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On the Swell as an Indicator of Typhoon

by

M. UDA
Tokyo Fisheries University

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1. Discussions on the Nature of Swell

Since long before the swell in the ocean as well as sea-noise *etc.* was considered as an important indicator of typhoon by navigators, fishermen and weather forecasters. Swells are also generated by the sudden beginning of monsoon and the frontal gusty wind. Hitherto the theories on the nature of swell were the following (i) and (ii) :

(i) Long waves generated by the impulsive variation of barometric pressure in the vicinity of a typhoon-centre and the accompanied effect due to the impulsive gusty wind on the sea surface. (so-called radiated swell).(1)(2)(3)

(ii) Long waves propagated from the typhoon area generated by the steady blow of stormy wind in cyclonic direction. (so-called cyclonic swell).(2)

The present author wishes to propose (iii) as a principal factor of swell.

(iii) Long waves started from the source region of the pyramidal waves generated by the interference of the wave-systems having different directions near the typhoon-centre which resembles to the source of *Tsunami* and intensified by the progression of typhoon.

(A) By the interference of the stormy wave-trains from different directions near the typhoon-centre the formidable pyramidal waves are generated at the points of the superposed crests of the wave pattern.

On Sept. 26, 1935 many war-ships belonged to the Japanese navy fleets were met by a violent typhoon (its lowest pressure p_c 718 mm=949 mb and its max. wind velocity 35-40 m/s) off Sanriku coast and passed through near the storm centre with severe damages.

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(1) K. Honda and T. Terada: Secondary Undulation of Oceanic Tides. *J. Coll. Sc. Imp. Univ. Tokyo* p. 101, 1908

(2) T. Otani and Y. Takasina: Waves and Swells in Relation to Winds of Typhoons. *Journ. Met. Soc. Japan.* **17** (1) 1939

(3) V. Cornish: Waves of the Sea and other Water Waves, 1911

Summarizing the observations carried out in such difficult conditions, the nature and the distribution of the crossed waves near the storm centre were presented clearly. (Fig. 1). It was proved that the highest waves at that period (its max. height about 15 m and its wave length 200–300 m approximately) were generated by the wave systems such that the wave-system due to the comparatively persistent gale from S-SW direction, turning from E to SE and abruptly to S in the northerly progression of the storm centre, superposed on the wave-system due to the initial easterly gale.

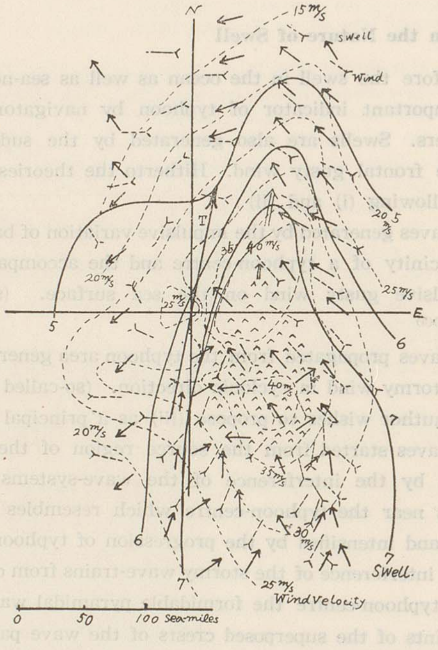

Fig. 1 Distribution of swells and winds in the typhoon area on Sept. 26, 1935 off Sanriku Coast

Dotted lines denote the direction and velocity of wind

Real lines denote the intensity and direction of swell

Figure ∧ means the source region of swell

Typhoon moves in the direction of arrow *T*

Glancing in Fig. 1, we can see the swell developing in the direction of typhoon movement with the long fetch as the synthetic result of the cyclonic air currents superposed on the general air currents in the right quadrant of the typhoon.

In this case, the greater the speed of the typhoon increases, the stronger the swell in that direction develops.

