PROCEEDINGS

OF

THE ROYAL SOCIETY.

"On the Relation between Tropical and Extra-tropical Cyclones." By Hon. RALPH ABERCROMBY, F.R.Met.Soc. Communicated by R. H. SCOTT, M.A., F.R.S. Received February 7,—Read February 24, 1887. Revised April, 1887.

The author has long been engaged in the study of cyclones in the temperate zone, as illustrated by those in Great Britain; but as doubts have been expressed by many meteorologists as to the identity between tropical and extra-tropical cyclones, he visited, in the year 1886, the observatories at Mauritius, Madras, Calcutta, Manila, Hong Kong, and Tokiyo, so as not only to procure more published materials for the investigation, but still more to learn from conversation with those who have had great experience of tropical hurricanes, some minute details of weather which were of primary importance, but which could not always be extracted from existing reports.

Though he was not fortunate enough to experience a hurricane himself, still he obtained sufficient information to enable him to arrive at a very definite conclusion on the matter, and now has the honour of laying before the Royal Society the results of his investigations.

He wishes to acknowledge here the assistance he has received from Mr. Meldrum at Mauritius; Mr. Pogson at Madras; Messrs. H. F. Blanford and A. Pedler at Calcutta; Padre Faura at Manila; Dr. Doberck at Hong Kong; and Messrs. Knipping and Wada at Tokiyo.

It will be convenient to sketch first the character of a British cyclone; then to detail the researches in India, the China Seas, and Mauritius; and, finally, to compare the results so as to arrive at a conclusion as to the identity or otherwise of the different kinds of cyclones.

The typical shape of a British cyclone is certainly oval, the successive isobars being non-concentric as in the diagram, fig. 1. The longer diameter of the oval may lie in any direction relative to the path of the cyclone, and often shifts during the existence of the same depression; but on the whole the tendency of the longer diameter is to approximate in direction to the line of the path of the cyclone.

Fig. 1.

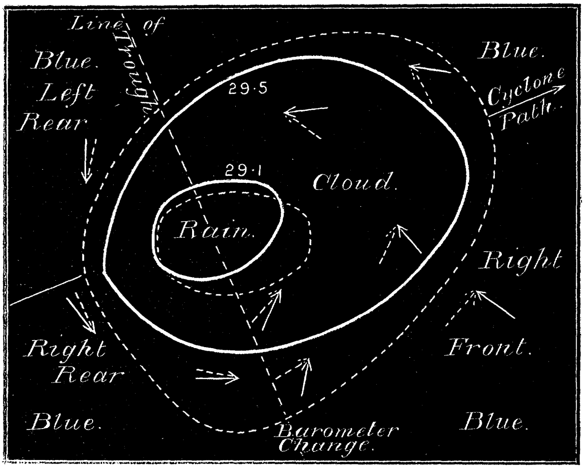


Diagram of cloud and rain in a British cyclone. The full lines are isobars, while the dotted lines define the areas of rain and cloud. The full-line arrows denote the direction of the surface winds, the dotted arrows that of the highest currents.

The side of the cyclone towards which the isobars are packed may also vary indefinitely, but is usually either in front or rear of the longer diameter. On the whole, the compression of the isobars in a typical cyclone seems to be towards the rear of the longer diameter.

The recognition of the oval form of cyclones is of the utmost importance in discussions as to the compass bearing of the centre relatively to the direction of the wind in any part of a storm field.

Another most important point is the fact that a cyclone is not an isolated phenomenon, but an episode in the general circulation of the atmosphere. For instance, most British cyclones are formed on the northern edge of a great anti-cyclone which constantly covers the North Atlantic, while tropical hurricanes are always controlled by their surrounding areas of high pressure.

Before every cyclone, temperate or tropical, there is always a complicated re-arrangement of pressure surrounding the true storm field; and many of the errors which occur in the handling of ships in hurricanes arise from a confusion between the premonitory and actual disturbances. For instance, in the normal distribution of pressure over the West Indies, these islands lie on the S.W. edge of the great Atlantic anti-cyclone, and it is manifest that a hurricane cannot develop as an isolated phenomenon without disturbing the distribution of pressure beyond the immediate sphere of cyclone activity. It

is for this reason that a rise of pressure so often precedes both tropical and extra-tropical cyclones.

The typical rotation of the wind round a cyclone is undoubtedly that of an in-going spiral, counter-clockwise in the northern, clockwise in the southern hemisphere. In the commonest British type, when the general distribution of pressure surrounding the cyclone is higher to the south than to the north, the greatest incurvature is in the right or south-east front of the depression. It is important to note this, for we shall find a different position for the most incurved winds in the China Seas and the South Indian Ocean.

The author has not yet found a satisfactory instance of the centre of the wind rotation not coinciding with the *minimum* of the barometer on a synoptic chart.

But when the sequence of wind and barometer trace at any single station is looked at, it is sometimes found that the sudden shift of the wind belonging to the centre occurs either before or after the actual *minimum*. The author has investigated the details of several examples, and found that the apparent anomaly is to be explained on the supposition that the depth of the cyclone was either increasing or decreasing rather rapidly.

For instance, in one case he found that the *minimum* of the barometer preceded the change of wind by three hours, because though the mercury was falling at the rate of 0·03 inch per hour owing to the passage of the cyclone, the depression as a whole was filling up at the rate of 0·07 inch per hour. The balance of rise was therefore 0·04 inch per hour. Full details of this example are given in a work by the author on "Weather," which is now in the press.

The rotation of the upper winds may be briefly stated thus:—At a level of about 4000—6000 feet the wind is nearly parallel to the isobars, and above that height tends to blow more and more outwards; but the amount of out-curvature varies in different parts of a cyclone, and need not be particularised here.

As a consequence of this we get the following law of the vertical succession of wind currents from the surface of the earth:—Stand with your back to the wind, and the successive layers of cloud will come continually more and more from your left hand. In the southern hemisphere the succession is reversed; that is to say, the upper currents come more and more from the right.

In fig. 1 the surface winds in a typical British cyclone are marked by full-line arrows, while the direction of the highest cirrus is denoted by dotted arrows.

The distribution of rain, cloud, and weather generally in a British cyclone may be described thus. An area of rain, surrounded by a ring-shaped district of cloud, is associated with every cyclone. The rain area is not exactly concentric with the isobars, as it usually

extends further in front than in rear of the centre of the cyclone, but still both rain and cloud are obviously related to that point (see fig. 1). But, strange to say, the kind and character of the cloud and the relative warmth and dampness of the weather are not related to the centre but to the front and rear of a line drawn through the centre and more or less perpendicular to the line of propagation of the cyclone, marked "trough" or line of barometer change in the diagram, fig. 1. For instance, the whole of the weather in front of that line is warm, muggy, and damp, while all in rear is cold and dry. The effect of this is that when a cyclone drifts past an observer, he experiences a sudden change from warm and damp to dry and cold weather the moment the trough has passed over him.

Then as to the kind of cloud.—A thin ring of halo forming cirro-stratus or cirro-nebula fringes almost all the outside of the front edge of the main cloud ring, but this kind of sky is rarely seen anywhere in rear of the cloud ring of the cyclone. Moreover all the cloud in front of the trough is usually more or less stratiform—cirro-stratus and strato-cumulus—while that in rear is distinctly of the cumulus type.

The portion of the line of the trough that is drawn southwards from the centre marks out the position of a long line of squalls, and of a very much more sudden shift of wind than the symmetry of the cyclone might have suggested. Instead of veering steadily from S.E. to N.W. the wind jumps during the passage of the trough sometimes as much as from S.S.W. to W.N.W., and then veers more gradually.

Considering then both cloud and wind, the sequence of weather to a solitary observer as a cyclone is propagated over him, the centre passing to the N., will be as follows:—Cirro-stratus and halo will appear in a blue sky, while the wind comes from about S.E. Gradually the clouds get lower and heavier, as they gather into strato-cumulus; then rain comes on, while the wind has veered steadily to S.W.

All this time the barometer has been falling fast, but suddenly just as the mercury has reached its lowest point a violent squall comes on, during which the wind jumps suddenly three or four points from the S.W. up to W. or W.N.W. Almost directly after, unless very near the centre of the cyclone, the clouds take the form of cumulo-nimbus, and then of simple detached cumulus, till the sky is completely blue again.

Any number of observers, situated on the southern side of the path of the centre, will find their weather change suddenly just as the mercury has begun to rise; and we, therefore, conclude that a line drawn across a cyclone at any moment, through all points where the barometer has just turned upwards owing to the onward motion of the depression, divides the cyclone into two halves which have different physical characteristics.

This line may be called the "trough" of a cyclone; and the characteristic squall, the sudden rise of the barometer, and the jump of the wind associated with the passage of that line, together with the different character of the weather and clouds in front and rear of that line, may conveniently be classed together as the "trough phenomena" of a cyclone.

The word "trough" requires some explanation, as that term has been strongly objected to by some. The difficulty of realising the applicability of the word arises from the difficulty of realising the forward motion of a cyclone when looking only at a set of oval isobars. But when it is considered that a cyclonic vortex is propagated somewhat after the manner of a wave; and that a barograph during the passage of the cyclone traces out a wave-like curve, the word trough comes in naturally to denote the line drawn across the isobaric plan of a cyclone to show all the points where the *minimum* has been attained, owing to the motion of the depression.

A cyclone is really a complex moving eddy of air. For some reason or other, pressure decreases under this eddy in a manner which is conveniently mapped out by isobars. In ordinary language the oval isobars are called for shortness a cyclone, but of course they are really only the symbol of what is taking place in the air overhead.

Isobars give the plan, barograms the sections of a cyclone, and it is always difficult to realise the relation of one to the other; but there is no difficulty in the conception of a moving vortex of air, which of course would have a trough like an ordinary wave.

A stationary vortex, like a stationary cyclone, would have no trough. Suppose a stationary cyclone to form over an observer and then to die out. His barometer would first fall and then rise, but there would be no trough, and he would experience no trough phenomena.

It is important to notice that the line of the trough does not appear to be always at right angles to the path of a cyclone, whose longer diameter is not perpendicular to the line of propagation; and that the trough phenomena are far more marked on the southern than on the northern side of the centre in Great Britain.

Taking a general view of the phenomena of a cyclone, they appear to have a double symmetry—a symmetry round a point, and a symmetry about a line. The rain area, cloud ring, and general rotation of the wind are obviously related to a point, the centre of the cyclone. On the contrary, the quality of the heat, the relative humidity, the character of the clouds, and a particular line of squalls have nothing to do with a point, but are related to the front and rear of the line of the trough.

No attempt has been made as yet to discover the origin of these trough phenomena; but from the results of his researches in th

tropics, the author was led to consider the relation between the intensity of the trough phenomena and the velocity of propagation of the cyclone. For this purpose he examined the meteorograms, published in the 'Quarterly Weather Reports' of the Meteorological Office, for all well-defined cyclones in the years 1872–76, and for part of the year 1879. The intensity of the trough phenomena was gauged by the amount of the effect of the squall on the barometric trace, and the suddenness of the shift of wind at the same time.

The result is given in the following table, by which it is evident that there is a decided relation between the velocity of the cyclone and the intensity of the trough phenomena.

Table showing the Connexion between the Intensity of the Trough Phenomena and the Velocity of a Cyclone.

Year.	Month.	Day.	Velocity of cyclone. Miles per hour.	Intensity of trough phenomena.	Remarks.
1872 ...	Aug.	10	16	Very slight	
" ...	Sept.	25	6	No trace	
" ...	Oct.	10	13	Very slight	
" ...	Dec.	8	19	Slight	
" ...	"	16	16	"	
1873 ...	Aug.	28	16	"	
" ...	Sept.	15	19	"	
1874 ...	April	13	27	Moderate	
" ...	Aug.	13	13	Slight	
" ...	Oct.	21	24	Moderate	
" ...	Nov.	29	12	Moderate (Kew)	Strong at Falmouth; earlier in course when velocity unknown.
1875 ...	Jan.	21	48	Strong	
" ...	"	24	25	Moderate	
" ...	Sept.	26	29	Strong	
" ...	Nov.	19	35	Moderate	
1876 ...	March	12	40	Strong	
" ...	"	14	6	Very slight	
" ...	"	25	10	No trace	
1879 ...	Dec.	28	70	Very marked	The Tay Bridge storm.

The author has made many efforts to find traces of a central spot of blue sky in the centre of a British cyclone. He has never observed one himself, and though such cases have been reported, he is not satisfied with the evidence. It is very common to see a patch of blue sky directly after the passage of the trough, some distance from the centre on the southern side of a cyclone, and soon to experience wind and rain continuing for some time afterwards; but

this is quite different from the central calm and blue sky of a tropical hurricane. Though he cannot say that a clear-centre cyclone never occurs in this country, it is perfectly certain that the phenomenon is very rare.

Indian Cyclones.

Attention will now be directed to Indian cyclones.

The result of the author's investigations, both of the published records of the various Indian meteorological departments and from verbal communications, gives the following as the general character of Indian cyclones.

The shape is usually oval; but the side towards which the isobars are pressed, and the consequent lie of the longer diameter, varies much, even in the same cyclone on different days.

The diameter is smaller than in the Atlantic; but pressure diminishes much more rapidly near the centre than in Europe, though the actual *minimum* need not be very low.

The general surroundings, the formation, development and dissipation of cyclones seem to be essentially the same as in Europe. There are two types of cyclones in the Bay of Bengal. Those in May are associated with the breaking up of a belt of high pressure, in a manner to which we find many analogies in Great Britain; while those in October are formed in a general depression over the Bay, exactly analogous to the commonest conditions of cyclone formation in the Atlantic.

Secondaries sometimes form on the side of the primary cyclone, but not nearly so often as in the temperate zone.

