An Analysis of a Pressure Pattern in Severe Typhoon Bart Hitting the Japanese Islands in 1999 and a Comparison of the Gradient Wind with the Observed Surface Wind

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1. INTRODUCTION

Typhoon Bart hit the Kyushu District of Japan on Sept. 24, 1999 with very strong intensity and caused disasters by high wind and storm surge. One of them was a storm surge with 12 deaths at Matsuai-area of Shiranui (Fig.1) in Kumamoto Prefecture.

The track of Typhoon Bart determined by Japan Meteorological Agency (JMA) is shown in Fig.1. The typhoon formed as a tropical storm over the sea south of the Okinawa Island on Sept. 19. It translated toward north-northeast with intensifying, and made landfall on the Kumamoto Prefecture in Kyushu District in the morning on Sept. 24. The typhoon translated over the warm sea water exceeding 28 ℃, and it maintained a mature stage of 935 hPa in central pressure and 45m/s in the maximum wind speed at 3 JST, Sept.24, when was 3 hours before landfall.

We have developed an objective method for analysis of the pressure pattern in a typhoon in the previous research (Mitsuta et al.[1)]). We analyzed the pressure pattern in Typhoon Bart by using this method, and computed the gradient wind from it.

In Kyushu, the wide area wind measurement system of high density called NeWMeK (Network for Wind Measurement in Kyushu) has been organized. Anemometers at sites of NeWMeK are installed at the top of the power transmission towers, and wind is measured at high altitude of about 30m to 50m above the ground surface. The sites are distributed at a distance of about 20 km, and total number of sites is 121.

In this study, the gradient wind is computed from the pressure pattern analyzed by the objective method, and it is compared with the ten-minute mean wind observed at the sites of the NeWMeK system along the coast line in Southwest Kyushu. It is also compared with the surface wind observed at the weather stations of JMA.

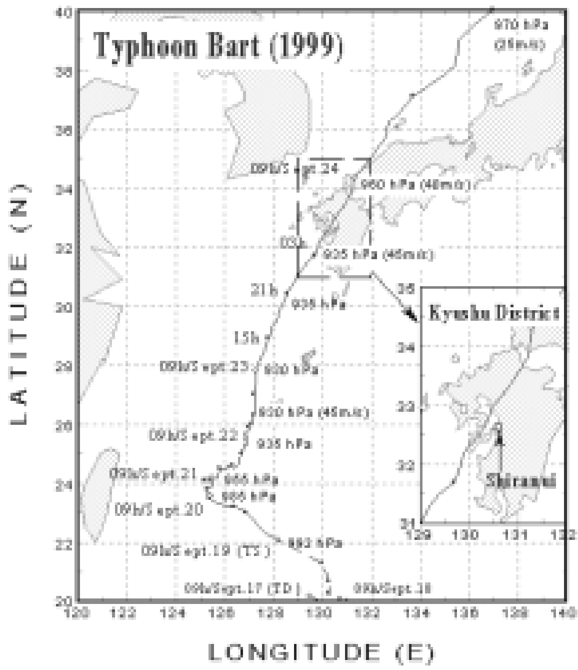

Fig. 1 The track, the central pressure and the maximum wind speed of Typhoon Bart of 1999. A broken line indicates a stage of a tropical depression. Date and time are represented by JST.

2. AN ANALYSIS OF PRESSURE PATTERN

2.1 Pressure formula

A tropical cyclone in a mature stage has a concentric pressure patterns, and the pressure distribution can be given by only a radial pressure profile. In order to represent a radial pressure profile for severe typhoons hitting the Japanese Islands, an experimental formula presented by Schloemer[3] has been used in the previous researches by us (Mitsuta *et al.*[1]: Fujii[2])

$$p = p_c + \Delta p \exp(-1/x) \quad (1)$$

where p is the sea level pressure at the radial distance r, p_c the pressure at a typhoon center, Δp the central pressure depth which equals to the pressure difference between the typhoon center and the periphery, and x a relative radius normalized by a radius of the maximum wind r_m, $x=r/r_m$.

Holland[4] extended this equation by adding another parameter, in order to represent the pressure patterns in tropical cyclones in a small scale in Australia. Fujii and Mitsuta[5] analyzed pressure patterns in three typhoons which made landfall on the Japanese Main Islands with a strong intensity in the recent years. The result by them showed that the pressure patterns can be approximated reasonably with by Eq.(1). So, Eq.(1) is used in the present study.

2.2 A method of pressure analysis

Eq.(1) is fitted to sea level atmospheric pressure observed at weather stations of JMA by the method of least squares (Fujii[2]). A weight in inverse proportion to a radial distance from the typhoon center is multiplied on pressure data, in order to get a close fitting to observed data near the typhoon center.

The fitting process starts from given initial values of a typhoon center position and r_m. Then, the first estimations of Δp and p_c are obtained by the method of least squares. A root mean square error is computed from the difference between computed and observed sea-level pressures at the weather stations of JMA.

With successive changes of r_m at the interval of 0.5 km, the root mean square error is computed, and values of Δp, p_c and r_m are chosen as a set of values showing the minimum error.

