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By Command,

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## RESULTS OF FURTHER INVESTIGATIONS CONCERNING TYPHOONS.

A pamphlet on *The Law of Storms in the Eastern Seas,* adapted for the use of the shipping ar embodying practically all that is now known about typhoons, was issued in September last year.

A distinguished German meteorologist in reviewing this pamphlet makes reference to the similarit which exists between the typhoons in the Far East and the hurricanes of the West Indies. An differences which may be ascertained must, I believe, be ascribed to dissimilarity between the coastline and islands, as the former, more especially, are found to have so great an influence on atmospheri disturbances.—The West India hurricanes may be divided into four classes. Those of the first class pas WNWestward to the south of Hayti and strike the coast of the mainland south of the norther promontory of Yucatan. Those of the second class pass generally NWestward and enter the Unite States. While those of the third class recurve generally between the West Indies and the Bermuda and pass away to the NE. Hurricanes of the fourth class, moving obliquely towards the equator in low latitude, are very rare.

My investigations on the typhoons in the past four years furnish already an insight into the sub-classes into which the different kinds of typhoons may be divided in the future. Thus the simi-larity between the paths of Typhoons V of 1885 and IV of 1886, Typhoons VI of 1885 and X of 1886, Typhoons XVII of 1884 and XVI of 1886, Typhoons X of 1885 and XVII of 1886 may be pointed out, the latter being particularly remarkable, so much so that doubts might reasonably have been entertained about its reality if the case had occurred but once.

Stormpaths in tropical seas are of a very simple nature,—much more so than in the case of minor depressions anywhere or storms in the temperate zones,—as long as the course lies far from any shore. That irregularities occur may be seen from such paths as are furnished by Typhoons VIII and XV of 1886. However there are while the typhoon is far from the shore seldom observations enough available to indicate small irregularities with certainty.

Whether a typhoon ever crosses the Pacific and Canada and reaches Europe is not known for certain. It is of course within the range of possibility, but must be doubted till clearly proved.

The coasts of China and Corea are now well furnished with stations. Wenchow in 28° 0′ N, 120° 35′ E with observations made at 9 a, 3 p and 9 p daily was added on the 1st September, 1886, and Chemulpo in 37° 29′ N, 126° 37′ E on the 1st November, 1886. Observations made every three hours were commenced on the 5th July, 1885, and were discontinued on the 27th February, 1887, in Port Hamilton in 34° 0′ N, 127° 20′ E.

The part of the Far East best supplied with meteorological stations is of course the Empire of Japan. One of the localities from which very poor information was hitherto available was the Philippine Archipelago, but the subject has now been taken up officially since a new Government Observatory was constructed. Meantime the want has been to some extent supplied by telegrams twice a day from Manila, by English volunteer-observers in Bolinao and Iloilo and by extracts from the logbooks of ships trading in the Archipelago.

Thunderstorms occur occasionally all round the centre of a typhoon in the ring of high pressure and gentle gradients beyond the area where the wind is fresh. Nearer the centre but before the wind begins to rise the clouds generally assume the form of Roll-cumulus which prevails till full typhoon force is reached. The mean monthly height of the mercurial column is scarcely lowered in conse-quence of the typhoons as the high pressure all round the typhoon counter-effects the low pressure near the centre. The monthly mean solar radiation is lowered both with regard to intensity and to duration, while the true air-temperature, the tension of water-vapour and the rain-fall are increased. The mean force of the wind is increased very considerably in months when typhoons approach the neighbourhood.

When the wind rises in a typhoon it blows in gusts and the mercury heaves in the barometer. In a strong gale the mercury fluctuates frequently three hundredths of an inch at intervals of perhaps about four minutes. But there is no heaving when the wind is not strong even if the centre is very close to a vessel. When the wind has attained storm-force it blows in fierce squalls of perhaps about ten minutes duration, while the mercury heaves up and down as much as eight hundredths of an inch. In these squalls the wind veers or backs in the direction towards which it is going to change owing to the progressive motion of the centre of the typhoon. As a general rule it may be said that the mer-cury gives a jump upwards when the wind begins to veer in the squall. Then it drops down and gives another jump upwards, while the winds shifts back to its original direction. But the mercury has been observed to behave in the opposite way occasionally and this point deserves further investigati

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rule a fraction of a degree and sometimes much more. But the wind does not return to quite its original direction. There is frequently a change. At the time when the centre is passing nearest to a vessel, a fierce squall is frequently entered in the log-book. The existence of a line of squalls perpendicular to the path of a storm-centre is well known in the storms that cross the British Isles.