The motion of the cyclone is almost invariably towards the N.N.W. or N.W. at first, with a marked tendency to recurve towards the N. and N.E. later on.

The velocity of translation is much less than in Europe, varying from about 3 to 20 miles an hour.

The rotation of the wind is always in an in-going spiral; but there does not seem to be any marked tendency to greater or less incurvature in any particular quadrant of the cyclone. The violence of the wind seems to increase as the centre is approached, which is not the case in the British Isles.

The author does not think that there is sufficient evidence for the assertion that the centre of wind rotation is not coincident with the barometric centre of the cyclone. In the cases that have been reported on board ship, which he has investigated, he is unable from the materials at his disposal to separate the barometric change due to the motion of the ship in her course from that due to the motion of the cyclone.

For instance, if a ship were motionless, and a cyclone passed over

her, the whole of the changes in the height of her barometer would be due to the motion of the cyclone. If the cyclone were both motionless and of constant depth, while she moved, the barometric changes would be due to her passage from a place of higher to a place of lower pressure, or *vice versâ*. In practice, the ship and cyclone are always both moving, and as an additional complication the cyclone is often increasing or decreasing rapidly in depth. Hence the difficulty of dealing with observations near the centre of a small cyclone. Suppose a ship was lying-to a short distance in front of the central point of the cyclone, but that the depression was filling up very rapidly. Her barometer would begin to rise before the centre passed over her, while the wind would not change till the vortex had passed. Then it would probably be reported that the centre of wind rotation was not coincident with her barometric *minimum*. The centre of wind rotation would, however, have been always really coincident with the centre of the isobars at any particular moment. The whole question deserves further attention. It should be noted that the blue centre is also sometimes reported as non-coincident with the barometric *minimum*.

There are very few observations on the motion of the upper clouds, but so far as they go, the general circulation of the air in a Bengal cyclone appears to be identical with that in higher latitudes.

There are no sufficiently detailed observations to enable us to construct synoptic charts of the distribution of rain, cloud, &c., round a cyclone; but by generalising the sequence of weather in many such depressions, we find squalls, showers, and dirty-looking clouds all round the cyclone, with more violent squalls and torrential rain surrounding the centre. The actual centre is always calm; and though blue sky does not seem to have been always observed, a cessation of rain is usually reported.

This clear "bull's-eye" is the most characteristic feature of a tropical cyclone. Otherwise the only difference is that the rear of the disturbance is not so clear in Bengal as in temperate cyclones; and that squalls are formed all round the centre instead of only in the right rear of the depression.

The sequence of weather to any observer appears to be as follows:—The first indication is always a strange coloration of the sky at sunrise and sunset. The author has examined this point carefully, and discovered that abnormal colours are developed not only before the barometer has begun to fall at the place of observation, but before any appreciable depression can be found anywhere on the synoptic charts. He has observed the same in England, and the fact is important, as it proves that the examination of synoptic charts can never supersede the necessity of observations on the appearance of the sky.

As the cyclone approaches, a peculiar uneasy way of blowing of the wind is sometimes reported, and the sky grows dirtier and dirtier till the rain appears to grow out of the air. This has always been described to the author as characteristic of cyclone rain, in opposition to the showery rain from cumuloform clouds which is typical of the ordinary precipitation of the monsoon.

This peculiar cyclone rain seems to be only an intensification of the rain associated with cyclones in Great Britain. There we see the blue sky grow pale and sickly, and then grey, till rain falls from a uniform gloom, and not from any defined cloud. In thunderstorm rain, on the contrary, we see mountainous cumulus above the rain.

Sometimes the front of an Indian cyclone is accompanied by thunder and lightning; but all observers are agreed that the absence of electrical disturbance is a sign of very bad weather.

As the cyclone approaches the rain increases, and the wind rises into the characteristic squalls of a hurricane.

The author has been able to find very few signs of any trough phenomena during the passage of a Bengal cyclone. Sometimes a rather sudden shift of wind is described, and a squall with a sudden jump of the barometer, just as is so common in England; but there does not appear to be the immediate change in the character of the clouds which occurs in these islands.

Almost all reports agree that the weather is quite as bad in rear as in front of the cyclone; and the clouds in rear seem to retain their characteristic wild and dirty appearance. The bad weather, however, usually extends much further in front than in rear of the centre.

Besides these primary cyclones there is another class of small oval depressions, which might either be called primary or secondary, according to the judgment of the meteorologist.

These form in the Bay of Bengal during the rainy season—from June to September—and though they are much less intense than the storms we have just described, their shape and the rotation of wind round them unmistakeably define their cyclonic nature. The wind round them is never strong; their special characteristic is rain. It has also been observed that they traverse the land and moderate mountain chains without material disturbance of their shape, while the great cyclones are invariably broken up or deflected as soon as their centres touch the coast.

It has been suggested, with a great deal of probability, that these small cyclones are formed at a higher level in the air than the larger ones. They will not be further considered in this paper.

The following examples will illustrate these facts. In figs. 2, 3, and 4 we give synoptic charts for India and the Bay of Bengal for the three days May 16—18, 1877. These and the extracts from ships'

logs are derived from an exhaustive memoir by Mr. J. Eliot, Meteorological Reporter to the Government of Bengal, entitled 'Report on the Madras Cyclone of May 1877.'

The broad features of these three days are very simple. In all the highest pressure lies over Burma and the eastern side of the Bay of Bengal, while a cyclone which has formed to the east of Ceylon passes up the western side of the Bay in a generally northerly direction. On every day the cyclone is oval, the longer diameter approximating in direction to the line of propagation; but while the isobars are packed towards the rear of the cyclone on the first two days, the centre is very decidedly pressed towards the front on the last day.

The cyclone increased half an inch in depth between the first and second days, and the last day especially the steepness of the central

FIG. 2.

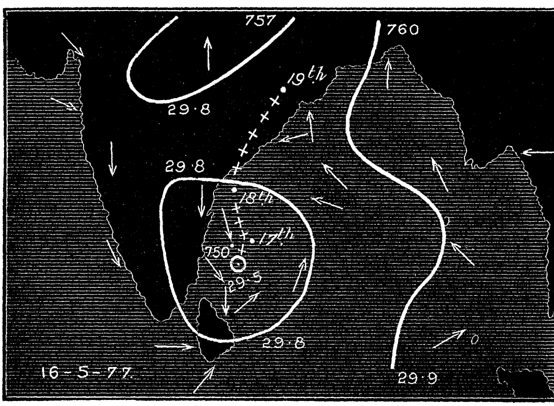


FIG. 3.

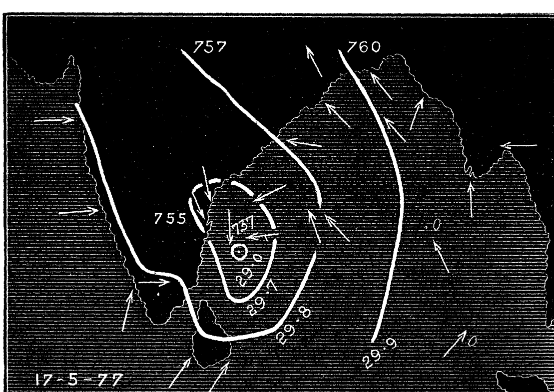
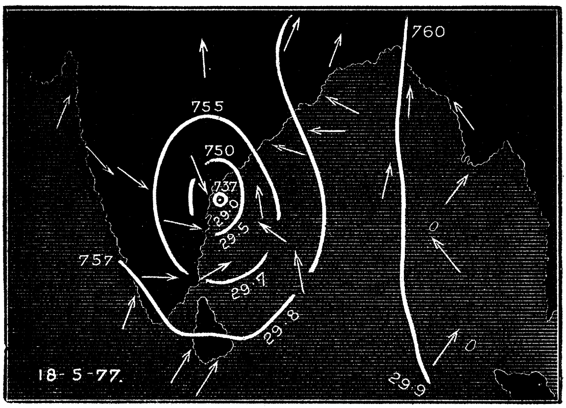


FIG. 4.



Figs. 2 to 4 : Cyclone in the Bay of Bengal. May type.

depression is very noticeable. The small scale of the charts does not permit of the isobars being drawn at regular intervals, or this fact would have been still more obvious. The numbers 760, 757, &c., are the approximate equivalents of the isobars in millimetres.

The path of the cyclone is given in fig. 2. The velocity of propagation was—

From 16th to 17th	......	4·3	miles per hour.
,, 17th ,, 18th	......	8·7	,, ,,
,, 18th ,, 19th	......	17·5	,, ,,

The rotation of the wind as an in-going spiral, counter-clockwise, is very obvious, and calls for no remark.

The following extracts from ships' logs will sufficiently illustrate the sequence of weather in this cyclone:—

The "Mistly Hall," on the west side of the cyclone, remarked a fiery sunrise as early as the 14th May, before the barometer began to fall. On the 15th and 16th she experienced rain, lightning, and squalls from N.E. to N. On the 17th, two hours after the barometric *minimum*, the wind went from N.W. to S.W., with lightning, torrents of rain, and terrific gusts. Twelve hours later the storm moderated.

In this report we see little trace of trough phenomena. The apparent non-coincidence of the wind sequence with the barometric *minimum* cannot be fully discussed for want of sufficient observations. There does not appear to have been any rapid filling up of the cyclone this day, as, on the contrary, the lowest reading report on the 17th is 29·043 inches, and on the 18th rather less, viz., 28·95. But we may

note a transference of the centre from the rear to the front of the depression, and we cannot determine the course of the ship from the published log.

The "Bride," also on the west side of the cyclone, reports a very similar sequence of weather, and no marked trough phenomena.

The "Witch," which passed through the vortex, ran out of Madras Roads on the 16th, with threatening weather, thunder, lightning, and St. Elmo's fire on her mastheads. On the 17th she ran before the N.W. wind, with a heavy gale and more thunder and lightning, right into the vortex. Then she experienced a calm for 10 minutes, when the wind flew to the S.W., with a sudden rise of 0·2 inch in the barometer, and thunder, lightning, and rain for 12 hours afterwards. Then the gale began to break, but the sun rose on the 18th with a pale sickly sky, like gold, green, and blue all mixed together.

What we have most to notice here is the amount of electrical discharge all across the cyclone, the sudden rise of the barometer as the first squall burst from the S.W.—exactly analogous to what we so often see in England,—and the dirty sky in rear of the whole disturbance.

The "Oxfordshire" also passed through the vortex only a day after the "Witch." The weather was similar in both cases; but the mercury began to rise on board the former at least an hour, and to the amount of 0·2 inch, before the wind jumped to the S.W. The cyclone was, however, filling up fast now, for while the lowest reading on the 18th was 28·95 inches, that on the 19th was only 29·36, a difference of nearly 0·4 inch.

The "Asia" passed on the east side of the cyclone. She experienced rain and squalls on the 16th, and on the 17th also rain, squalls, and lightning, till at 5 A.M. that day the wind veered suddenly from N.N.E. or N.E. to E.N.E., just at the lowest point of the barometer. About four hours later the storm seemed to collapse rather suddenly. Here we may note a sudden shift of wind at the passage of the trough.

There is only one observation on upper clouds. The Master Attendant at Masulipatam reports that on the 19th, while the wind was from the E., the scud had a more southerly motion. This is the normal vertical succession in the northern hemisphere.

The above exemplifies the May type of Indian cyclone; the next illustration will show the more violent October type.

In figs. 5, 6, and 7 are given reductions of a cyclone which passed up the Bay of Bengal from October 30 to November 1, 1876. These and the extracts from ships' logs are entirely derived from another exhaustive memoir by Mr. J. Eliot, entitled 'Report of the Vizagapatam and Backergunge Cyclones of October, 1876,' our diagrams referring to the latter cyclone.

On the first chart for October 30, fig. 5, a large oval area of low pressure covers the Bay of Bengal; the probable position of the vortex is marked by a small circle, but no reading can be given there for want of observations.

By next day, October 31, fig. 6, the centre has moved towards the N.N.E., and the cyclone has increased enormously in depth. The lowest reading for the day, about 20 miles west of the vortex, was 28·1 inch. As the next isobar is marked 29·6, the steepness of the

FIG. 5.

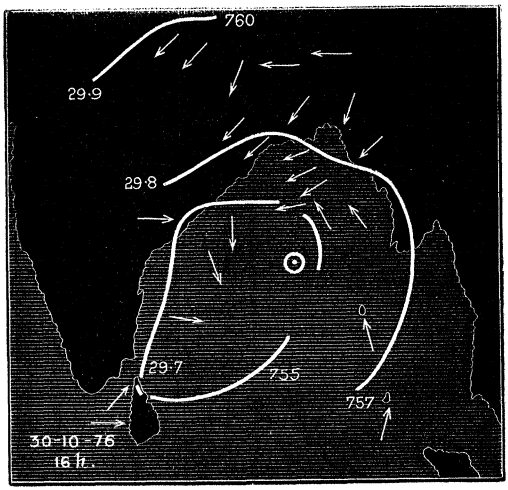


FIG. 6.