Then, the initial position of the typhoon center is shifted by 0.01^o in latitude or in longitude, and values of Δp, p_c and r_m are estimated. By repeating this procedure, the best estimated values of the center position (latitude and longitude), Δp, p_c and r_m are determined.

2.3 Analyzed pressure pattern

The analysis of a pressure pattern started at 01 JST, Sept.24, and a position (latitude and longitude) of the typhoon center, p_c, Δp and r_m were determined. It was repeated at the interval of 10 minutes. The pressure pattern obtained by the objective analysis at 04:30 JST, when it was about one hour and half before landfall, is shown in Fig.2. The value of p_c is

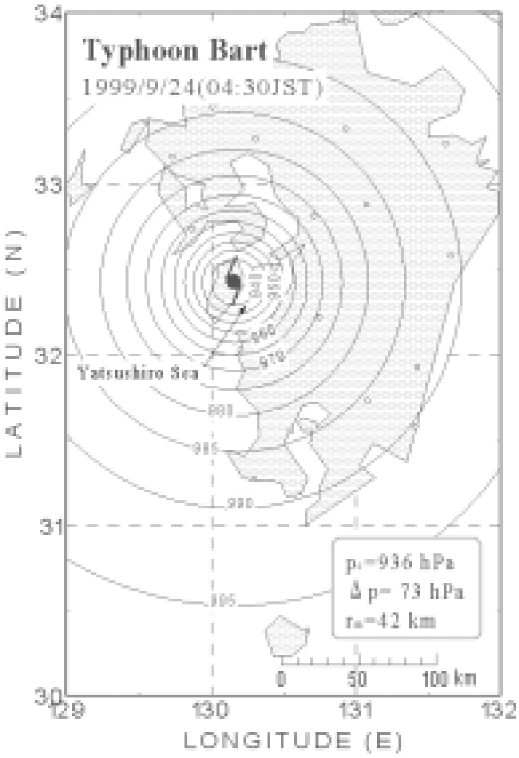

Fig.2 A pressure distribution obtained by the objective analysis. An open circle is a weather station of JMA used for the pressure analysis.

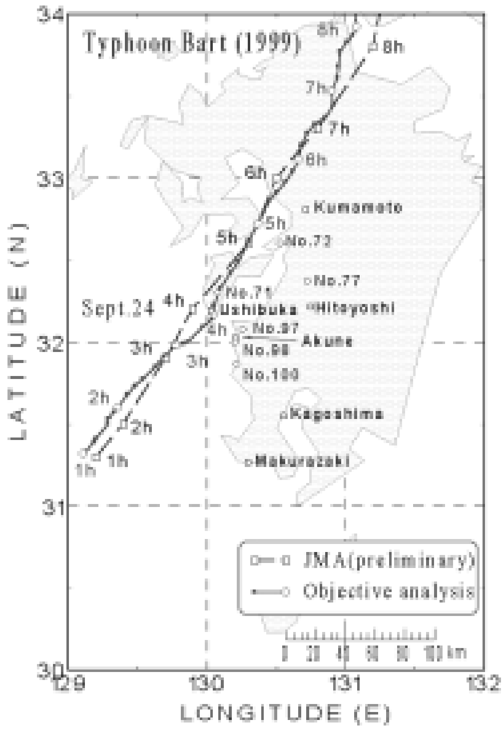

Fig.3 Tracks of typhoon centers determined by the objective pressure analysis and JMA. A small circle denotes an anemometer site of NeWMeK and a small square a weather station of JMA.

936 hPa, and the typhoon maintains very severe intensity. The value of r_m is 42 km, and the area including the maximum wind passes the coast area along the Yatsushiro Sea.

A track of the typhoon centers determined by the objective pressure analysis is shown with the track determined preliminarily by JMA in Fig.3. These two typhoon tracks are 30 km apart in maximum.

3. THE GRADIENT WIND

Under an assumption of neglecting the friction force, the gradient wind speed, V_{gr}, can be computed from the pressure pattern approximated by Eq.(1).

$$\frac{V_{gr}^{\ 2}}{r_t} + fV_{gr} = \frac{1}{\rho}\frac{dp}{dr} \qquad (2)$$

where r_t is the radius of curvature of air parcel trajectory, f the Coriolis parameter, ρ air density.

The radius of curvature in air parcel trajectory in Eq. (2) for a moving typhoon is replaced by that of the streamline, r_s, by the Blaton's formula (e.g. Holmboe *et al.*[5]).

$$\frac{1}{r_t} = \frac{1}{r_s}\left(1 - \frac{C}{V_{gr}}\sin\theta\right) \qquad (3)$$

where C is the translation speed of a pressure pattern, θ an angle measured from the translating direction of the pressure pattern clockwisely.

Then, an unsymmetrical pattern of the gradient wind speed is obtained. At the right-hand side of the typhoon translation direction, the wind is evaluated stronger than that of a stationary typhoon, and at the left-hand side, it is weaker.

