoverings are blown off, windowpanes and even walls are thrown outwards at the side opposite to that, exposed to the strongest wind, even if the walls on that side remained intact, as has been observed in many cases. This also explains the possibility of very different directions of fall of trees at neighbouring places. This, lastly, explains why heavy objects may be carried through the air over rather large distances, borne by a diminution of pressure over and before them, and forced on by air streaming towards the depression and ascending at the same time [1]).

[1]) I consider this explanation to be more acceptable than WEGENER's supposition, that transport over large distances would take place in a horizontal part of the vortex.

However — even when taking into account these forces, wind pressures of the order of 200 kg. are required to explain several of the masterpieces accomplished by whirlwinds; hence we are obliged to assume windvelocities of more than 50 m. p. s.

We give in the following the few observations, where the funnels of the spouts were actually seen.

Borculo. Dr. J. W. GRONDIJS. "From the Southwest approaches a funnel of a dirty yellow-greenish colour. In a short time the colossus has reached the village. Violent wind. I see the trees in the Bloemerstraat falling with a single blow, direction S.—N., but at the upper end of the street the trees lie N.-W.—S.-E."

Borculo. H. W. HEUVEL. "The clouds arrived revolving like a whirlpool. Somebody tells: At once we saw in the sky something strange. A long straight tube, which rotated quickly at a horrific pace and approached with a terrifying roar."

Nijmegen. R. TEN KATE. "When the squall had approached a good deal and it had grown very dark, I saw at once a large frayed cloud approaching somehow from N.-W. with an amazing velocity in the direction of the squall. This attracted my attention to such a degree, that I inspected the sky more closely and then I saw from a southern direction another cloud approaching in the direction of the squall. Just before the squall had reached the North-Southline over my dwelling, it was reached by the two clouds, whereupon they assumed together a rotary motion and proceeded in the direction of the squall. At the moment this rotation started, the trees began to wave wildly without a distinct direction. The rotation was rather quick (one revolution in about 6 seconds.)"

Zevenaar. Drs. J. G. A. HONIG. "Various persons have seen a dark rotating(?) column moving from S.-W. to S.-E."

Uden. J. TH. FRUNT. "The clouds came together from the directions N.-W. and S. .... Everyone cried fire. .... But there was no fire. Then the clouds descended .... to about 50 m. above the surface, and much sand came with them .... then towards Uden, there the whole motion of the air was involved in rotation."

These data and the ensuing notice about the estate "Het Espelo" prove beyond doubt that whirlwinds have occurred. The very dark sky and the velocity with which everything proceeded are sufficient reasons, why more numerous descriptions were not received.

4. Details of local destructions are to be found at random in papers and periodicals, and this is not the occasion to treat further of these. Very important however is the result of Dr. H. K. DE HAAS' investigation, which is resumed in fig. 4. For orientation the railways and principal roads in the vicinity of Ruurlo, Lochem and Borculo have been indicated. Every arrow marks the direction of fall of a tree, which stood at the spot, indicated by the *point* of the arrow. Some curved arrows indicate spots, where one

gets very strongly the impression of quickly rotating forces, f.i. because the branches of a group of firs were entirely coiled up. Only those directions