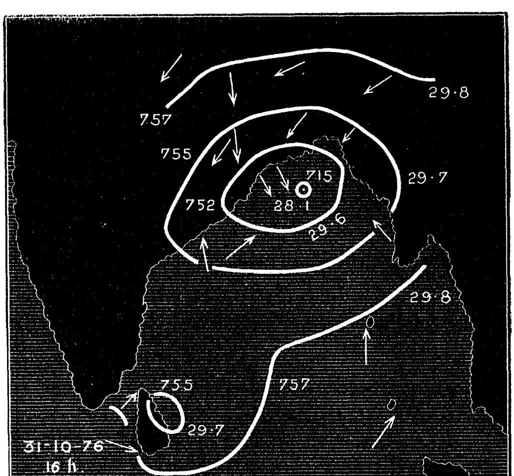
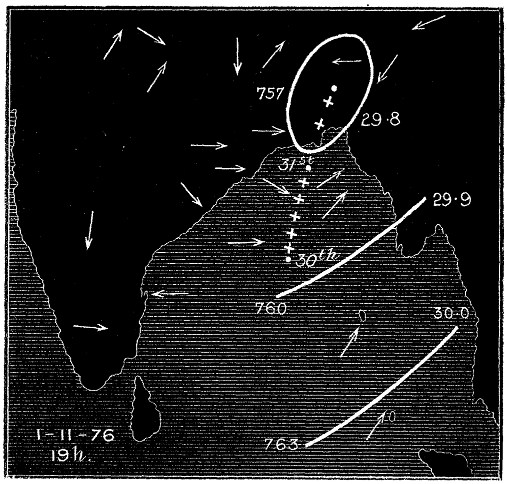


Fig. 7.



Figs. 5 to 7: Bengal Cyclones.
The Backergunge Cyclone.

central depression is of an amount unknown in higher latitudes. The longer diameter of the cyclone lies about east and west, or nearly at right angles to the path of the disturbance. The portion of the general depression which lay near Ceylon on the previous day has now developed into a well-defined secondary over that island. This is very interesting, as we very often see precisely the same thing in our own country, when a long oval depression gathers itself up into two regular cyclones, or into a primary and secondary.

By the third day, November 1, fig. 7, the cyclone is dying out over the delta of the Ganges, and the longer diameter is now nearly in a line with the direction of propagation.

The velocity of translation appears to have increased irregularly, but on the mean the rate was 9 miles an hour between the 30th and 31st, though during the last six hours the rate increased to 12 miles an hour, and no less than 22 miles an hour between the 31st October and 1st November.

The ship "Tennyson" passed about 20 miles west of the vortex. So early as the 28th the clouds had a bad appearance at daybreak. On the 29th the weather looked very bad, with lightning and squalls, while the barometer had begun to fall fast. During the 30th she had rain with furious gusts, but no lightning. By 11 A.M. on the 31st the wind went from N.E. to N.N.E., by noon to N., and by 1.30 P.M.—just as the barometer reached the *minimum* of nearly 28·0 inches—to N.N.W. with a perfect howl, but no rain fell from then to 6 P.M. No

lightning was seen any time during the day, and next morning was beautifully clear.

In this description the absence of lightning in the "kernel" of the cyclone is very noticeable; also, to a certain extent, the difference between the threatening clouds a long way in front of the centre and the beautifully clear sky in rear.

Thus, when we combine this with the sudden shift of wind and increased howl just as the mercury touched its lowest point, we see slight traces of trough phenomena.

The "Palmas" also passed to the west of the centre, and experienced slight trough phenomena. On the 31st she encountered thick rain with increasing gale from N.E., while the barometer fell fast. At 6 P.M., when the mercury marked 28·20—apparently its lowest point—she had the heaviest blow, the wind hauling to N.N.W. and N.W., with fearful vivid flashes of lightning, thunder, and rain. By 7 P.M., one hour later, the gale began to abate.

The "Allahabad" passed on the east of the centre. By the 29th a brickdust sunrise was observed, and by the 30th the weather became threatening, the wind from S. to E., but the clouds from S., with squalls and constant rain. On the 31st the cyclone commenced with fury from E.S.E., barometer falling fast with rain and lightning, and by 8 to 10 P.M., when the mercury touched its lowest point, the wind veered to S.E. and S.S.E. to S., with lightning and heaviest blow. By noon the next day the weather was fine.

Here, and in all the other logs, we should notice how much further the bad weather stretches in front than in rear of the cyclone. This also is exactly in accordance with our experience of temperate zone cyclones.

At Noakholly, on the Sunderbund coast, the moon shone clear in the "bull's eye" of the cyclone; and the observations point to the existence either of two separate vortices, or of a single oval one whose longer diameter was perpendicular to the line of propagation of the whole cyclone or parallel to the trough.

Typhoons in the China Seas.

Manila.—The author will now consider the nature of typhoons in the China Seas. These are very valuable, as they can be traced from their origin in the Philippines till they gradually acquire an extra-tropical character in the Japanese Islands. The notice will therefore commence with the author's researches in Manila, where, through the courtesy of Padre Faura, he obtained an immense amount of information, which has not hitherto found its way to England.

The general shape of typhoons in the Philippines is undoubtedly oval, but the side towards which the centre lies is not only variable,

but changes during the course of the same cyclone. On the whole, the centre seems to have a tendency to lie towards the front of the typhoon.

There seems to be very little tendency for cyclones to form secondaries in these latitudes, and therein they differ greatly from depressions in the Atlantic.

On the other hand, we find the same tendency for two typhoons to follow one another closely, and along the same path, which is such a characteristic feature of extra-tropical cyclones. For instance, the typhoon of October 20, which will be illustrated presently, had scarcely died out on the 22nd to the south of Hainan, before a new cyclone formed on the 23rd to the south of Panay—a little south of Manila—which also died out near Hainan, on the 27th. Then by November 3rd, another typhoon formed to the east of the Philippines, and traversed a line almost coincident with the path of the first cyclone.

The intensity of typhoons in the China Seas appears to be about the same as the October cyclones in the Bay of Bengal, but less than that of the hurricanes of Mauritius and of the West Indies.

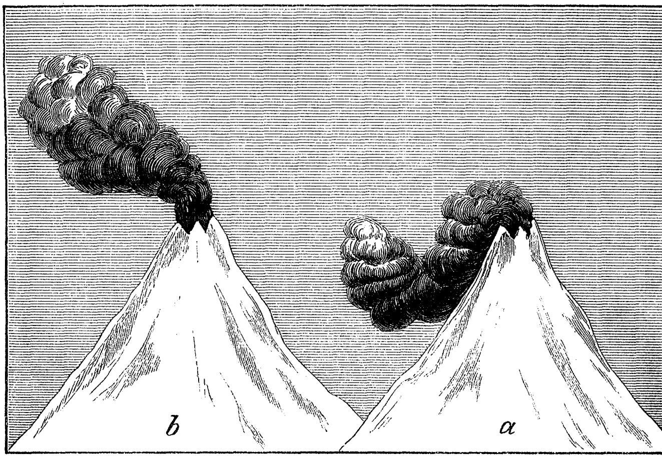
In the Philippines, as elsewhere in the tropics, a rise of the barometer very frequently precedes a typhoon; and much has been written about the relation of this high pressure area to the cyclone itself. No synoptic charts which have yet been constructed in the tropics are sufficiently detailed to enable us to say much on the subject; but so far as they go, the changes, or re-adjustment of pressure surrounding such an abnormal occurrence as a tropical hurricane, are precisely analogous to the changes which precede a temperate cyclone.

The weather in this high-pressure area is reported as beautifully fine, often with great visibility; and the formation of feathery cirrus on the blue sky is one of the first and most certain forerunners of a typhoon. This is exactly analogous to the "wedges" of high pressure, and very fine weather, which we find in front of many European cyclones.

But there is one phenomenon connected with the outskirts of a typhoon that has been observed by Faura, and which is so important and interesting that it may be described here. In the periphery of the cyclone, that is to say in the winds blowing two or three days before the storm from N. and N.W., the smoke of the chronically active volcano of Abayon, in the island of Albay, descends. During the typhoon no observations have been possible, owing to the low-lying nimbus; but when this breaks up, after the passage of the hurricane, the smoke is rising.

Fig. 8*a* represents the appearance of the smoke before, fig. 8*b* that after a typhoon, as shown in some sketches belonging to Padre Faura.

Fig. 8.



Volcano of Abayon.
a. Before typhoon.
b. After typhoon, and usually.

These sketches were shown to the author as proofs of a descending current in front of a typhoon, but he is not altogether satisfied with the evidence. It is very difficult to decide on such a question without personal observation. It has been suggested that the downward curl of the smoke was merely the vortex eddy on the lee side of the volcano, and that a similar phenomenon is obvious in any factory chimney during a high wind. The original sketches, however, did not the least convey that impression; and there must be some reason why the smoke does not curl that way with other winds. In England there is a well-known saying, that when smoke falls down rain may be expected. This is often true, and is undoubtedly due to some peculiarity in the way of blowing before certain kinds of rain, and not merely to the velocity of the wind. The author believes that the downward curl of the smoke of Abayon is due to some peculiarity in the wind preceding a typhoon, though he is not prepared at present to assume the existence of a regular downward current in the high pressure area that precedes the typhoon.

Some physicists have apparently doubted the existence of downward currents at all, on the ground that the stream lines of an air current must be tangential to the earth's surface, and that wind cannot slant downwards in the ordinary sense of the word. This would be perfectly true, if air were a perfect fluid, and wind blew like a continuous theoretical current; but in practice wind blows irregularly,

and forms eddies and vortices that break the continuity of the stream lines. As a matter of observation, nothing is commoner than to see a gust of wind blow down from a mountain on to a lake, and then ricochet up again.

The wind round a typhoon is always an in-going spiral. The incurvature is usually strong, but differs in every segment, not only in each cyclone, but even in the same cyclone at different periods of its existence. So much is this the case, that it seems impossible to give any mean incurvature for the Philippines. This is curious, for farther north the variation of incurvature seems more constant.

The motion of the lower nimbus is always more nearly parallel to the isobars, and therefore more nearly eight points from the bearing of the centre, than the surface winds. This is identical with the experience of European cyclones, and has an important bearing on the rules for handling ships at sea, though that question cannot be discussed here.

The observations of Padre Faura on the variation in the destructive effects of the wind in different parts of a typhoon, and the manner in which he uses this knowledge in forecasting, are so important and so unknown in this country, that the author proposes to devote one or two paragraphs to their consideration.

Faura finds that the position of the strongest winds relatively to the centre of the cyclone varies not only in every typhoon, but in the same one; and also that for the same velocity, the wind will unroof houses in one cyclone, but do comparatively little damage in another. He assumes that the unroofing wind is blowing slightly upwards, and the wind that does little damage moves horizontally or slightly downwards.

If then he can find evidence that the wind is rising up in front of a typhoon, he can be pretty certain that it will descend in rear; and therefore can and does forecast that the wind in that portion of the storm will be less destructive.

From all this, he has been led to the conception that the axis of a typhoon is inclined, and that it nutates during the progress of the vortex.

For instance, in the typhoon of October 20th, 1882—figured below—he believed that the wind in front was certainly rising and low; a beam lying near the sea, at a distance of 300—400 metres, was thrown upon the observatory (height 34 metres) and destroyed the Beckley's anemometer, while the roofs of many houses were pulled off. From this Faura concluded that the rear would not have the same force as the front, because the wind would be high and falling; and he published a notice at noon on the 20th—"The S.W. winds will be very short."—This prognostication was justified by the event.

The contrary took place in the typhoon which followed a few days

later on November 4th and 5th, the wind falling, as he considered, in front, and doing comparatively little damage.

Again in the typhoon of August 19th, 1881, the wind blew during eight hours with a rapidity of 44 metres a second, and nevertheless did not damage the roofs, because it did not hit from beneath, but from above.

These facts are very interesting, as similar observations on the variable destruction for equal velocities have been made by Piddington in Bengal; and the same has been observed on a much less pronounced scale in Great Britain. The utilisation of the idea in forecasting has, we believe, never been suggested by anyone except Faura; and his views are worthy of the most attentive consideration from those engaged in forecasting hurricanes.

Faura thinks that this can all be explained by the supposition that the axis of a typhoon is inclined to the earth's surface, instead of being truly vertical, and that the whole system nutates like a top.

The author, however, believes that there are insuperable difficulties in the conception of a nutating axis of a cyclone, though he does not propose to discuss the question in this paper. The idea that the variation of destruction for the same velocity was due to a slant in the wind has often been suggested before, and though slanting gusts undoubtedly occur, he is not prepared to pronounce a definite opinion on the question, from the evidence at present available. His object in introducing the subject here, was to point out how the variability of destruction can be used in practical forecasting, even if Faura's theory cannot be maintained as a whole.

The weather in and surrounding a typhoon is very characteristic. The whole storm is surrounded by a ring of cirrus. Halo is an almost constant precursor of a cyclone, and is sometimes seen in rear. The author made special enquiry on this point, for herein tropical differ very much from extra-tropical cyclones. In Great Britain we rarely see cirrus of any description in rear of a cyclone, still less the formless ice-dust called *cirro-nebula* by Ley, which is almost essential to the formation of halo.

The form of cirrus in this ring, especially in front, is typically that known as "cat's tails" or "cock's plumes" (*rabos de gallo*); and there seems to be a tendency for the lines of cloud to radiate from the vortex. This idea was first suggested by Padre B. Viñes of Havana, but requires further investigation, for the author was informed at Hong Kong that they had not observed that allineation there.

All observers are agreed that here, as elsewhere, cirrus is seen before the barometer begins to fall.

Inside the cirrus comes a ring of dense black cloud, and then a smaller ring of heavy rain and dense nimbus. When a typhoon can

be observed approaching at a distance, mountainous cumulus are seen over this central rain.

But, just as in higher latitudes, the clouds in front are dirtier than those in rear of the trough; for when, in the latter portion of the typhoon, the fracto-cumulus begins to break, either blue sky or firm fracto-cumulus becomes visible.* Thus trough phenomena appear to be only slightly marked in the Philippines, but very much information on this point could not be procured.

Lastly in the vortex of the typhoon we find the "bull's-eye" or calm clear spot, a few miles in diameter, surrounded on all sides by the fury of the hurricane. Many accounts received agree in saying that light cirri are usually seen over this area, that near land this space is full of birds taking refuge from the terrific surrounding squalls, and that the heat is suffocating. During the passage of the vortex over Manila, on the 20th October, the thermometer rose rapidly, and the relative humidity decreased to an extent hardly known in the driest months. The universal exclamation was "the air burns." In the succeeding typhoon, November 4th and 5th, no such central heat was observed, but the intensity of the cyclone was much less.