It is remarked that typhoons often arrive in quick succession followed by intervals without typhoons, but during the height of the typhoon-season there is generally a typhoon to be found somewhere at any time. The following table exhibits the number of typhoons that occurred during the past three years within squares of 2° extent in longitude and latitude:—

FREQUENCY OF TYPHOONS IN 1884-1886 INCLUSIVE.

| Latitude North. | Longitude East. | | | | | | | | | | | | | | | | | | | | Sums. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 104°—106° | 106°—108° | 108°—110° | 110°—112° | 112°—114° | 114°—116° | 116°—118° | 118°—120° | 120°—122° | 122°—124° | 124°—126° | 126°—128° | 128°—130° | 130°—132° | 132°—134° | 134°—136° | 136°—138° | 138°—140° | 140°—142° | 142°—144° | |
| 42° – 44° | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 1 | 3 | 1 | 1 | ... | ... | 2 | 3 | 2 | 2 | 15 |
| 40° – 42° | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 2 | 2 | 1 | 1 | 2 | 3 | 3 | 4 | 5 | 4 | 27 |
| 38° – 40° | ... | ... | ... | ... | ... | 1 | ... | ... | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 5 | 6 | 7 | 6 | 3 | 45 |
| 36° – 38° | ... | ... | ... | ... | ... | 1 | ... | 2 | 2 | 2 | 3 | 1 | 2 | 2 | 7 | 5 | 3 | 3 | 2 | 2 | 37 |
| 34° – 36° | ... | ... | ... | ... | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 3 | 4 | 6 | 7 | 4 | 4 | 4 | 3 | 3 | 46 |
| 32° – 34° | ... | ... | ... | ... | 1 | 2 | 4 | 2 | 2 | 1 | 4 | 5 | 2 | 7 | 3 | 5 | 4 | 4 | 2 | ... | 48 |
| 30° – 32° | ... | ... | ... | ... | ... | 1 | 4 | 3 | 4 | 2 | 4 | 3 | 4 | 6 | 3 | 5 | 1 | ... | ... | ... | 40 |
| 28° – 30° | ... | ... | ... | ... | ... | 2 | 5 | 3 | 5 | 3 | 2 | 2 | 5 | 6 | 5 | 1 | ... | ... | ... | ... | 39 |
| 26° – 28° | ... | ... | ... | ... | 1 | 2 | 3 | 2 | 5 | 5 | 6 | 4 | 5 | 4 | 4 | ... | ... | ... | ... | ... | 41 |
| 24° – 26° | ... | ... | ... | ... | 1 | 1 | 2 | 3 | 5 | 5 | 8 | 5 | 5 | 3 | ... | ... | ... | ... | 1 | ... | 39 |
| 22° – 24° | ... | ... | ... | 1 | 2 | 2 | 2 | 3 | 5 | 2 | 8 | 7 | 4 | 5 | 2 | 1 | 1 | 1 | 1 | ... | 47 |
| 20° – 22° | 1 | 1 | 1 | ... | 1 | 2 | 2 | 5 | 4 | 3 | 9 | 4 | 4 | 4 | 3 | 2 | 1 | 1 | ... | ... | 48 |
| 18° – 20° | 1 | 1 | 3 | 3 | 4 | 7 | 6 | 8 | 7 | 5 | 8 | 5 | 2 | 4 | 3 | 3 | 1 | 1 | ... | ... | 72 |
| 16° – 18° | 3 | 2 | 3 | 2 | 3 | 3 | 3 | 5 | 6 | 6 | 9 | 8 | 3 | 2 | ... | 1 | 1 | ... | ... | ... | 60 |
| 14° – 16° | ... | 1 | 2 | 1 | 2 | 2 | 1 | 1 | 4 | 5 | 7 | 8 | 5 | 2 | 2 | ... | 1 | 1 | 1 | ... | 46 |
| 12° – 14° | ... | ... | ... | 2 | 4 | 3 | 2 | 2 | 1 | 2 | 4 | 5 | 4 | 1 | 2 | 2 | ... | ... | ... | ... | 34 |
| 10° – 12° | ... | ... | ... | 1 | ... | 1 | 3 | 4 | 2 | 2 | 2 | 2 | 2 | 2 | ... | 2 | 2 | ... | ... | ... | 25 |
| 8° – 10° | ... | ... | ... | ... | ... | ... | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | ... | ... | ... | ... | 10 |
| Sums. | 5 | 5 | 9 | 10 | 20 | 31 | 39 | 46 | 55 | 46 | 82 | 71 | 57 | 60 | 47 | 40 | 30 | 29 | 23 | 14 | 719 |