(B) Also I. Cline (1926) has proved the swell starting from the wave source in the right rear quadrant near the centre of the hurricane in the Gulf of Mexico and propagating strongly towards the moving direction of the hurricane.(4)

(C) On Oct. 5-7, 1944 in the sea region of (24°-25°N, 135°-136°E) the survey ship "*4-Kaiyo-maru*" belonging to the Japanese Hydrographic Department was met with the abnormally violent typhoon (p_c 898 mb) and carried out observations at the risk of life. The results in Fig. 2 indicate the strongest swell at 21^h on Oct. 6th and the crossed or confused seas during 17^h on 6th—4^h on 7th, showing the source region of swells.(4')

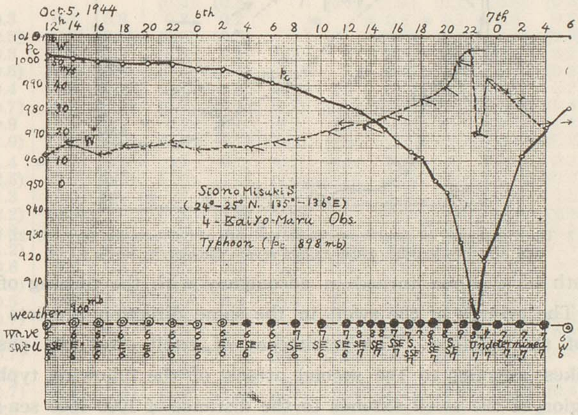

Fig. 2 The lowest pressure in the typhoon centre, the wind, weather, wave and swell in the case of typhoon on Oct. 5, 1944

2. The Variation of Swell Related with the Path of Typhoon

Inspecting the distribution of swells plotted in the monthly maps (*e.g.* Fig. 3) from the daily weather charts (published by CMO) referred to the paths of the conspicuous typhoons during the years from 1929 to 1939 which described in the "Records of Typhoons in Japan" (1944, CMO) the author recognized

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(4) I. M. Cline: Tropical Cyclones. 1926; I. R. Tannehill: Hurricanes. 1950

(4') M. Sato: *Hydrographical Bulletin*. No. 11. Mar. 1949 obviously the remarkable development of swell in the right side region along the path of typhoons.

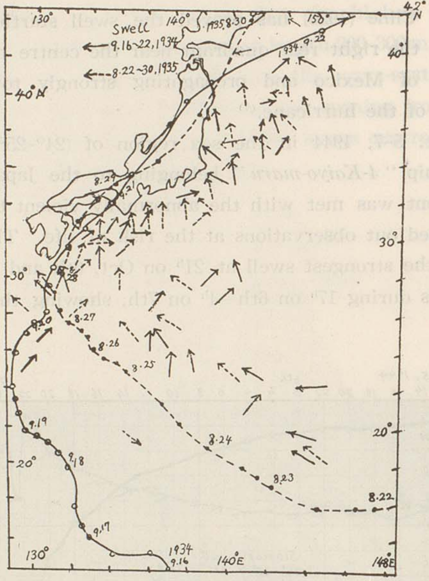

Fig. 3 The distribution of swell related with the path of typhoons (on Sept. 16~22, 1934 and Aug. 22~30, 1935) which caused severe damages by storm waves

The path of typhoon turned in accompany with the turning of the swell direction. The growth of the swell in the same direction predicts the direct approach of the typhoon. The persistence of swell after the passage of a typhoon takes warning to the second attack of the following typhoon. The sensible region of the swell extends to the distance of 1000–1500 sea-miles from the centre of typhoon. When typhoon appeared in the seas north of Luzon, the south coast of Japan begins to feel the swell. The lower the min. pressure descends, the stronger the swell develops.

3. Coastal Observation of Swell and the Path of Cyclone

(i) *Coastal wave observation in summer (June, July and Aug.) in 1945*

The results of observation shown in Fig. 4 represents the relation between the growth of swell together with surf and the passage of cyclone and front. Table 1 indicates the maximum swell with the movement of cyclone along the south coast of Japan.

Table 1 Mean and max. (in parenthesis) height of swell (meter) in July, 1945
(● day of min. pressure)