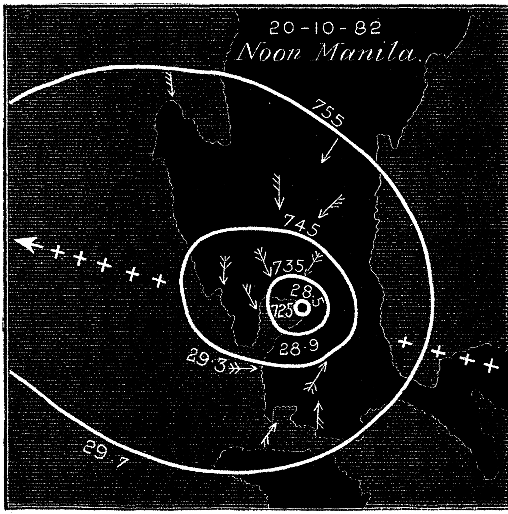
The instrumental observations at Manila on these two occasions are almost unique; but there is no doubt that a clear hot central spot is a normal feature of tropical cyclones. The oppressive heat and great dryness would probably point to the existence of a slight down draft in the core of the cyclone. It is extremely difficult to form a definite conception of such a system of circulation, for there is not the slightest doubt that the main mass of air in the centre of a cyclone is rising. The only reasonable suggestion which has yet been made, has been proposed by Vettin and Sprung, who think that under certain conditions a local downward eddy is formed in the centre of an atmospheric whirl. We must, however, consider the question to be as yet unsolved, and there is no point in the mechanism of a cyclone to which more attention should be directed.

But the most remarkable point is that the blue centre does not always coincide with the barometric vortex. Sometimes the blue is in front, sometimes behind, sometimes to one side of the absolute *minimum;* and this has been considered as a proof of the inclination of the axis of the typhoon. This non-coincidence of the blue and of the barometric centre of the vortex has been noticed in every other hurricane country, but at present it is impossible safely to do more than record the fact for further investigation. The supposed non-coincidence of the centre of wind rotation with the barometric *minimum* has been noticed when discussing Indian cyclones.

All the characteristics of a typhoon are well exemplified in figs. 9

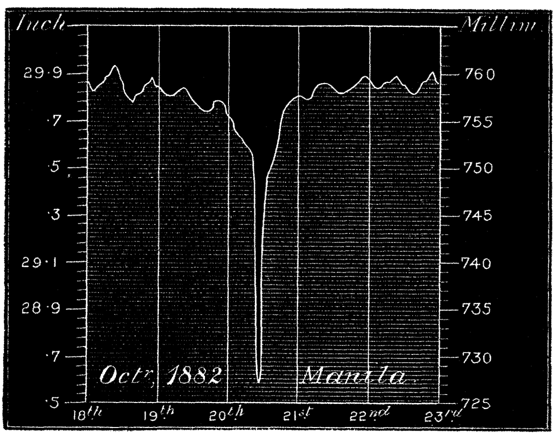
* Fracto-cumulus is a name applied at Manila to scud and irregular broken cumulus.

FIG. 9.



Typhoon in the Philippines, October 20th, 1882.

FIG. 10.



Barogram in Typhoon.

and 10, where reductions are given from two diagrams in the 'Observatorio Meteorológico del Ateneo Municipal de Manila. Observaciones verificadas durante el año de 1882.'

In fig. 9, the oval form, and centre displaced towards the rear, are almost identical in general character with the British cyclone given in fig. 1; only the sharpness of the central depression is much

greater. The isobars are drawn at intervals of 0·4 inch, and as the longer diameter is only about 315 miles, and the shorter one 245 miles, the intensity of the depression can be readily realised.

But perhaps this will be even more strikingly exhibited if we look at the barogram during the typhoon at Manila, as given in fig. 10. There we find many of the typical features of a tropical cyclone, in the strong diurnal variation of pressure on the top of the general diminution of pressure which preceded the typhoon by several days, and in the very sudden depression near the centre of the hurricane.

The incurvature of the wind is very pronounced; and it is, perhaps, important to note that the strong supposed rising impulse in front of the centre, to which we have already alluded, is associated with a rearward compression of the isobars.

The vortex was almost exactly centred over Manila at the moment for which the chart is constructed, and though the rain ceased and the overcast sky grew higher, there was no blue visible.

The velocity of the whole typhoon appears to have been about 19 miles an hour.

Hong Kong.—From Manila the author went to Hong Kong, where Dr. Doberck, of the Observatory at Kow-long, has been giving much attention to the subject of typhoons.

Among other interesting points, Dr. Doberck has remarked that he has never found any indications of secondaries dependent on a primary cyclone; that the vertical succession of upper currents is the same as obtains in higher latitudes; and that the incurvature of the wind is less in front than in rear of a typhoon. The last is identical with what Meldrum has found in the South Indian Ocean, but the contrary of what usually occurs in Great Britain. Dr. Doberck also considers that the incurvature of the wind in a typhoon decreases as the depression recedes from the equator.

There are many observations to the effect that the central calm does not coincide with the *minimum* of the barometer; but nothing has yet been remarked with reference to trough phenomena.

Thunder and lightning do not occur in the heart of the typhoon; but 600 to 800 miles to the S. or S.W. of the centre thunderstorms may be experienced.

Japanese Typhoons.

From Hong Kong the author proceeded to Tokiyo, in Japan, to study the transitional district between tropical and extra-tropical cyclones; and through the courtesy of Mr. E. Knipping and Mr. Y. Wada, he succeeded in obtaining most valuable information.

The result of all his researches may be briefly summarised as follows:—

The shape of Japanese cyclones is usually oval; but well-defined typhoons are more nearly circular than the ordinary depressions of that country. The latter are, however, as a rule, far more pronounced ovals than in Europe. As typhoons move into higher latitudes, they certainly tend to become larger, more irregular in shape, and to move with greater rapidity. The centre is almost always more or less displaced, but the longer diameter tends in a marked degree to lie nearly parallel to the line of propagation.

Secondaries seem to be rare on the sides of the primaries; but the latter have the same reluctance to traverse land, and the same tendency to follow one another along the same path, which are found so frequently in European cyclones.

The velocity of translation is greater than in the Philippines; but the July typhoons usually move more slowly than those in August or September.

Mr. Knipping thinks from observations on the upper clouds that the height of some typhoons does not exceed three-quarters of a mile, or about 4000 feet; but the author considers this estimate far too low.

The wind is usually less incurved in front than in rear of the centre; and at some distance in front, with a S.E. wind, the centre may bear S. This is a very important point with reference to handling ships, but cannot be discussed here for want of sufficient information. It is, however, quite certain that though the barometer may have begun to fall, a ship may not really be within the sphere of the typhoon.

Much information could not be got on the movements of the upper clouds. Some of the observations at Nagasaki are very discrepant.

The author believes, however, that there is not the slightest doubt that the general circulation of a typhoon is exactly similar to that in an extra-tropical cyclone, for Mr. Harries ('Quarterly Journal of the Royal Meteorological Society,' vol. 12, p. 10) has traced a typhoon from the Philippines across the Pacific and the United States into Europe. This, like all other long-lived cyclones, received accessions of intensity from time to time by fusion with other cyclones which had formed outside the tropics; and it is inconceivable that two eddies, circulating on different systems, could coalesce without destroying one another. Cyclones are supposed to have the same general circulation, or to circulate on the same system, when the whole body of the storm circulates in the same manner—in-going counter-clockwise below, tangential to the isobars at low levels, outgoing at the highest altitudes. Two such cyclones, near one another, can and do easily coalesce; but if the upper currents in a typhoon were essentially different from those in extra-tropical cyclones, two adjacent cyclones could not coalesce without destroying each other. Cyclones south of the

equator circulate on an opposite system to those in the northern hemisphere, and it is certain that a hurricane generated south of the line could not coalesce with one developed north of the equator.

All accounts agree that cirrus is seen all round a typhoon in Japan as at Manila, and that rain extends much further in front than in rear of the centre, as in higher latitudes. In some typhoons the development of squalls is far greater in front than in rear of the trough; and this is the opposite of what is found in England.

Lightning is sometimes seen in front of the centre of a typhoon, but apparently rarely in the true storm field.

Cirrus cloud is observed over the blue of the "bull's-eye," and Mr. Knipping informed the author that the clear central spot is not seen in quick-moving cyclones, while it is a very marked phenomenon of those whose progress is slow. This is a most important observation.

The "bull's-eye" and the centre of the wind's rotation do not appear to be always coincident with the barometric centre of the cyclone; but there are not enough land observations to enable the author to do more than note this point.

There are certainly traces of trough phenomena, though not strongly defined. Mr. Wada told the author that the clouds sometimes brighten a little about the passage of the trough, and then become dark again; but he had never noticed a line of squalls along the line of the trough.

Temperature is usually higher in front and lower in rear of

FIG. 11.

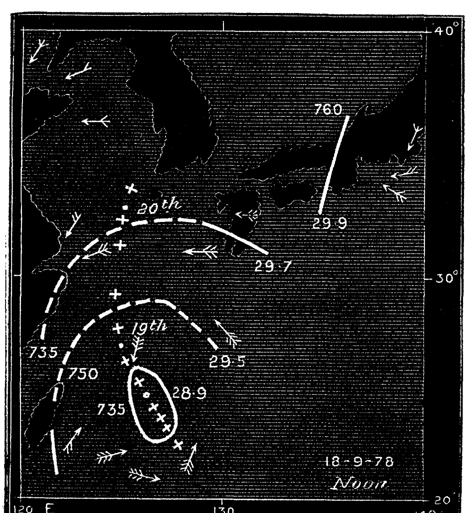


FIG. 12.

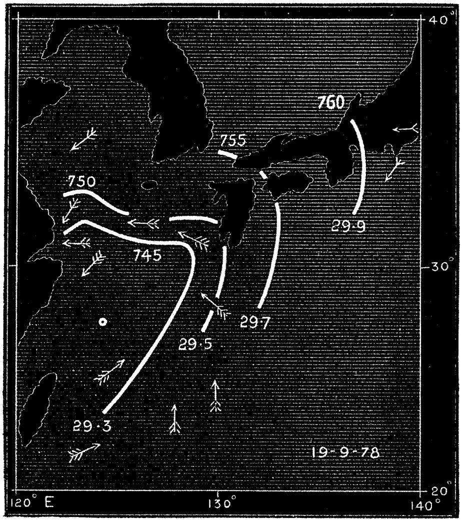
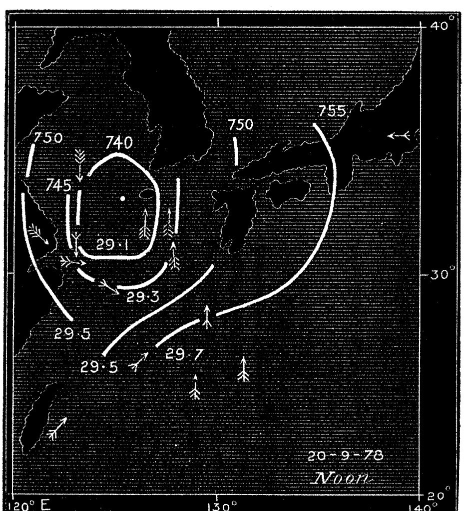


FIG. 13.



Figs. 11 to 13: Typhoon in China Seas.

Japanese typhoons, and here therefore they approximate more nearly to the European type of cyclones.

Most of the above characteristics of cyclones in the China Seas

are well illustrated by the diagrams given in figs. 11, 12, 13 of a typhoon which raged from September 18th to 20th, 1878, which are taken from Mr. Knipping's paper "The September Taifuns, 1878," in the 'Mittheilungen der Deutschen Gesellschaft für Natur- und Völkerkunde Ostasiens,' Heft 18, p. 333.

In figs. 11 and 13 the usual oval form and pressing of the centre to one side are very obvious; and on the intervening day, fig. 12, we find the typhoon in a transitional irregular form, with all the indications of secondaries. The intensity of the whole is also much less than in our example from Manila.

The mean velocity of translation was 10 miles an hour, but varied at times from 2·3 to 25 miles per hour.

The incurvature of the wind is obviously much less than at Manila; and the squalls were far more pronounced in front than in rear of the typhoon.

The rain also extended much further in front than in rear; and the improvement in the weather after the passage of the trough was very rapid.

The amount of precipitation was so great that Mr. Knipping calculates that no less than 30,000 million tons of water fell on the 19th September on the portion of the earth's surface lying between 30° and 35° N. lat., and 120°—130° E. long.

Mauritius.

The author does not propose to detail here his researches on hurricanes in the Mauritius, as they bear more on the great value of Mr. Meldrum's rules for handling ships in cyclones than on the subject of this paper. All that need be said here is that allowing for difference of wind rotation due to the southern hemisphere, the phenomena of a Mauritius hurricane are exactly analogous to those in the Bay of Bengal or in the Philippines.

He finds the same oval shape, with displaced centre, and the same variations in the shape during the progress of any particular hurricane. The wind is also very slightly incurved in front, and very markedly so in rear of the cyclone. Cirrus extends all round the storm field; a blue bull's-eye is almost constant; and any "trough phenomena" are very slightly marked. But, just as at Manila, when the nimbus breaks in rear the clouds are harder there than in front; and M. Bridet at Réunion has noticed that the squalls are rather worse when the barometer turns to rise, *i.e.*, along the trough of the cyclone.

The propagation of these hurricanes is usually very slow.

Western Pacific.