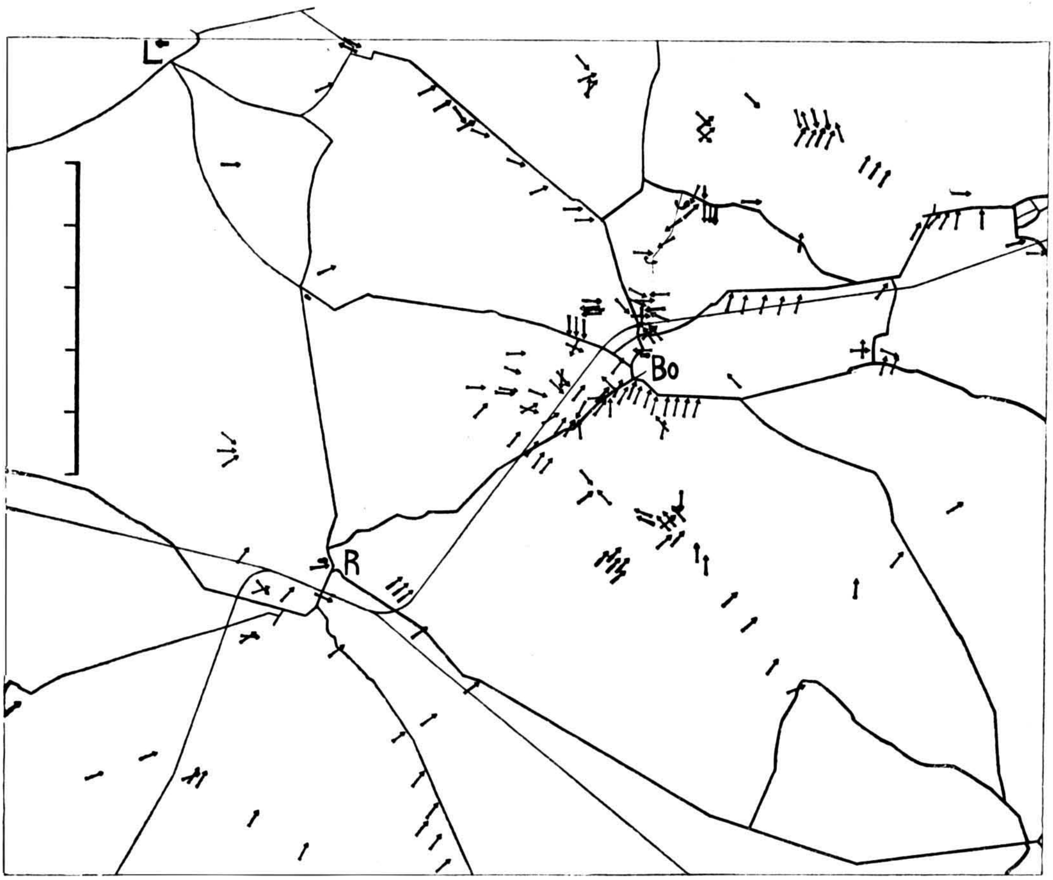

Fig. 4.

of fall have been inserted, where it was certain that the tree lay untouched. As of course in many spots soon clearing had taken place, the number of arrows and their distribution do not give a true picture of the intensity of the whirlwinds; but they do, as far as the direction of the largest forces in any point is concerned. Fig. 5 is a reproduction of the sketch received from Ruurlo. Here the directions of fall diverge still more.

A comparison of these figures with tracks of whirlwinds in WEGENER'S collection shows, that this case is among the most complicated. If a single whirlwind proceeds along a straight line, we are able to predict entirely the direction of fall with respect to the track, after making certain suppositions about the velocity of translation and the angle of incidence of the wind with respect to the axis of rotation. It then appears that near the centre all trees must fall in the direction of propagation, whereas on both sides a region is found, in which the trees are found lying under angles up to 135° with the track — of course subject to the nature of the trees and the minimum windforce sufficient to fell them.