St. No.	Kyushu			Sikoku		Tokaido				Sagami Bay		Chiba	
in Fig.	3	4	5	9	10	11	12	13	14	15	17	18	19
Data (July)	Kusikino	Makura-zaki	Sibusi	Akaoka	Muroto	Singu	Maisaka	Yokosuka	Yaidu	Nagatoro	Odawara	Katuura	Katakai
1	0.5 (0.8)	0.1 (0.2)	—	0.3 (0.6)	0.2 (0.4)	—	0.2 (0.3)	0.3 (0.4)	0.2 (0.3)	● 0.6 (**1.0**)	0.2 (0.3)	0.8 (1.2)	1.3 (2.0)
2	0.7 (1.2)	0.2 (0.4)	—	0.3 (0.6)	0.2 (0.4)	—	0.2 (0.3)	0.2 (0.3)	0.2 (0.3)	0.5 (0.8)	0.2 (0.3)	0.5 (0.7)	● —
3	0.5 (0.9)	0.1 (0.1)	—	0.4 (0.6)	0.3 (0.4)	—	0.2 (0.4)	0.2 (0.3)	0.2 (0.4)	0.6 (0.8)	0.3 (0.6)	0.6 ● (0.8)	—
4	0.3 (0.4)	0.1 (0.2)	—	0.3 (0.4)	0.3 (0.3)	—	0.2 (0.2)	0.3 (0.4)	0.2 (0.2)	0.3 (0.4)	0.2 (0.2)	0.5 (0.8)	0.4 (0.5)
5	0.1 (0.2)	—	—	0.2 (0.3)	0.2 (0.3)	—	0.1 (0.2)	0.2 (0.3)	0.1 (0.2)	0.3 (0.5)	0.1 (0.1)	0.7 (1.0)	—
6	—	—	—	0.2 (0.5)	0.2 (0.3)	—	0.1 (0.1)	— (0.85)	0.1 (0.2)	0.5 (0.8)	0.1 (0.3)	0.6 (0.7)	—
7	0.3 (0.5)	0.1 (0.2)	0.3 (0.5)	0.3 (0.5)	0.2 (0.3)	—	● —	● 0.6 (0.8)	● 0.1 (0.2)	● 0.6 (1.0)	0.2 (0.3)	0.6 (0.8)	0.3 ● (0.4)
8	0.3 (0.6)	0.2 (0.3)	0.2 (0.3)	0.3 (0.6)	0.3 (0.4)	0.3 (0.4)	—	0.8 (**1.0**)	0.2 (0.3)	0.4 (0.7)	0.2 (0.3)	● 0.7 (1.0)	—
9	0.4 (0.7)	0.2 (0.3)	0.2 (0.4)	0.4 (0.5)	0.2 (0.4)	0.3 (0.3)	0.1 (0.2)	0.5 (1.0)	0.1 (0.2)	0.5 (0.8)	0.2 (0.4)	0.6 (0.9)	0.5 (0.8)
10	0.9 (1.9)	0.6 (1.0)	0.2 (0.2)	0.3 (0.5)	0.4 (0.7)	0.3 (0.4)	0.1 (0.2)	0.3 (0.7)	0.2 (0.2)	0.3 (0.5)	0.2 (0.2)	0.4 (0.7)	0.3 (0.5)
11	1.4 (**2.5**)	● 0.7 (**0.9**)	0.6 (**0.9**)	0.7 (1.0)	0.7 (1.4)	0.7 (**1.0**)	0.2 (0.5)	0.8 (1.5)	0.1 (0.2)	0.5 (1.5)	0.2 (0.2)	0.4 (0.8)	—
12	1.3 (2.2)	0.6 (0.8)	—	● 1.1 (**1.5**)	● 1.2 (**1.8**)	0.5 (0.8)	0.5 (0.7)	1.6 (**1.9**)	0.3 (0.6)	1.6 (**2.5**)	0.5 (**0.8**)	0.5 ● (0.9)	— ●
13	0.8 (1.2)	0.4 (0.7)	0.4 (0.6)	0.9 (1.5)	0.8 (1.2)	● 0.6 (0.8)	● 1.0 (**1.3**)	● 1.6 (**1.9**)	● 0.6 (**1.0**)	● 1.8 (**2.5**)	● 0.3 (0.5)	0.8 (**1.3**)	0.8 (1.2)