The author has also visited New Caledonia and Fiji to gather information as to the character of hurricanes in that part of the world. He was not, however, able to collect sufficient materials to justify him in saying more than that those hurricanes seem to differ from those in the Mauritius in little except their smaller intensity.

The subject of wind in cyclones has already been fully investigated in many countries, but the points on which further research is urgently required are:—1. The nature of the central "bull's-eye"; 2. The phenomena of the trough; and 3. The nature of the high pressure areas which immediately surround a cyclone.

[*Note.*—The difference of temperature in front and rear of all tropical hurricanes is much less than in extra-tropical depressions. At the outskirts of a hurricane, about the time that cirrus first begins to form in the blue sky, the heat is sometimes very oppressive. The thermometer does not rise much; but as the ordinary breezes have failed, and been replaced by a suffocating calm, and the increasing humidity diminishes the evaporation of perspiration, the quality of the heat is peculiarly distressing.

As the sky gets overcast and the rain commences, temperature always falls, and continues relatively low till the sun shines again after the disturbance has passed away. This cold appears to be simply due to the obscuration of the sun's rays by cloud, and possibly partly also to a little cold air being brought down by the heavy rain.

All this is very different to the temperature disturbance of a British cyclone. The thermometer rises in England rapidly after the sky has become overcast, and remains high until the trough has passed, when a notable diminution of temperature suddenly takes place.

In a tornado, the rise of temperature in front, and diminution in rear of the disturbance, are very marked, and so far diminish the analogy between a tornado and a hurricane.

Since this paper was in type the author has had an opportunity of studying Padre B. Viñes' 'Apuntes relativos á los Huracanes de las Antillas.' That work confirms all the peculiarities of tropical cyclones found in other countries.

In Cuba hurricanes have the same oval shape and displaced centre as in other tropical countries; and the same rise of pressure with unusually fine weather occurs just before the advent of the depression.

The wind is little incurved in front, but very much so in rear; and a clear "bull's-eye," surrounded first by a ring of squally rain and then by a fringe of feathery cirrus, is the normal distribution of weather round the centre of the hurricane. No trough phenomena appear to have been observed by Padre Viñes.—*Added June*, 1887.]

Conclusions.

The conclusions as to the relation of tropical to extra-tropical cyclones which the author has derived from the researches of which this paper gives an account may be stated thus :—

All cyclones have a tendency to assume an oval form; the longer diameter may lie in any direction, but has a decided tendency to range itself nearly in a line with the direction of propagation.

The centre of the cyclone is almost invariably pressed towards one or other end of the longer diameter; but the displacement may vary during the course of the same depression.

Tropical hurricanes are usually of much smaller dimensions than extra-tropical cyclones; but the central depression is much steeper and more pronounced in the former than in the latter.

Tropical cyclones have less tendency to split into two, or to develop secondaries than those in higher latitudes.

A typhoon, which has come from the tropics, can combine with a cyclone that has been formed outside the tropics, and form a single new, and perhaps more intense, depression.

No cyclone is an isolated phenomenon; it is always related to the general distribution of pressure in the latitudes where it is generated. The concentric circles, which are usually drawn to represent a cyclone, ignore the fact that a cyclone is always connected with and controlled by some adjacent area of high pressure.

In all latitudes pressure often rises over a district just before the advent of a cyclone. The nature of this rise is at present obscure; but the character of the unusually fine weather under the high pressure is identical both within and without the tropics.

In all latitudes a cyclone which has been generated at sea appears to have a reluctance to traverse a land area, and usually breaks up when it crosses a coast line.

After the passage of a cyclone in any part of the world there is a remarkable tendency for another to follow very soon, almost along the same track.

The velocity of propagation of tropical cyclones is always small, and the average greatly less than that of European depressions.

There is much less difference in the temperature and humidity before and after a tropical cyclone than in higher latitudes. The quality of the heat in front is always distressing in every part of the world.

The wind rotates counter-clockwise round every cyclone in the northern hemisphere; and everywhere as an in-going spiral. The amount of incurvature for the same quadrant may vary during the course of the same cyclone; but in most tropical hurricanes the incurvature is least in front, and greatest in rear, whereas in England

the greatest incurvature is usually found in the right front. Some observers think that, broadly speaking, the incurvature of the wind decreases as we recede from the equator.

The velocity of the wind always increases as we approach the central calm in a tropical cyclone; whereas in higher latitudes the strongest winds and steepest gradients are often some way from the centre. The portion of a cyclone which is of hurricane violence forms, as it were, a kernel in the centre of a ring of ordinarily bad weather. In this peculiarity tropical cyclones approximate more to the type of a whirlwind tornado; but the author does not think that a cyclone is only a highly developed whirlwind, as there are no transitional forms of rotating air.

The general circulation of a cyclone, as shown by the motion of the clouds, appears to be the same everywhere.

All over the world unusual coloration of the sky at sunrise and sunset is observed not only before the barometer has begun to fall at any place, but before the existence of any depression can be traced in the neighbourhood.

Cirrus appears all round the cloud area of a tropical cyclone, instead of only round the front semicircle as in higher latitudes. The allinements of the stripes of cirrus appear to lie more radially from the centre in the tropics, instead of tangentially to the isobars, as indicated by the researches of Ley and Hildebrandsson in England and Sweden respectively.

The general character of the cloud all round the centre is more uniform in than out of the tropics; but still the clouds in rear are always a little harder than those in front.

Everywhere the rain of a cyclone extends farther in front than in rear. Cyclone rain has a specific character, quite different from that of showers or thunderstorms; and this character is more pronounced in tropical than in extra-tropical cyclones.

Thunder or lightning are rarely observed in the heart of any cyclone, and their absence is a very bad sign of the weather. Thunderstorms are, however, abundantly developed on the outskirts of tropical hurricanes.

Squalls are one of the most characteristic features of a tropical cyclone, where they surround the centre on all sides; whereas in Great Britain squalls are almost exclusively formed along that portion of the line of the trough which is south of the centre, and in the right rear of the depression. As, however, we find that the front of a British cyclone tends to form squalls when the intensity is very great, the inference seems justifiable that this feature of tropical hurricanes is simply due to their exceptional intensity.

A patch of blue sky in the centre of a cyclone, commonly known as the "bull's-eye," is almost universal in the tropics, and apparently

unknown in higher latitudes. This blue patch does not apparently always coincide exactly with the barometric centre. The author's researches show that in middle latitudes the formation of a bull's-eye does not take place when the motion of translation is rapid; but as this blue space is not observed in British cyclones when they are moving slowly, it would appear that a certain intensity of rotation is necessary to develop this phenomenon.

The trough phenomena—such as a squall, a sudden shift of wind and change of cloud character and temperature just as the barometer turns to rise, even far from the centre—which are such a prominent feature in British cyclones, have not been even noticed by many meteorologists in the tropics. The author, however, shows that there are slight indications of these phenomena everywhere; and he has collated their existence and intensity with the velocity of propagation of the whole mass of the cyclone.

Every cyclone has a double symmetry. One set of phenomena such as the oval shape, the general rotation of the wind, the cloud ring, rain area, and central blue space, are more or less related to a central point. Another set, such as temperature, humidity, the general character of the clouds, certain shifts of wind, and a particular line of squalls, are more or less related to the front and rear of the line of the trough of a cyclone.

The author's researches show that the first set are strongly marked in the tropics, where the circulating energy of the air is great and the velocity of propagation small; while the second set are most prominent in extra-tropical cyclones, where the rotational energy is moderate and the translational velocity great.

The first set of characteristics may conveniently be classed together as the rotational; the second set as the translational phenomena of a cyclone.

Tropical and extra-tropical cyclones are identical in general character, but differ in certain details due to latitude, surrounding pressure, and to the relative intensity of rotation or translation.

"Conduction of Heat in Liquids." By C. CHREE, B.A., King's College, Cambridge. Communicated by Professor J. J. THOMSON, F.R.S. Received March 31,—Read April 21, 1887.

The conduction of heat in liquids has of late years been considered by several observers in Germany. In this country Mr. J. T. Bottomley and Professor Guthrie carried out experiments a good many years ago, but in neither case do the results agree well with those obtained abroad. In all the more recent methods the conduction has taken

FIG. 1.

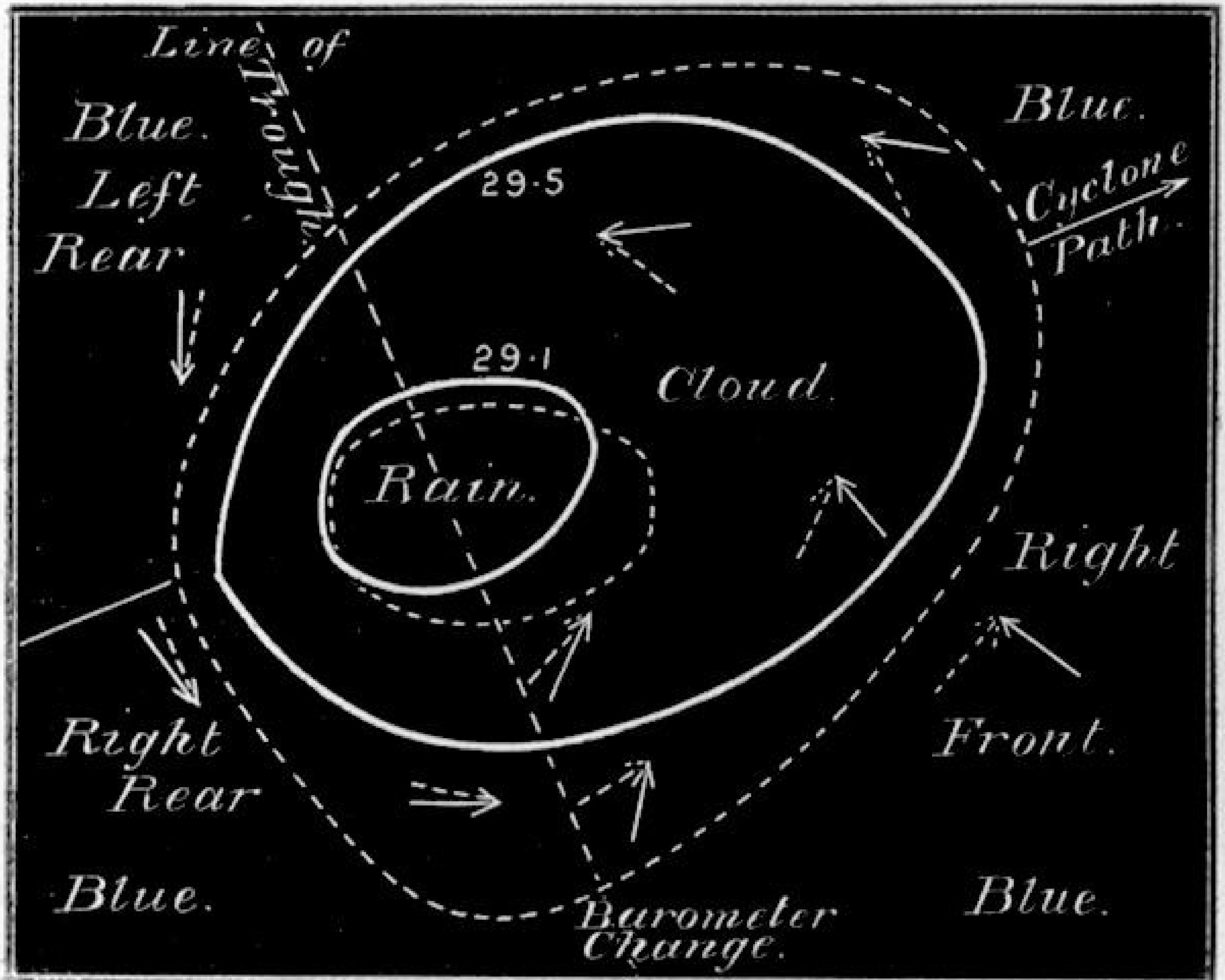


Diagram of cloud and rain in a British cyclone. The full lines are isobars, while the dotted lines define the areas of rain and cloud. The full-line arrows denote the direction of the surface winds, the dotted arrows that of the highest currents.

FIG. 2.