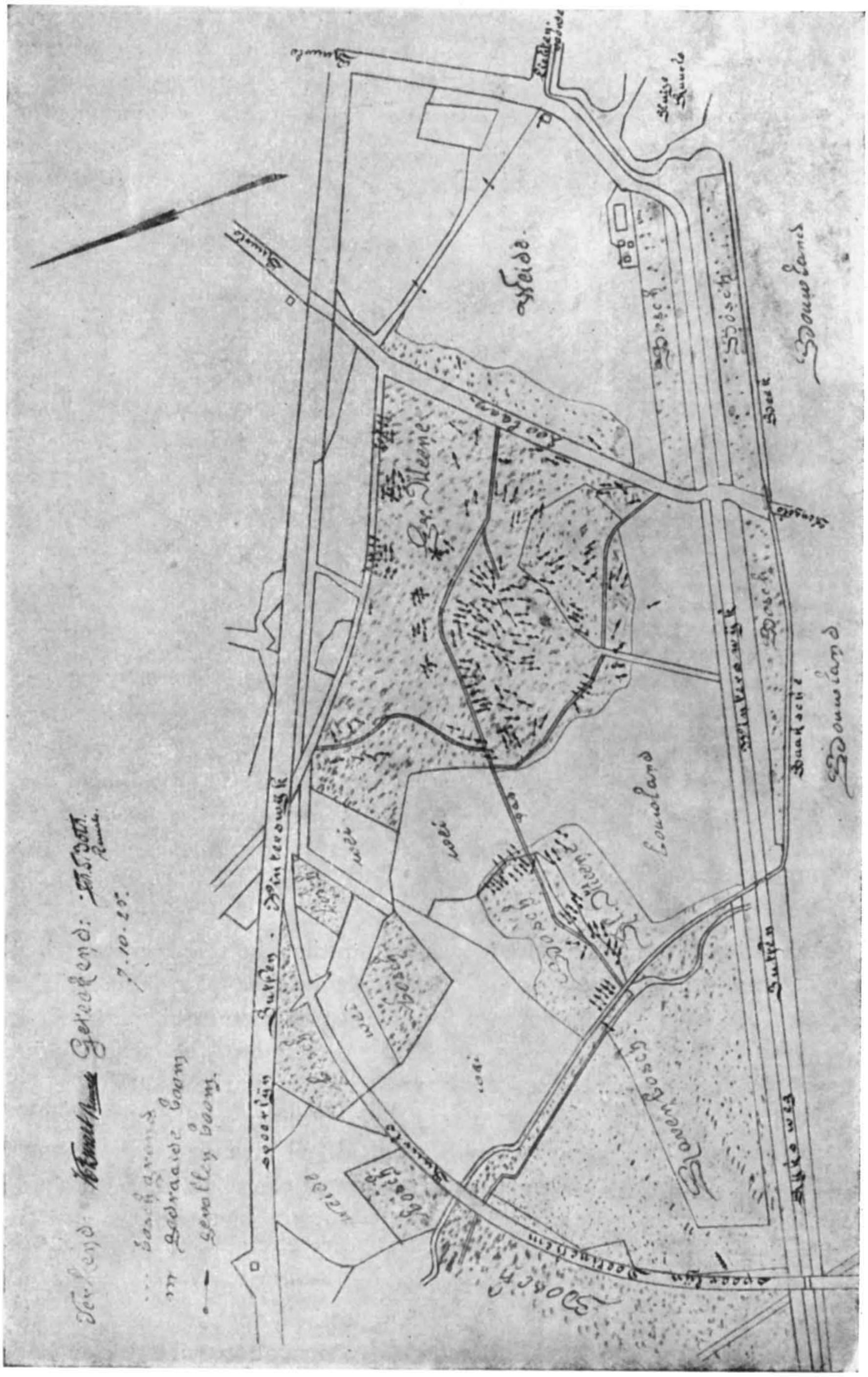

Fig. 5.

Nothing like such a picture here — only small portions along certain roads show some resemblance to it [1]), so as to favour the supposition, that a great number of whirlwinds of relativily small dimensions has been in action, and that sometimes, diverging from the principal direction, these whirlwinds followed the rows of trees along the roads. It is even not impossible, that some whirlwinds followed an adverse track, or showed an adverse direction of rotation. At various places it was possible to conclude to the time-sequence of the successive hurricane blasts, because we can take for granted that the tree lying uppermost had fallen latest. On the evidence of facts like these Dr. DE HAAS thinks he must assume that N.-W. of Borculo several right-hand rotating whirls have occurred.

In the Ruurlo map we are struck especially by the great number of trees, felled from N.-E. in the centre of the Gr. Meene, secondly the great number of isolated spots with numerous felled trees amidst uninjured regions. In these smaller spots the direction of fall does not diverge so much. Everything seems to indicate, that the whirlwinds, descending from the cloudlevel, touched the surface here and there in a saltatory way, and on the occasion of an extremely deep descent over the Gr. Meene developed enough force to fell trees also at the front side. If we assume a general motion in the direction N.-E., we have to distinguish at least 5 whirlwinds in this case only. In these considerations we start from the supposition, confirmed by numerous observations in the case of solitary whirlwinds, that next to the surface the rotation plays only a secondary part in the whirl, the afflux of air being the principal phenomenon. Hence the origin of the rotation, which constitutes the cause of the diminution of pressure, must be looked for in higher strata. In this supposition the progressive motion of the whole mass of air is added to the afflux behind the whirl near the track of the centre, subtracted from it on the front side. If we put the general windvelocity at 20 m. p. s., the felling of trees on the front of the whirl would indicate a velocity of afflux of 40 to 50 m. p. s., if we overlook the pressure-forces, — at the backside then velocities of 60 to 70 m. p. s. must have occurred. We remarked before that the action of pressure differences weakens these conclusions, except in the case of tall trees like firs or poplars, where the pressure effect cannot be very large. But also in other ways estimates are obtained of windforces between 50 and 80 m.p.s.