From the figures in the horizontal lines the average longitude for every 2° of latitude was computed in analogy with the theory of the lever. A curve was then drawn among the points laid down on the map. The result was as follows:—

| Lat. | Long. | | Lat. | Long. | |
|---|---|---|---|---|---|
| | read. | corr. | | read. | corr. |
| 43° | 135° | 136°.9 | 25° | 124° | 123°.8 |
| 41 | 137 | 135 .2 | 23 | 125 | 123 .1 |
| 39 | 134 | 133 .5 | 21 | 124 | 122 .6 |
| 37 | 133 | 132 .0 | 19 | 122 | 122 .4 |
| 35 | 132 | 130 .2 | 17 | 121 | 122 .3 |
| 33 | 129 | 128 .4 | 15 | 124 | 122 .5 |
| 31 | 127 | 126 .8 | 13 | 123 | 123 .1 |
| 29 | 125 | 125 .5 | 11 | 124 | 124 .3 |
| 27 | 125 | 124 .6 | 9 | 126 | 126 .1 |

South of 11° latitude the typhoons move on an average NWestward. Between 11° and 15° they move NNWestward between 15° and 22° Northwards, between 22° and 30° NNEastward and north of 30° about NEastward. But it must be remembered that there is comparatively little information available about the paths to the East of the Philippines. If the data were as extensive there as in the China Sea the southern half of the mean path would probably be shifted to the East, and the mean curve would look more like a parabola. The mean curve given above must therefore be considered to represent the mean path of typhoons encountered,—not the actual mean path of typhoons. By and by we may be able to lay down the mean path of each class of typhoons, and of typhoons in each month of the year.

The longitude in which typhoons are most frequently encountered, is 125° E. The latitude is $18\frac{1}{2}$° N. But there is a slight secondary maximum in $33\frac{1}{2}$° N.

The gradients, expressed in parts of an inch in 15 miles, corresponding to different forces (f) of the wind in typhoons have been calculated ($g_c$), and compared with the values ($g_o$) deduced from a comparison of the observed values by aid of Ferrel's formula in the following form:—

$$g_c = \left(\frac{\sin\phi \sec i}{1667} + \frac{v}{873\, r}\right) \frac{B\, v}{30\,[1 + 0.002\,(t-32)]}$$

in which $\phi$ designates the latitude, i the complement of the angle between the wind and the gradient, v the velocity of the wind in miles an hour, r the distance from the centre in miles, B the height of the barometer in inches, reduced to 32° and mean sea-level, and t the temperature of the air in degrees Fahrenheit. B is assumed=29, t=80, $\phi$=20° and i=45°:—

| $g_o$ | $f$ | v | $r$ | $g_c$ |
|---|---|---|---|---|
| 0.02 | 6 | 34 | 200 | 0.015 |
| .03 | 7 | 40 | 160 | .02 |
| .04 | 8 | 48 | 125 | .03 |
| .05 | 9 | 56 | 95 | .05 |
| .07 | 10 | 65 | 70 | .08 |
| .10 | 11 | 75 | 50 | .13 |
| .30 | 12 | 90 | 35 | .26 |

The first part of the expression for gc exceeds the second as long as the force of the wind is below a moderate gale. Thereafter the second part, depending upon the centrifugal force generated by the rotation, exceeds the first, which may be neglected when storm-force is reached and has no appreciable influence when it is blowing with full typhoon force

Assuming:—

$$a = \frac{\sin\phi \sec i\ B}{50010\,[1 + 0.002\,(t-32)]} \text{ and } b = \frac{B}{26190\,[1 + 0.002\,(t-32)]}$$

the velocity of the wind corresponding to a certain gradient in a certain latitude is determined by a quadratic equation having only one positive root:—

$$v = \frac{ar}{2b}\left(-1 + \sqrt{1 + 2\,\frac{bg}{a^2 r}}\right)$$

The strongest typhoon during the past three years and perhaps as strong as any hurricane ever encountered was that experienced on board of the S. S. *Airlie* in 12° N on the 16th July, 1885, when the gradient rose to about an inch in 15 miles. To gain an idea of the velocity of the wind in that typhoon the simple formula:—

$$v = \sqrt{\frac{gr}{2b}}$$

suffices.—According as r is assumed to have been 50 or 60 miles, we obtain v equal to 158 or 173 miles, and the velocity of the wind must therefore have reached about 150 miles an hour.

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Hongkong Observatory, 13th December, 1887.