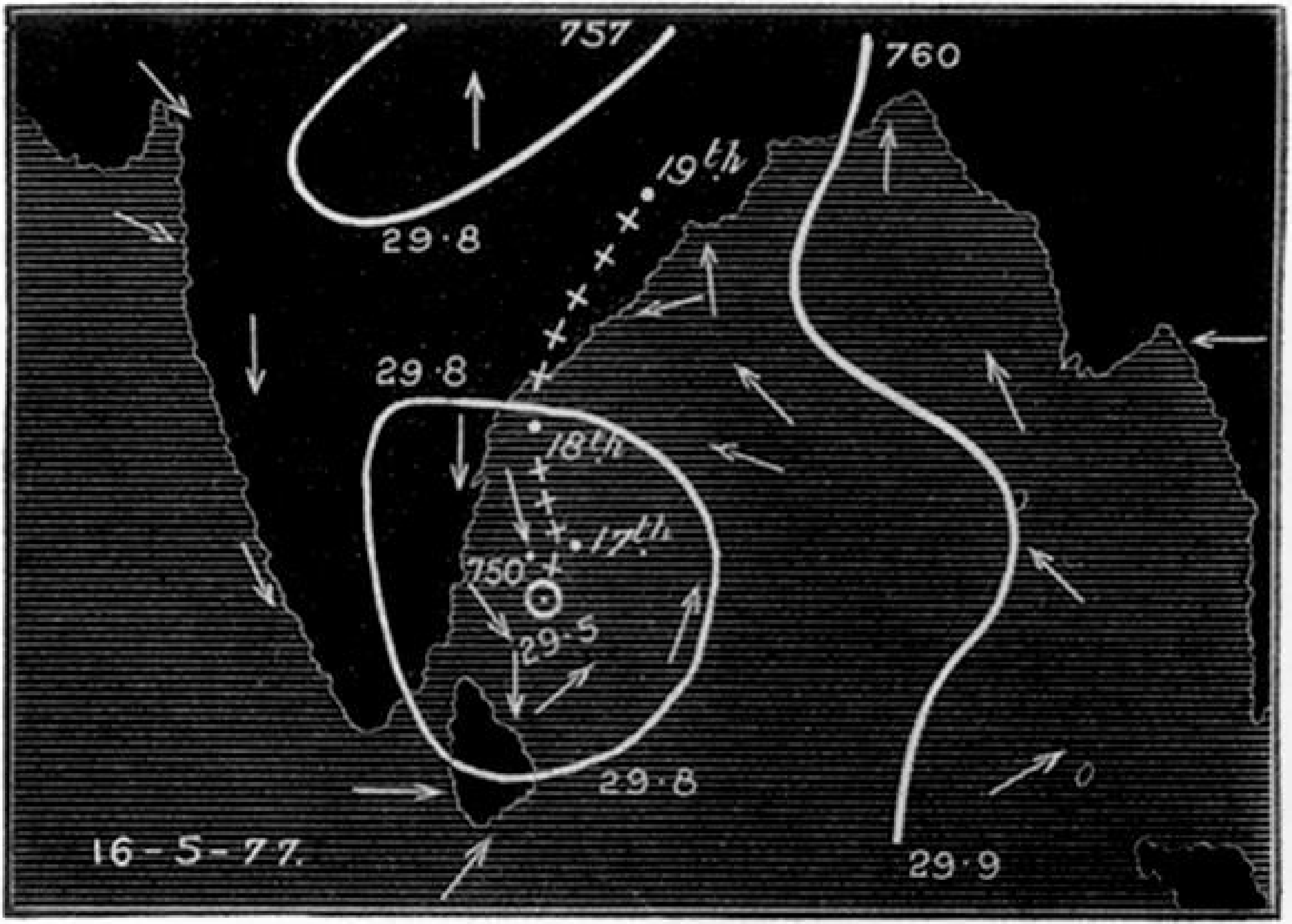


FIG. 3.

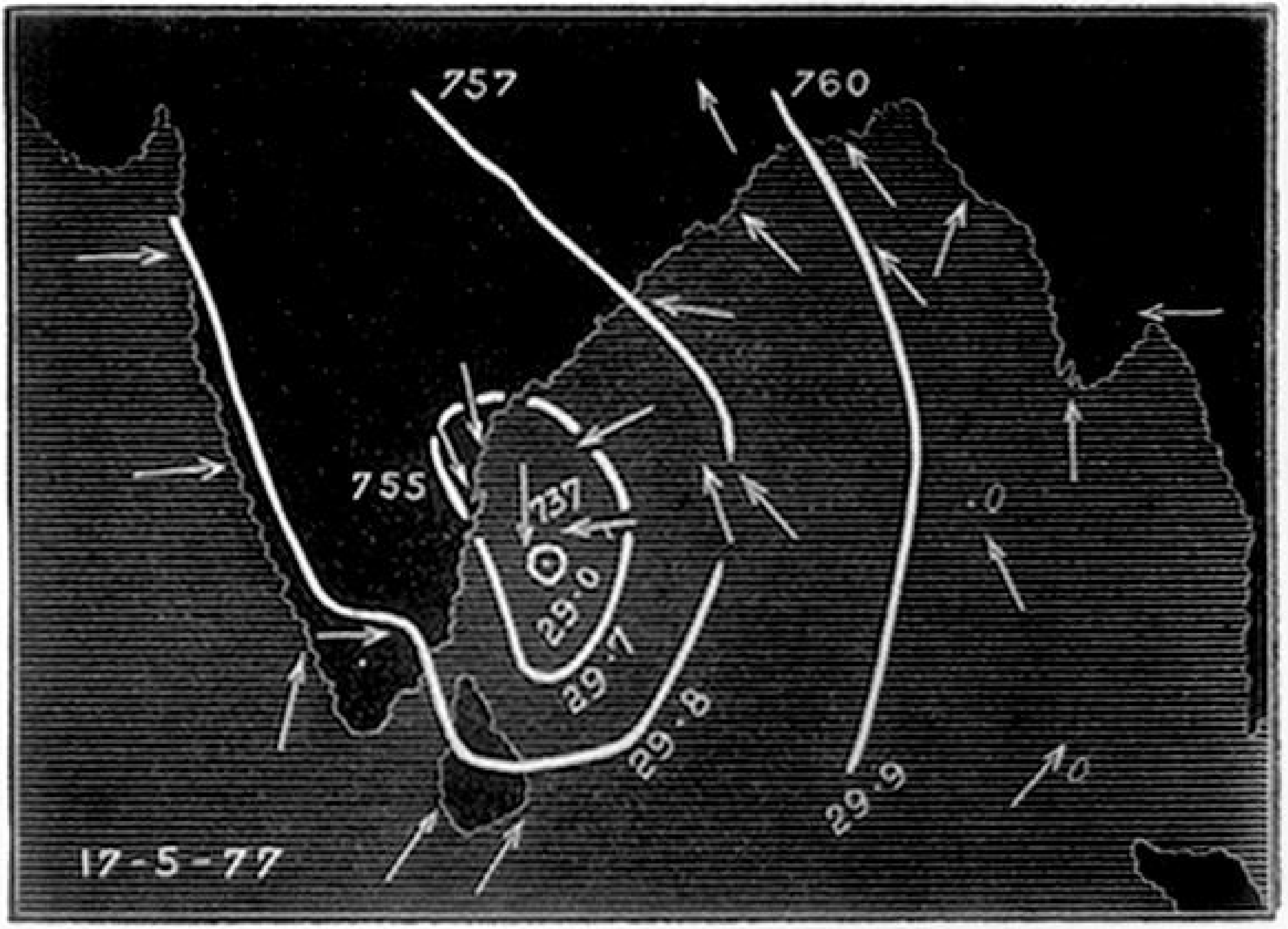
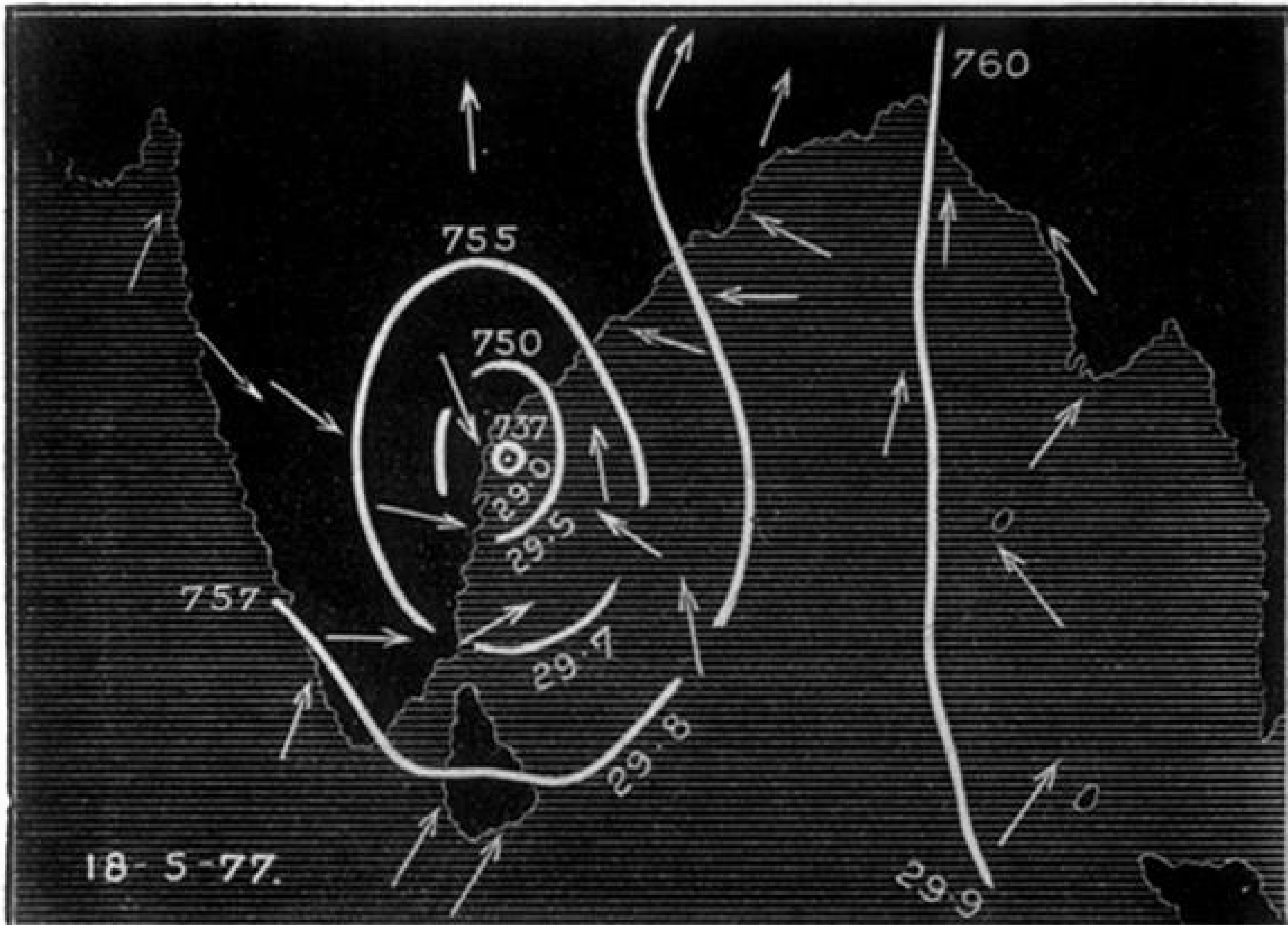


FIG. 4.



Figs. 2 to 4: Cyclone in the Bay of Bengal. May type.

FIG. 5.

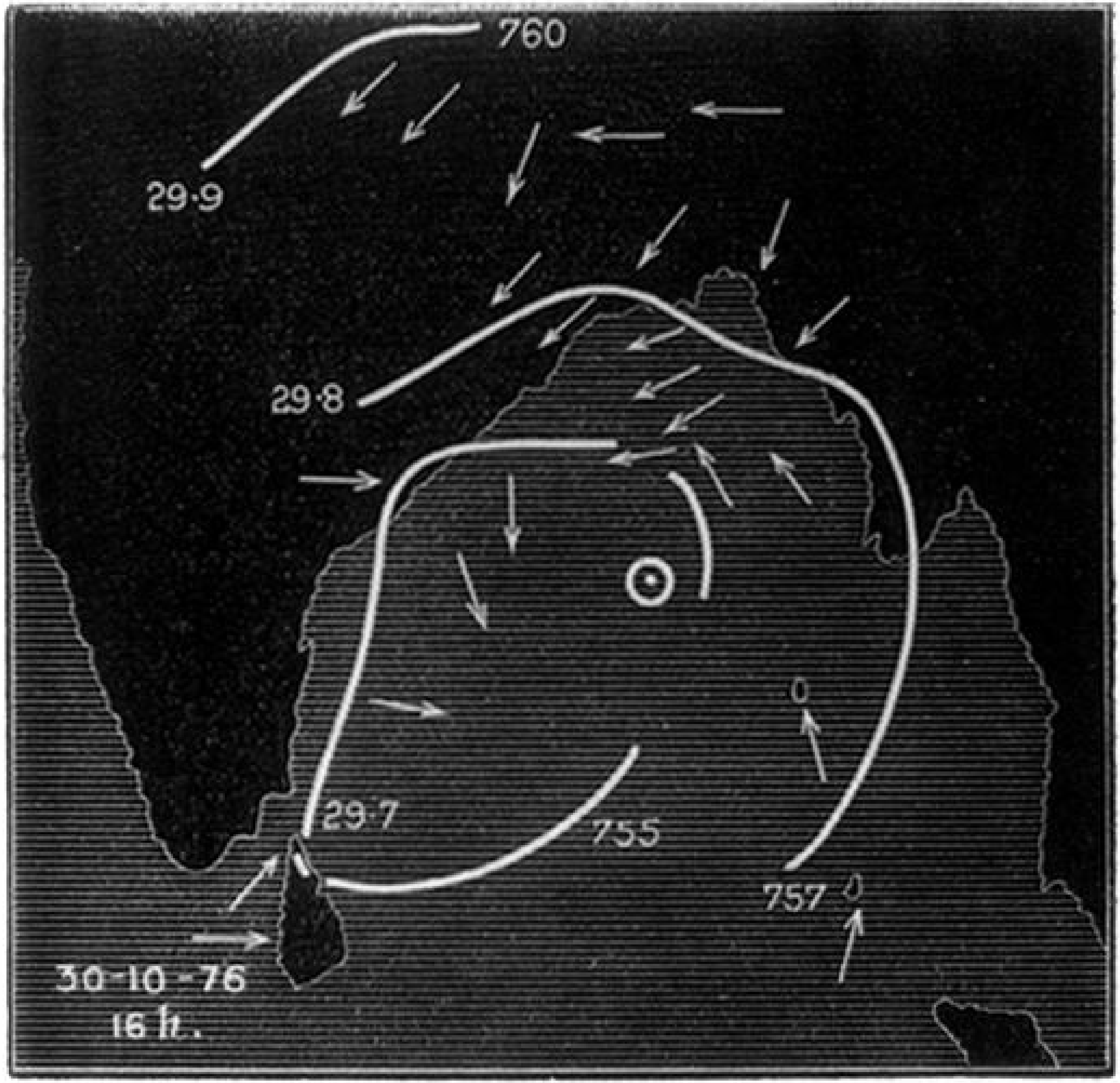


FIG. 6.