5. In spite of the very extensive investigations on whirlwinds we cannot say that at the present moment their origin is completely explained. Many facts and experiments however are in favour of the mechanic theory, which assumes that a horizontal vortex is formed when an ascending current forces its way into layers of air, where the velocity strongly increases

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[1]) On the estate „Het Espelo" near Enschedé f.i. in a wood a passage has been cut, about 10 m. wide, in which the trees not only have been blown down, but also snapped off. (J. VERKOREN Jr. Director of the Gas- and Waterworks, Enschedé).

upwards. Considering that in thunderstorms firstly strong ascending currents occur, but a thunderstorm of some importance requires also an inversionlayer, over which almost always a sudden change in the wind may be expected, this explains at the same time the frequent simultaneous occurrence of thunderstorms and whirlwinds.

Starting from this point of view we have tried in the first place to coordinate the facts, observed at the surface, on the supposition that the whirlwinds occurred everywhere at the moment of the passage of the principal line-squall of the thunderstorm. A great number of reports of the thunderstorm were available for determining the motion of this squall line. Though some possibility of confusion arose from the occurrence of several other thunderstorms, f.i. at de Bilt half an hour before the principal squall, we are of opinion that the squall-lines copied on fig. 2 have a sufficient degree of certainty [1]).

A first item of the research dealt with the air-pressure at the surface. In consequence of our request in the papers for communications of observations and sketches for this day, we got a.o. barograms from Nijmegen, Berg en Dal, Lochem, Goor, and Boekelo, all localities situated pretty near the track of the whirlwinds.

None of these diagrams did however show extraordinary variations of pressure, and this is what we might expect, seeing that the distance remained much greater than the diameter of the biggest whirls. Very important was therefore the receipt of the diagrams of the registering gas-pressure gauges at Nijmegen from the Director of the Gas-works, Mr. G. Philips, as the gauge at Hatert was only few kilometers from the track of the whirlwinds, and did show much bigger variations. In order to reduce the indications of these watermanometers to variations of air pressure we assumed, that a barograph, stationed at Nijmegen on the Oranjesingel, would have registered the same variations of air pressure as a barograph, installed at the Gas-factory, safe a difference of few minutes in time. After correction for the difference of level of the observing stations and reduction to pressure in mm. of mercury, the differences of the watermanometer at the factory and at the other points allowed the calculation of the air pressure variations there. We know that all registering cylinders show errors of time, and in this case these were very considerable. Therefore we assumed, that the most marked increase of pressure, shown in the diagram, coincided with the moment of the passage of the whirlwind, so as to allow a calculation of the time-error from the time of passage of the squall-line. The same procedure has been adopted afterwards for the barograms in the vicinity of Borculo.

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[1]) The very large velocity of this squall, about 72 km. per hour explains the velocity with which, according to eye-witnesses, the destruction approached, and is in harmony with the estimates of the lapse of time in which Borculo was destroyed, which vary from 7 minutes to a quarter of an hour. (Addition during correction: In Germany the velocity increased even to 90 km. per hour).

Fig. 6 shows the barograms for Hatert and Daalsche Dijk near Nijmegen, obtained in this way and compared with the diagram of the float-mercury-barograph at de Bilt. The latter shows a marked thunderstorm-unrest, but nothing particular at the passing of the line-squall at 6.00 — the diagrams for Nijmegen however show very large fluctuations, especially at Hatert.

As evident from fig. 2 the destruction stopped temporarily just beyond Nijmegen, and therefore it was not certain, that the difference in registration at Hatert and Daalsche Dijk was only due to a difference in distance from the track of the whirlwinds. For this reason we abstained from trying to estimate the fall of pressure on the central line by an extrapolation.

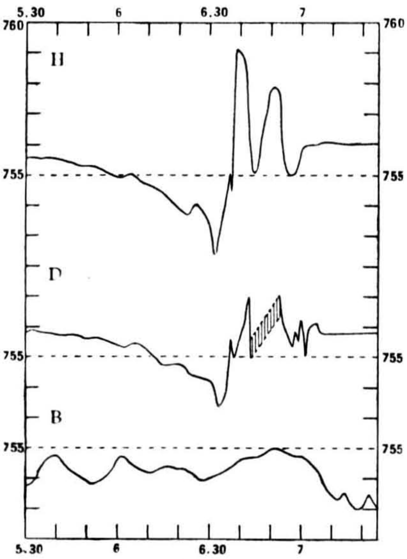

Fig. 6.