14	0.6 (1.0)	0.4 (0.7)	0.4 (0.7)	0.5 (0.8)	0.4 (0.5)	0.3 (0.4)	0.6 (0.8)	0.9 (1.6)	0.2 (0.5)	0.6 (1.1)	0.2 (0.4)	0.6 (0.9)	0.4 (0.5)
15	0.5 (0.7)	0.3 (0.4)	0.6 (1.3)	0.5 (0.8)	0.5 (0.8)	0.4 (0.5)	0.3 (0.5)	0.8 (1.2)	0.3 (0.4)	0.9 (2.2)	0.2 (0.3)	0.6 (0.8)	0.9 (**2.0**)
16	0.8 (0.7)	0.6 (**1.0**)	1.1 (**1.5**)	0.7 (0.8)	0.7 ● (1.0)	0.4 (0.5)	0.4 (0.6)	1.0 (1.4)	0.3 (0.7)	1.3 (2.2)	0.2 (0.3)	0.7 (0.9)	0.6 (1.2)
17	0.8 (0.7)	0.4 (0.5)	1.0 (1.4)	0.8 (**1.0**)	0.8 (**1.5**)	0.4 (0.5)	0.4 (0.9)	1.1 (1.5)	0.3 (0.4)	0.7 (1.2)	0.2 (0.4)	0.6 (1.0)	0.5 (1.2)
18	0.6 (0.9)	0.3 (0.5)	0.4 (0.6)	● 0.8 (**1.0**)	0.7 (1.0)	0.3 ● (0.5)	0.5 ● (0.8)	1.4 ● (**1.6**)	0.3 ● (0.5)	● 1.9 (**3.8**)	0.3 ● (0.4)	● 0.9 (**1.3**)	● 0.4 (0.6)
19	0.8 (**1.4**)	0.2 (0.3)	0.3 (0.4)	0.5 (0.9)	0.4 (0.6)	0.3 (0.5)	0.2 (0.3)	0.7 (1.0)	0.2 (0.4)	0.6 (1.2)	0.2 (0.3)	0.6 (0.8)	0.9 (**1.5**)
20	0.3 (0.6)	● 1.1 (**2.0**)	1.2 (**3.2**)	0.5 (0.7)	0.4 (0.7)	0.5 (**0.8**)	0.5 (**1.3**)	0.4 (0.6)	0.3 (0.5)	0.3 (0.5)	0.3 (0.4)	0.4 (0.6)	0.8 (1.0)
21	0.4 (0.6)	—	1.8 (**2.6**)	1.1 (**1.2**)	1.7 (**3.0**)	0.5 (0.7)	0.3 (0.5)	0.8 (1.3)	0.7 (**0.8**)	—	0.5 (**1.0**)	0.7 (**2.0**)	0.5 (0.7)
22	—	—	0.3 (0.4)	0.4 (0.7)	0.6 (0.7)	● 0.3 (0.5)	● 0.2 (0.3)	● 1.0 (**1.3**)	● 0.2 (0.6)	—	—	● 0.7 (1.0)	1.0 ● (**1.5**)
23	—	—	0.3 (0.5)	0.3 (0.5)	0,3 (0.5)	0.2 (0.4)	0.2 (0.4)	0.5 (0.7)	—	—	—	0.8 (1.1)	0.7 (1.0)
24	—	—	0.3 (0.4)	0.3 (0.4)	0.4 (0.6)	0.4 (0.6)	0.3 (0.4)	0.4 (0.6)	0.2 (0.4)	—	—	0.9 (1.1)	0.7 (1.5)
25	—	—	0.2 (0.3)	0.6 (1.0)	0.5 (0.6)	0.4 (0.5)	0.2 (0.2)	0.4 (0.7)	0.2 (0.3)	—	—	0.8 ● (1.3)	0.4 (0.8)
26	—	—	0.3 (0.4)	0.8 (1.0)	0.5 (0.6)	0.4 (0.5)	0.3 (0.5)	0.5 (0.6)	—	—	—	0.7 (1.0)	0.4 (0.6)
27	—	—	0.4 (0.7)	0.5 (0.8)	0.3 (0.4)	0.4 (0.5)	—	0.6 (0.8)	0.1 (0.3)	—	—	0.5 (0.8)	0.6 (1.0)