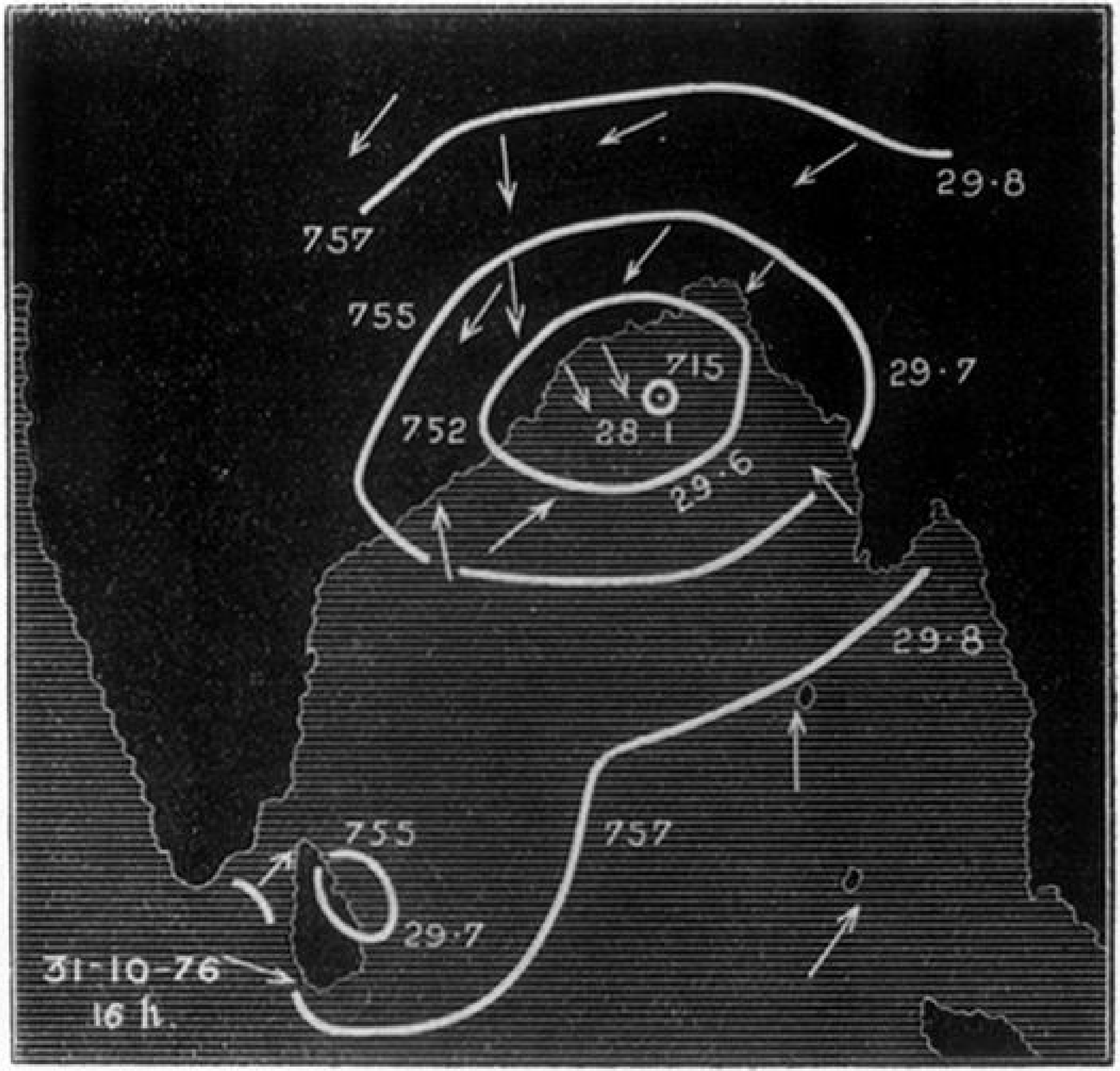
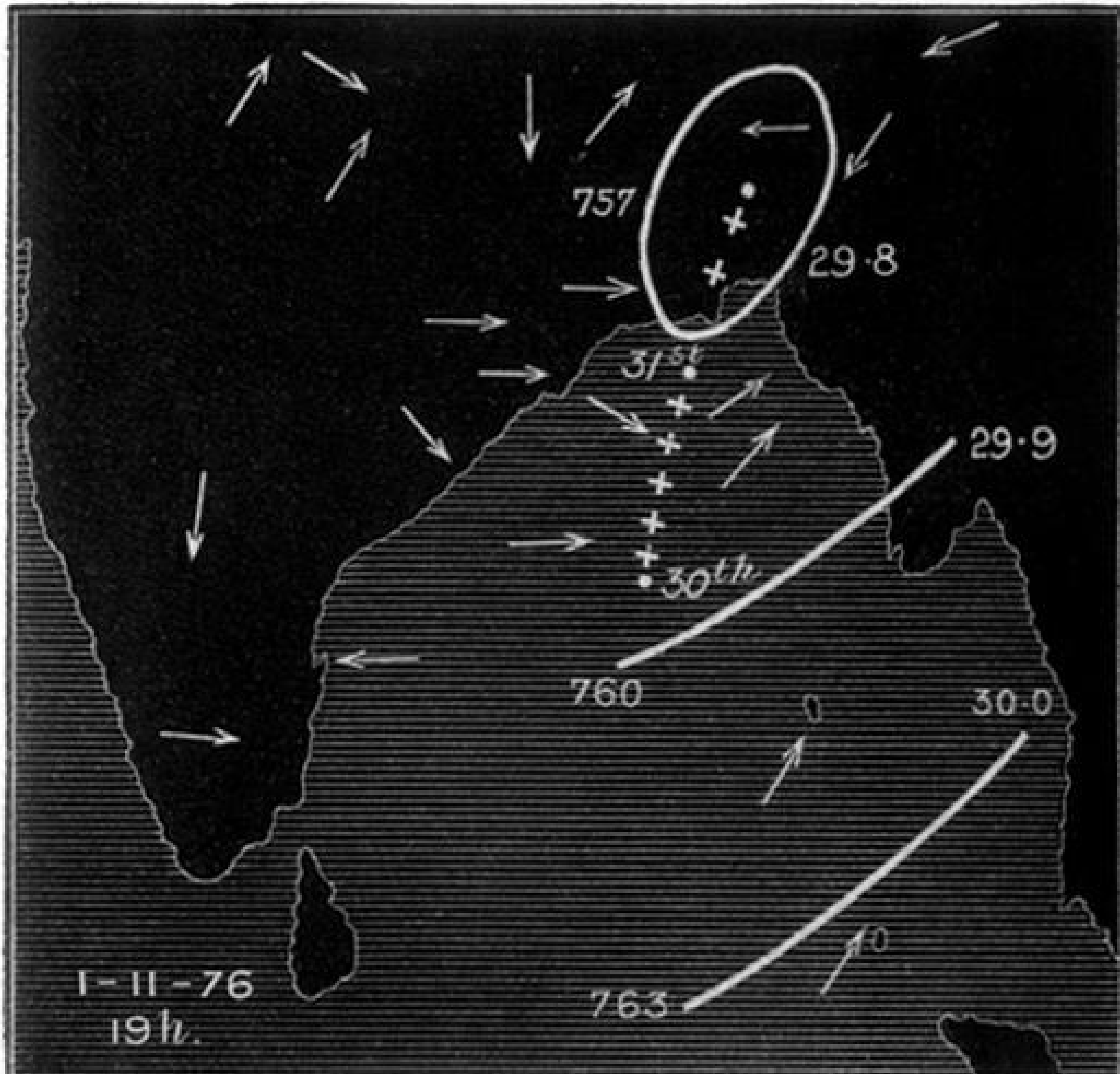
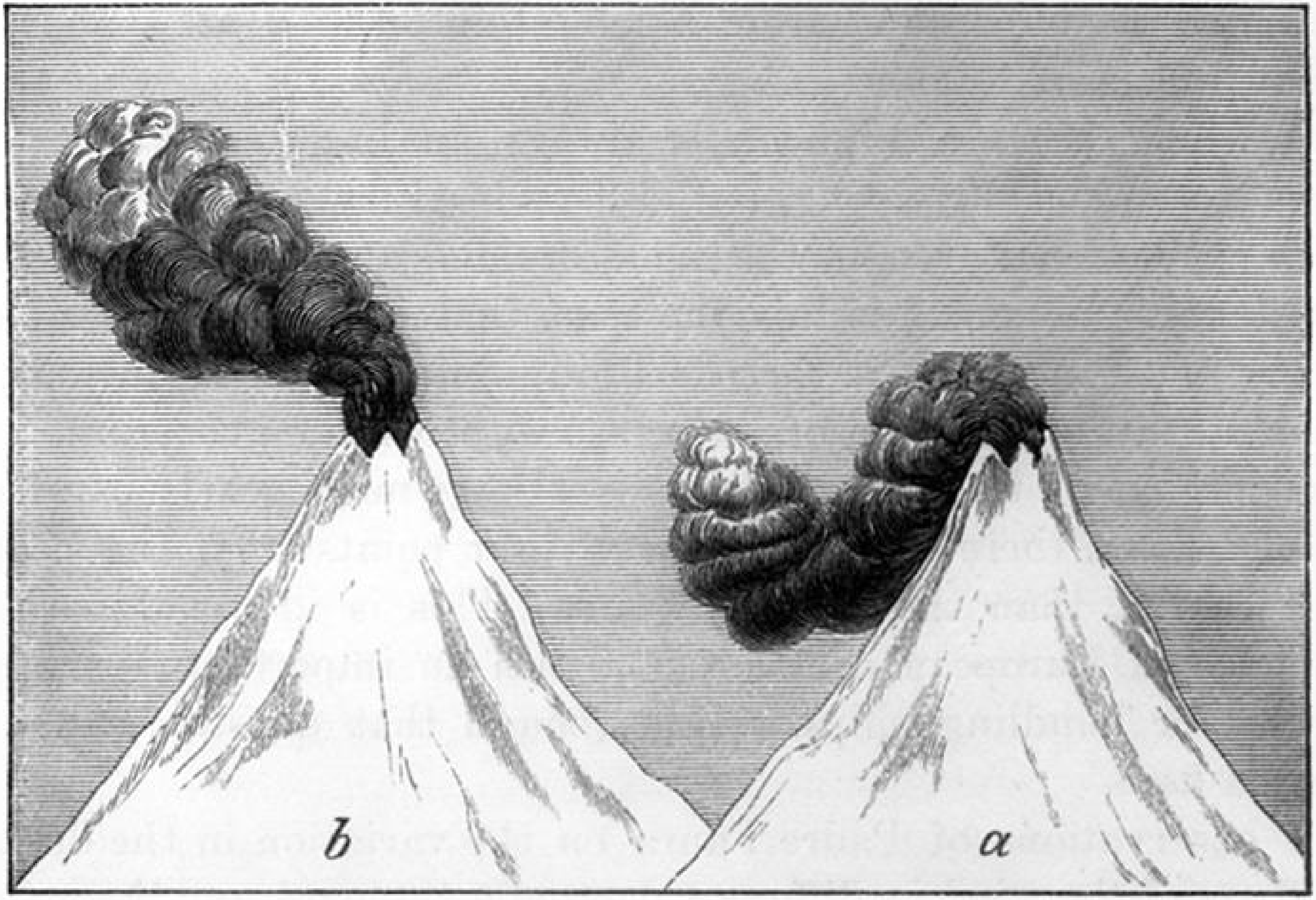


FIG. 7.



Figs. 5 to 7 : Bengal Cyclones.
The Backergunge Cyclone.

FIG. 8.

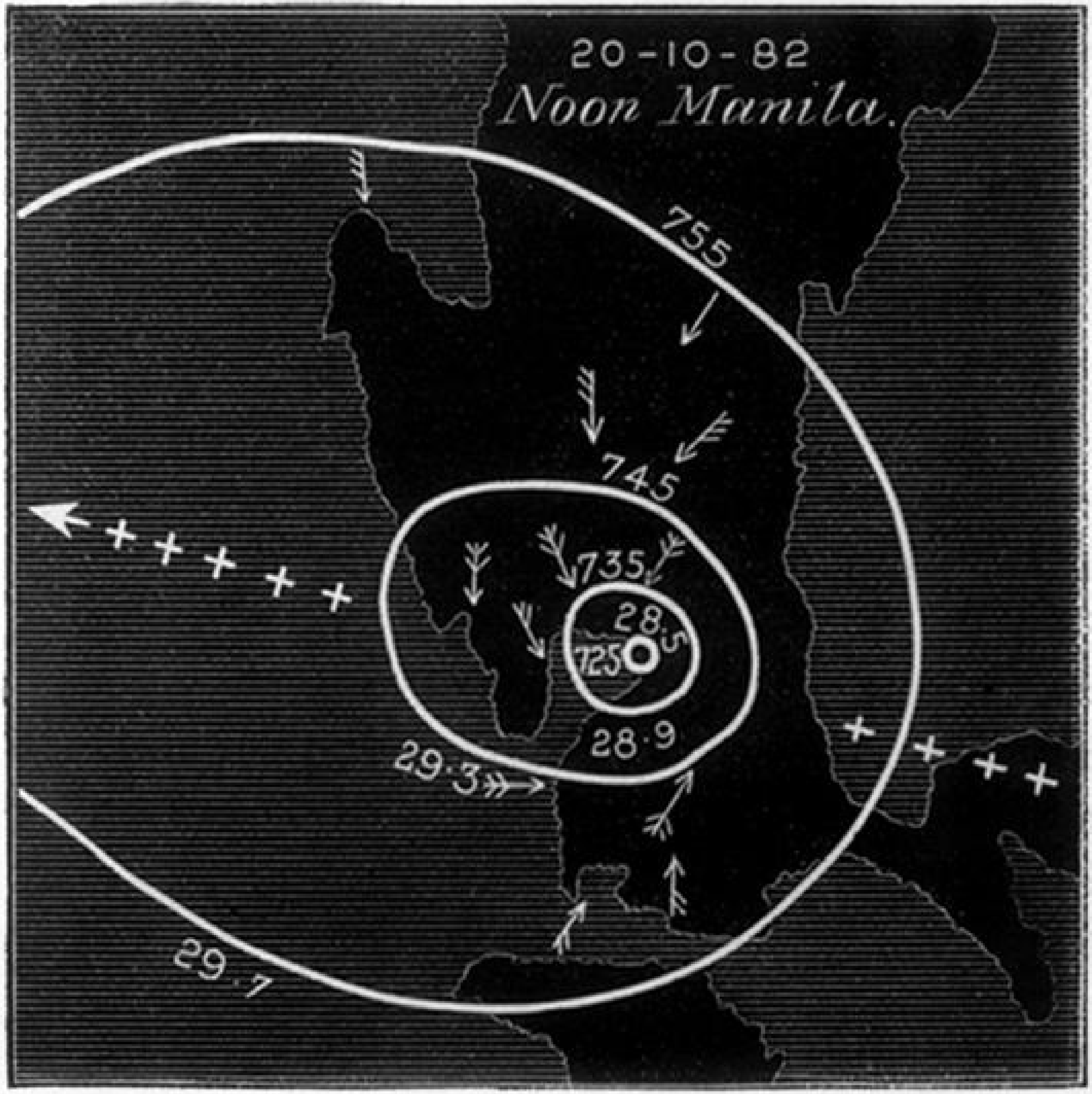


Volcano of Abayon.

a. Before typhoon.