Using the observations at principal stations, second order stations and a number of other barograms received, we have then drawn the diagrams in fig. 7 for the distribution of pressure at 2, 4, 5, 6, 6.30 and 7.00 p. m. Only at the moment of the passing of the whirlwinds extraordinary isobars are displayed, but these are very remarkable indeed, as in the neighbourhood of the track 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 a 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 windforce. There are no indications of the occurrence of similar gradients farther S.-W., before the whirlwinds appeared. Therefore though we don't exclude the possibility, that in the first place N.-W.ly 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. A large part of the rise in pressure can be ascribed to the replacing of warm by cold air : a temperature difference of 6° C. through a column of air 2000 m. in height gives a rise of pressure of about 4 mm.

6. Fig. 8 shows the distribution of the rainfall in our country according to the reading of the raingauges, at 8.00 a.m. on August 11. It would have been desirable to draw this map exclusively for the rain that fell

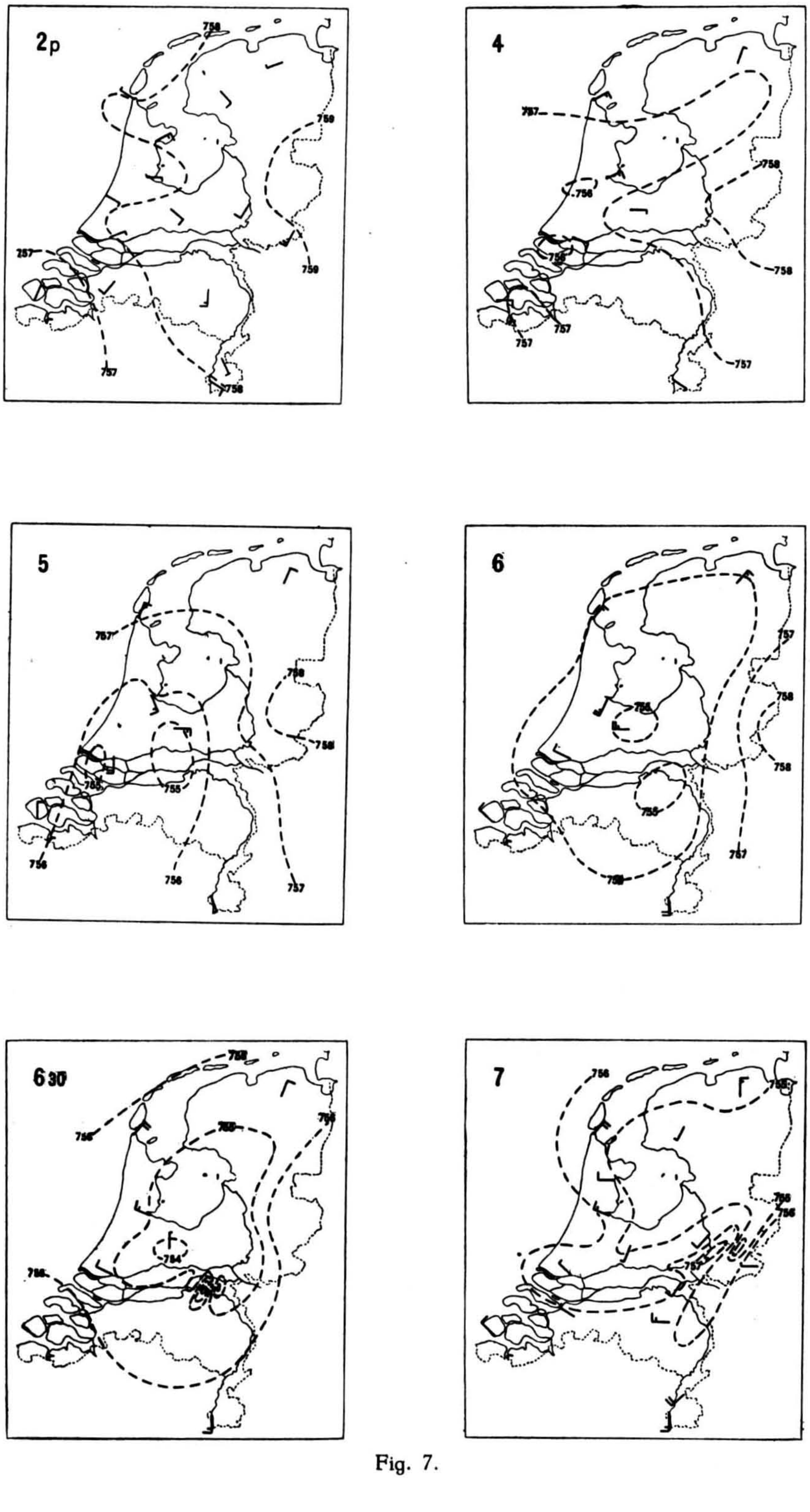

Fig. 7.