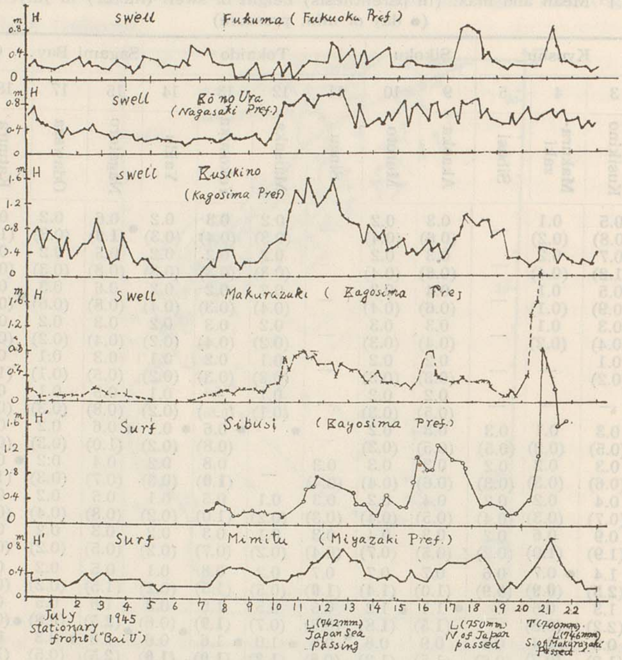

Fig. 4

Taking H(m), T(sec) and λ for the height of swell, its period and wave length (m) respectively, we get

$$H = aT^2,$$

where $a = 1.7$ at Makurazaki in Kagosima Pref.
and at Kusikino in Kagosima Pref.

The max. height of swell $H_{\max.}$ is 30-50% higher than the average height of swell Hm.

$$H_{\max.} = kHm.$$

where $k = 1.3$ (Makurazaki in Kagosima Pref.)
$= 1.4 \sim 1.5$ (Kusikino in Kagosima Pref.)
$= 1.33$ (Konoura in Nagasaki Pref.)
$= 1.3$ (Fukuma in Fukuoka Pref.)

For the period exceeding 6 seconds the wave height of swell increases suddenly. The swell of typhoon nature has the period of the order 6~20 sec. The height of swell has a linear relation with the height of surf H'.

$$H' = cH,$$

where $c = 1.14$ (Makurazaki)

$= 1.35$ (Mimitsu in Miyazaki Pref.)

$= 1.2$ (Konoura).

It shows that the height of surf is 14~35% higher than that of swell.

For the period of surf $T' > 5$ sec, $H' = 1.6(T' - 4)$ at Makurazaki. The period of surf is nearly the same as that of the swell in the offing. The relation $T = f(p_c)$ is not yet obvious.

(*ii*) *Coastal Observation of swell during Aug. 5-Sept. 25 in 1947*

The survey carried out by Nagasaki Marine Observatory at Konoura in Nagasaki Pref., Makurazaki in Kagosima Pref. and Todoro in Miyazaki Pref. In that summer the appearance of typhoon was scarce in number and in consequence the sea was very calm except the passage of Kathleen Typhoon.

At Todoro in Miyazaki Pref. swell was felt 5 days before the day of max. height (2.5 m) on Sept. 14 corresponding to the approach of typhoon to the south of 2300 km distant. (See Fig. 5 and 6.)

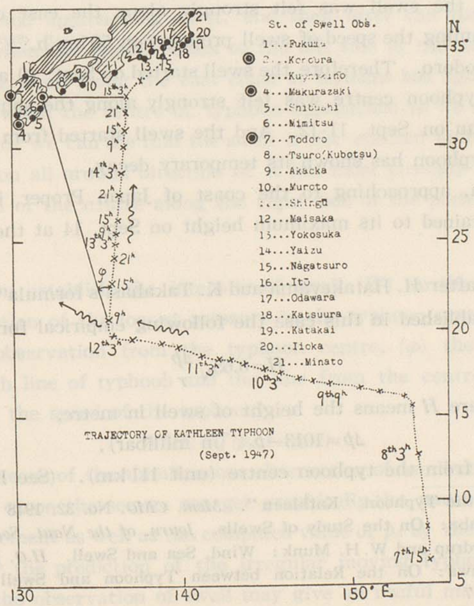

Fig. 5 Station of swell observation and the path of Kathleen Typhoon on Sept. 1947

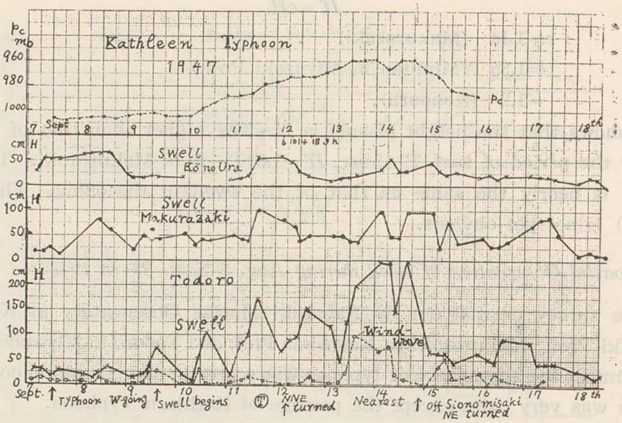

Fig. 6 The variation of swells along the coast of Kyushu and the lowest pressure of the Kathleen Typhoon