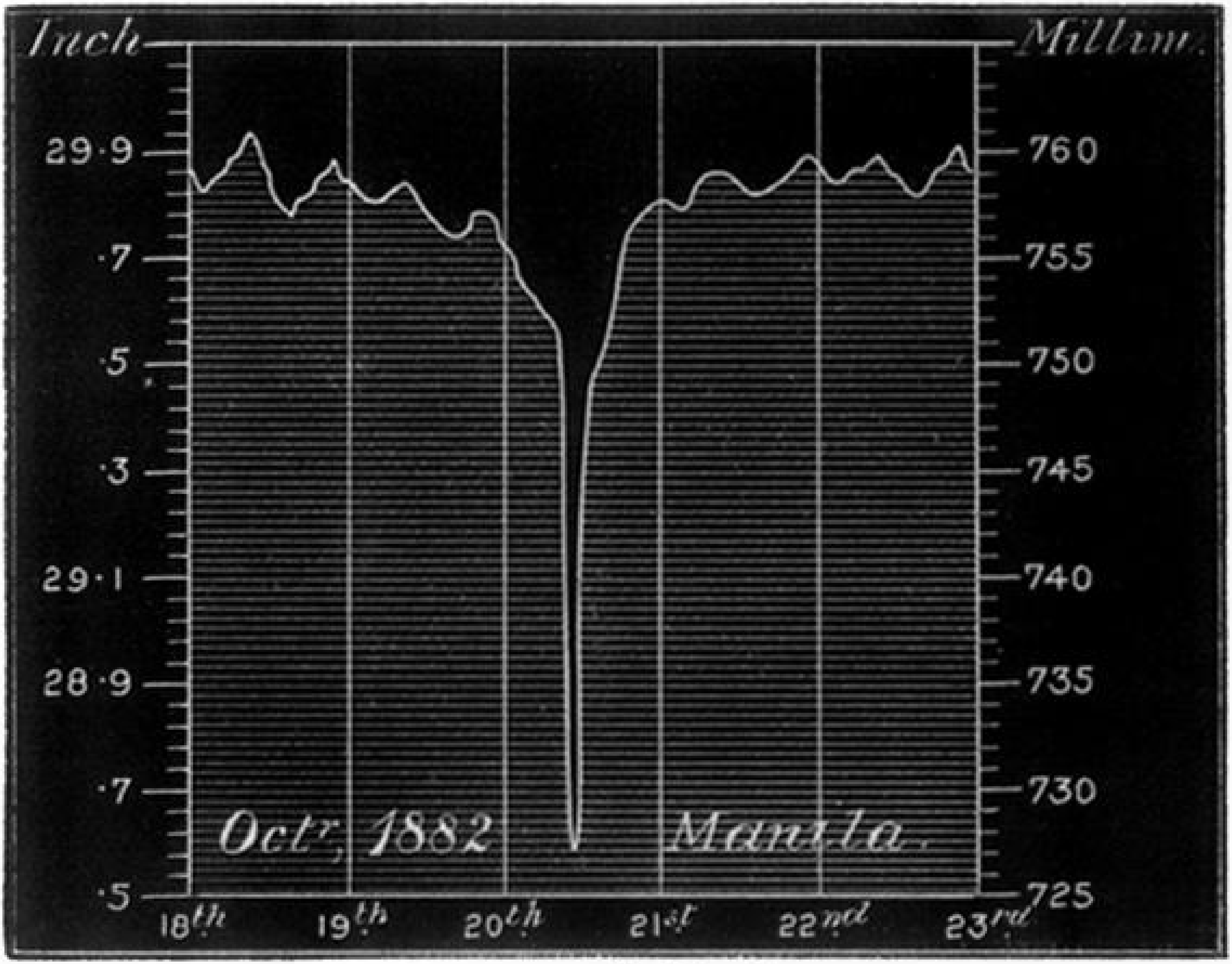
b. After typhoon, and usually.

FIG. 9.



Typhoon in the Philippines, October 20th, 1882.

FIG. 10.



Barogram in Typhoon.

FIG. 11.

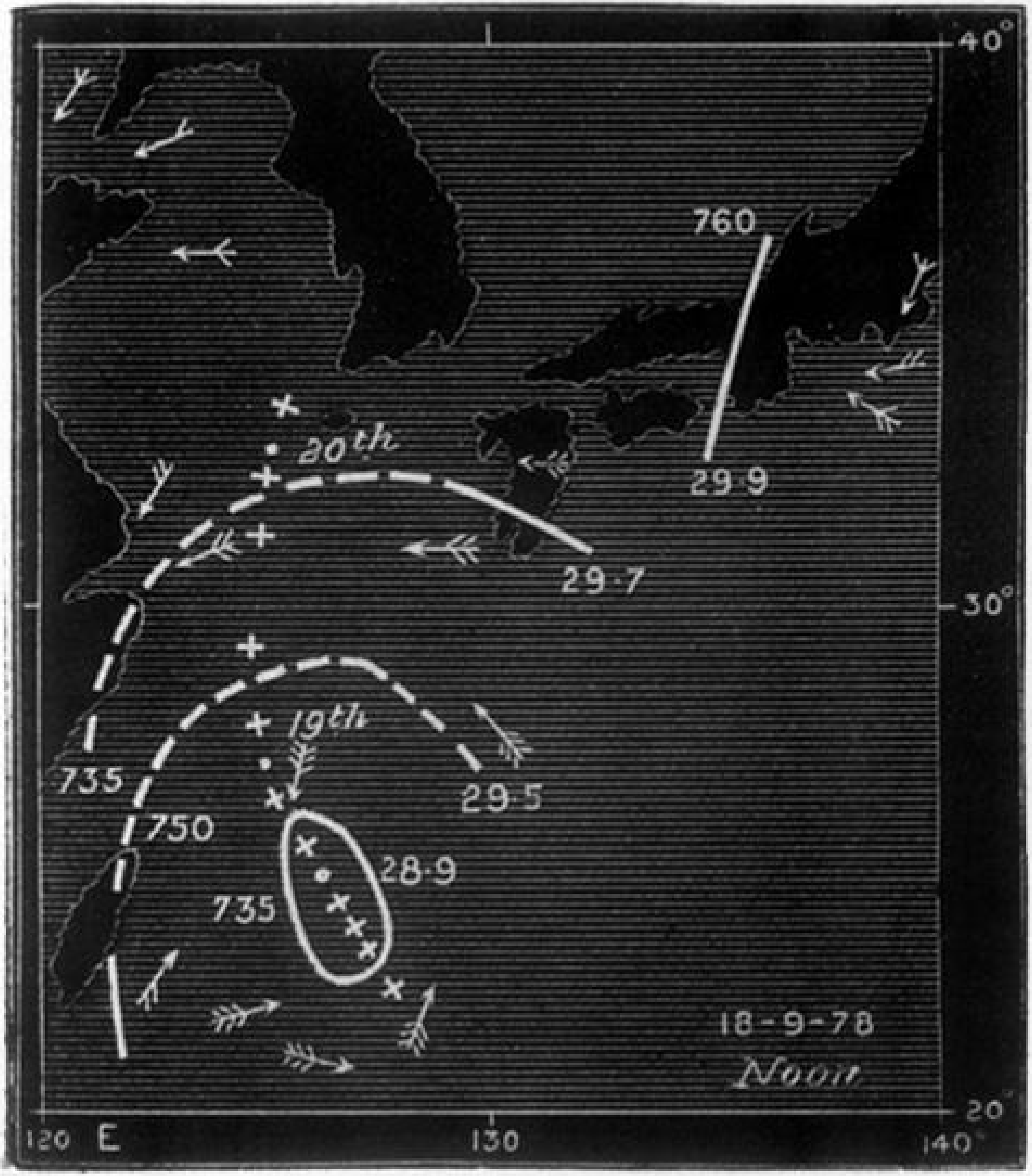
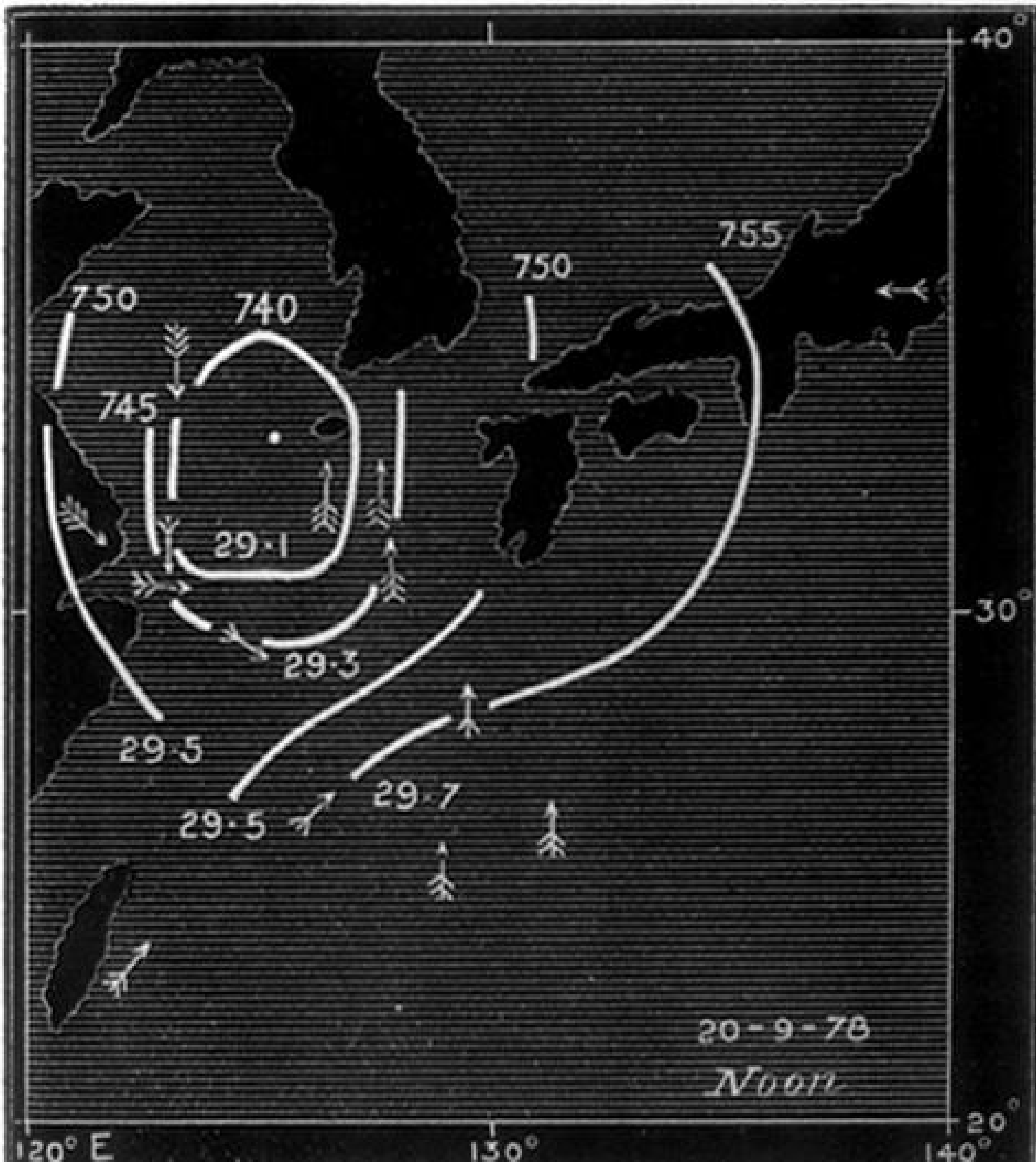

40°
30°
20°
120
E
130
140°
760
29·9
20th
29·7
19th
735
750
29·5
28·9
735
18-9-78
Noon

FIG. 12.

FIG. 13.



Figs. 11 to 13: Typhoon in China Seas.