with the squall charted in fig. 2. But only a small fraction of the observers has measured separately the rain of this squall, and we only know that at various places this squall has indeed had the largest share in the day's rain. As main result of this investigation we find : 1^0. that the quantity of rain has been very different, varying between 38.5 mm. and nihil ; 2^0. that the region devastated by the whirlwinds has not experienced the heaviest precipitation, but that a region of heavy rain is to be found somewhat to the North and to the left of the track of the whirlwinds in Brabant and Gelderland. From the intensity of the rain the velocity of the ascending currents can be calculated, if we know the vertical extension of the saturated layer and its temperature. If we put the temperature at the surface at 25° C., the weight of the layer of air per m^2. at 1000 kg., then for a rainfall of 35 mm. in half an hour a vertical velocity of more than 6 m. p. s. is required. Hence it is very probable, that locally and temporarily the ascending velocity surpassed the limit of 8 m. p. s. and so grew larger then the highest velocity of falling raindrops. Perhaps this is the explanation for the phenomenon, that at many places the squall was preceded by an inkblack sky, from which rain did not yet fall. If such ascending velocities occur simultaneously over a few square kilometers, and if they are fed at the front part of a wedge of incident cold air only by an afflux with a height of a few hundred meters, then we find even in the case of a supply from all sides velocities of more than 20 m. p. s., with an afflux from one side much higher values.

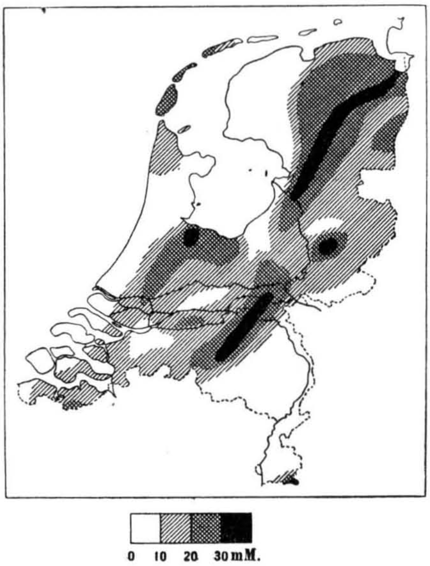

Fig. 8.

7. The direct cause of the thunderstorm was given by an invasion of cold air from W. under a warm and moist body of air supplied from South. Neither the temperature which occurred even in the eastern part of the country, which remained below 30° C., nor the fall of temperature can be called extraordinary, and doubtless these figures have been surpassed considerably in many heat-thunderstorms. It will appear lateron that in the higher strata more important differences were found. Figures 9 and 10 give the course of the isotherms at 2.00 and 7.00 p. m., the arrows indicate roughly the streamlines of the two masses of air. Given the irregular character of the pressure variations and the variable winds caused by these, many more observations would be required to completely determine these lines. Even in this rough form however they suggest the rising

currents due in the Achterhoek (Eastern Gelderland) about 7.00 p. m. and the ascending currents on the Veluwe (Western Gelderland), which fed the heavy winds in the back of the squalls.

It is evident from a comparison of fig. 2 and 8, that at different points

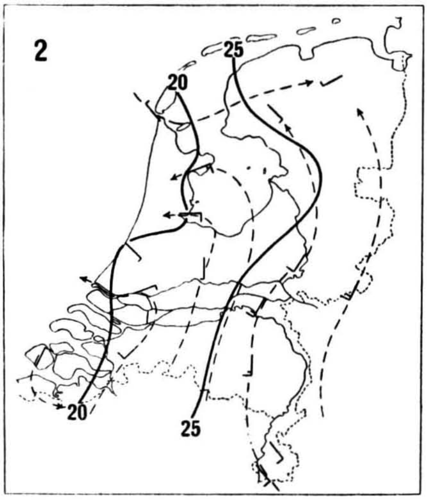

Fig. 9.