On Sept. 12 the Kathleen Typhoon(4'') turned suddenly from the WNW-going course to the NNE direction. During 3^h–9^h on Sept. 12, just near the time at turning point the swell was felt strongly along the east coast of Kyushu. However, assuming the speed of swell propagation 50 km/h,(5)(6)(7) it needs about 30 hours to Todoro. Therefore the swell started on Sept. 10 and 11th from the WNW-going typhoon centre was felt strongly along the south, west and east coast of Kyushu on Sept. 11–12. And the swell started from near the turning point of the typhoon has shown its temporary decay.

After then, approaching to the coast of Japan Proper, it increased again rapidly and attained to its maximum height on Sept, 14 at the nearest position to Todoro.

Following after H. Hatakeyama and K. Takahasi's formula(8) $\left(W=1.34\sqrt{\frac{\Delta p}{r}}\right)$, the author established in this case the following empirical formula:

$$H=0.65\sqrt{\frac{\Delta p}{r}},$$

at Todoro, where H means the height of swell in metre,

$$\Delta p=1013-p_c \quad \text{(in millibar)},$$

and r distance from the typhoon centre (unit 111 km). (See Fig. 7).

(4'') Report of the Typhoon "Kathleen". *Mem. CMO.* No. 32. 1948

(5) Y. Kawanabe: On the Study of Swells. *Journ. of the Naut. Soc. Japan.* **4**, 5. 1951

(6) H. U. Sverdrup and W. H. Munk: Wind, Sea and Swell. *H.O. Publ.* No. 601. 1947

(7) M. Kabasawa: On the Relation between Typhoon and Swell. *J. Meteorol. Res.* (CMO) **1**, 7

(8) H. Hatakeyama and K. Takahasi: Ijō Kishō Oboegaki. 1944

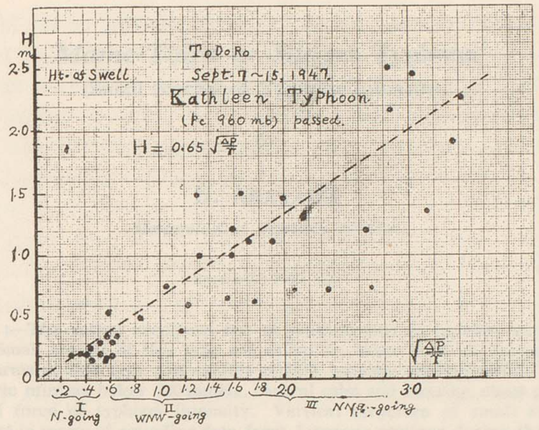

Fig. 7 Relation between the height of swell and the intensity of typhoon with its remoteness

Concluding the above we can mention that the swells along the coast of Kyushu were higher when the Kyushu region lies to the right side of the path line of typhoon and approaching to it, and then after the turning point the swells decayed when the region comes to the left side of the path line.

However, the swell along the east coast of Kyushu has again grown up to its max. height when the centre of typhoon approached to its nearest position to Todoro. Hence we can see that the swell is not emitted uniformly from the centre of typhoon all around direction of it but most strongly develops to the moving direction of the centre along the right side of the path line.(3)(4)

4. Conclusion

Thus we can establish the intensity of swell (W) on the height of swell (H) as the function of the lowest pressure in the typhoon centre, the distance of the St. of observation from the typhoon centre, (φ) the angle included between the path line of typhoon and the line from the centre to the St. of observation, (v) the speed of the typhoon.

$$W(H) = f(p_c, r, \varphi, v).$$

Hence, by means of the simultaneous observation of swell at several stations along the coast or on the sea we can get graphically the centre of typhoon and its mode of movement as well as the computed value of p_c by the above formula. In such way for the prediction of the irregular moving typhoon or the small scale typhoon, the observation of swell may give an useful method.