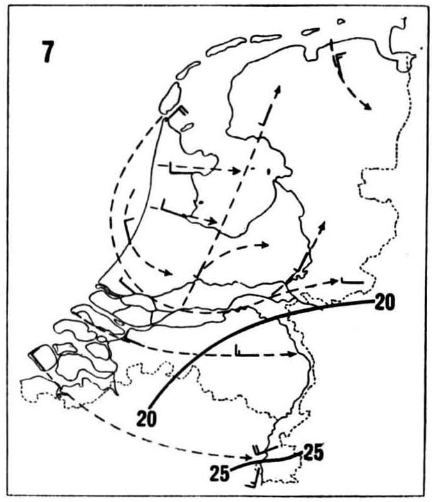

Fig. 10.

of a same squall-line very different amounts of rain fell; also fig. 10 suggests various independent squalls, so as to permit doubt, whether the squall-lines connected by a dotted line in the North and the South of the country really belong together. Hence the conditions of flux differed much locally; other differences in the ascending velocities depend on the orographic conditions, whereas preceding thunderstorms may have altered here and there the conditions in the higher strata. Together these are sufficient reasons to explain the large differences in rainfall.

8. 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 winddirections in the higher strata at various times of the day. Fig. 11 and 12 give a compilation of the morning observations for the levels of 1000 and 2000 m. (1 m.m. = 2.5 m. p. s.)

Remarkable is here especially the large temperature difference at the level of 1000 and 2000 m., between England and Central Europe. With a view to the observation on the Puy de Dome in France, which gives a temperature of 20° at 1500 m., we may assume that this condition existed likewise in Central France and that the southerly to southwesterly winds at 1000 to 2000 m. carried this warm air to our country. Above 2000 m.

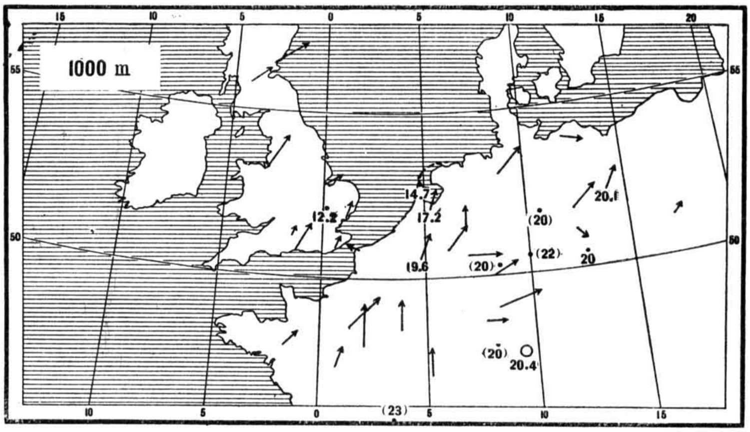

Fig. 11.

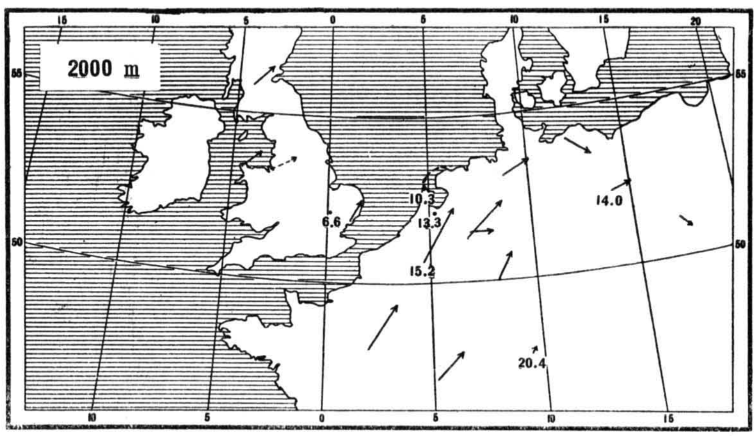

Fig. 12.

the temperature over Friedrichshafen decreased quickly. Whereas in the morning the lapse-rate of temperature over Soesterberg was not very favourable for developing a thunderstorm, conditions grew more and more favourable for such a storm in the afternoon, the more so in the easterly part of the country, where the temperature at the surface was much higher, and surpassed 29° C. If we assume that the conditions experienced in the morning over Friedrichshafen had spread in the afternoon from France to our country, then we find a total lapse of 18° up to 3000 m., in which however at about 2000 m. an inversion must have occurred. These are conditions for heavy thunderstorms as soon as other causes force the lower strata upwards and make them break through the inversion. These other causes are to be found in the much lower temperature and more westerly direction of the air layers in the West, which penetrated like a wedge under the warmer and moist air.

As first demonstrated by MARGULES, the gravitational force accomplishes a considerable amount of work when cold masses of air, which first were found beside warmer masses, spread out under these. With a vertical extension of the layers of 3000 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.

9. We now come to the observations which in our view contain the key for the explanation of the whirlwinds. The older theories, which f.i. 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 continuities 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 bend-down ends of the horizontal vortices in the higher strata. If both ends are bent towards the earth, the end on the right of the horizontal vortex will show a cyclonic rotation (anti-clockwise), 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 favour 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 kind of complications — f.i. 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. We should expect then, that the yearly range of the whirlwinds bears a certain resemblance to that of the thunderstorms, as the latter ask for a strong rising current, breaking through an inversion. It appears that such is really the case ; in this country, the yearly range of the thunderstorms is, expressed as percentages of the number of days with thunderstorms a year :

Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2.5	2.5	5.0	8.2	13.2	14.1	15.4	15.1	9.0	8.2	3.9	2.9

that of the whirlwinds :

1.2	2.4	2.4	3.7	11.0	13.4	24.4	23.2	11.0	2.4	4.9	—

In July and August the whirlwinds are comparatively very numerous. Also the local differences in frequency of thunderstorms — winter thunderstorms more frequent on the coast, summer thunderstorms on the higher sandy grounds, — are shown in the local distribution of whirlwinds given in fig. 1. 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 of the whirlwind. This is confirmed by our fig. 8. 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. In calculating the velocities of the various layers of air from the observation of pilot balloons from *one* station, we have to assume the velocity of ascension to be constant — if the balloon gets a leak, then the velocity of ascension diminishes and too big velocities are calculated. The observation at de Bilt at 1.35 p. m. yielded the following results :

Height	500	1000	1500	2000	m.
Velocity	5	13	20	31	m.p.s.
Direction from	190	200	220	220 [1])	

The observation at Uccle was made even later, 4.44—4.54, Amsterdam S. T. hence nearer to the disaster

Height	500	1000	1500	1800	2000	m.
Velocity	16	24	36	41	36	m.p.s.
Direction from	218	222	226	224	223	

Lastly it appeared that in the morning in East-England, at Orleans and at Brussels at heights from 2000 to 2400 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

[1]) In degrees, counted from N. through E.

occurred at a height of 2000 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.

11. 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 2000 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 warm masses of air moved from a southerly or south-westerly direction, the cold masses showed a more westerly direction, which accentuated itself especially in the afternoon and penetrated at the surface during the thunderstorm. The difference in barometric pressure between S. England and Friedrichshafen, which in the morning amounted to 7 mm. at 2000 m., to 10 mm. at 5000 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 almost at 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 2000 m. is about 13 m.p.s. per mm. of gradient.

With the general motion of the whole weathersituation towards E. or N.-E., also the region with high windvelocities was transported Eastward. At 11 o'clock the limit just touched the Eastcoast of England (Felixstowe); with the W.-E. components, which during the afternoon were found over England, the displacement until 7 o'clock in the evening would have been about 40, that is about to the central part of our country.

The boundary will probably have had the direction of the warm winds, S.-S.-W. or S.-W., hence in the northern part of our country it was situated further towards East. This is probably the reason, why the thundercloud which caused heavy rain in the northerly part of our country, from Zwolle to Delfzijl, at den Hulst 32.2 mm. in the course of half an hour, has given no rise to the development of heavy whirlwinds, though the destructions in the neigbourhood of Staphorst and Zorgvlied (Smilde), (the isolated spots north of the principal track), show that the limit was nearly reached.

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.

Résumé : 1. The destructions on August 10, 1925 are to be ascribed to heavy whirlwinds, accompanying a thunderstorm otherwise of no extraordinary intensity, and distinguished from the whirlwinds observed during the last 40 years principally by the extension of their range.

2. Almost all the phenomena observed are in harmony with the view that whirlwinds are the prolongations towards the surface of horizontal vortices in higher strata, a view first pronounced by WEGENER and KREBS.

3. The extraordinary intensity of the whirlwinds is a consequence of the very strong increase of the wind over the level of 2000 m., which in its turn is explained by the very large differences in temperature between W. and Central Europe in the lower kilometers.