A distribution of the gradient wind speed computed from the pressure pattern in Fig.2 is shown in Fig.4. In the coast area along the Yatsushiro Sea, the gradient wind exceeds 50 m/s, and the maximum wind is 53 m/s.

4. A RATIO OF THE OBSERVED AND GRADIENT WIND SPEEDS

The gradient wind speeds computed from the analyzed pressure pattern are compared with the ten-minute mean wind speeds recorded at the six sites of NeWMeK in the southwest coast area of Kyushu, where violent wind was observed. These sites are Nos. 71, 72, 77, 97, 98, and 100, and their locations are shown in Fig.3. The recorded wind speed is represented as a ratio to the gradient wind. This ratio is shown in relation to the relative radius, x, in Fig. 5. The ratio is about 0.5 in average and has no systematic variation with the relative radius in the outside of the maximum wind radius, $x>1.0$. However, in the inside of the maximum wind radius, $x<1.0$, the ratio increases rapidly with decrease of x.

This increase of the wind ratio with approaching to the typhoon center is considered to be caused by inflow in the atmospheric boundary layer. In the boundary layer, angular momentum is transported inward across isobars by inflow produced by the ground surface friction. This transport accelerates air parcels inward and, as a result, causes the increase of the wind ratio.

It is well known that the surface wind sometimes exceeds the gradient wind in the inside of the

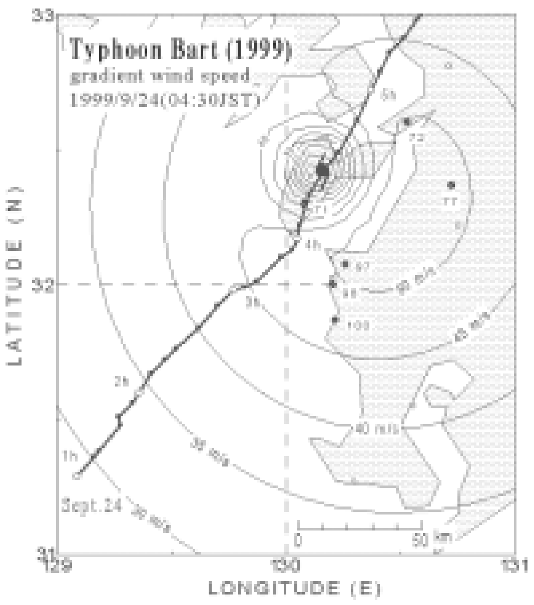

Fig.4 A distribution of the gradient wind speed at 04:30 JST, Sept. 24. This distribution was computed from the pressure pattern shown in Fig.2.

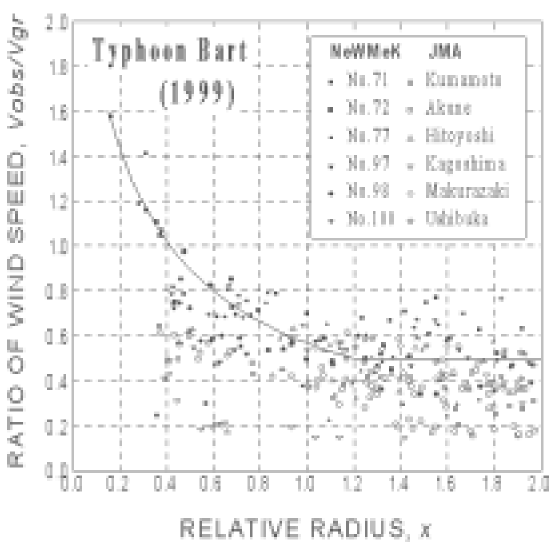

Fig.5 A change of the ratio of the wind speeds with relative radius, x. The line represents an averaged variation at the sites of NeWMeK.

maximum wind radius, and it is called as the super gradient wind (Gray [7]; Mituta *et al.* [8]).

The surface wind speed observed at the six weather stations of JMA along the coast line of the Yatsushiro Sea and the East China Sea is also represented as the ratio to the gradient wind speed, and it is added in Fig.5.

Generally, the ratio at stations of JMA is smaller than those of NeWMeK. It is considered to have its cause in difference among anemometer heights. So, the ratios in a radius of 1.0<x<2.0 having no systematic variation with *x* is shown in relation to the anemometer height in Fig.6. There is a wide scattering in ratios at the same station, and it is considered to be caused by topography which is different by a wind direction. A vertical profile obtained by synthesis of the wind ratios at different places may have little important significance, but a regression line is drawn on an assumption of an increase of the ratio in proportion to a power of height. Then, the ratio increases in proportion to 0.33 power of height.

5. SUMMARY

We analyzed the pressure pattern in Typhoon Bart having made landfall with very strong intensity on the Kyushu District of Japan on Sept. 24, 1999. The gradient wind was computed from the pressure pattern and was compared with the wind observed at the sites of NeWMeK. The ratio of the observed wind speed to the gradient wind speed was about 0.5 in the outside of the maximum wind radius, but increased rapidly with decrease of relative radius in the inside of it. In addition of the wind data at six stations of JMA, the wind ratio in the outside of the maximum wind increased with height in proportion to 0.33 power of the anemometer height.

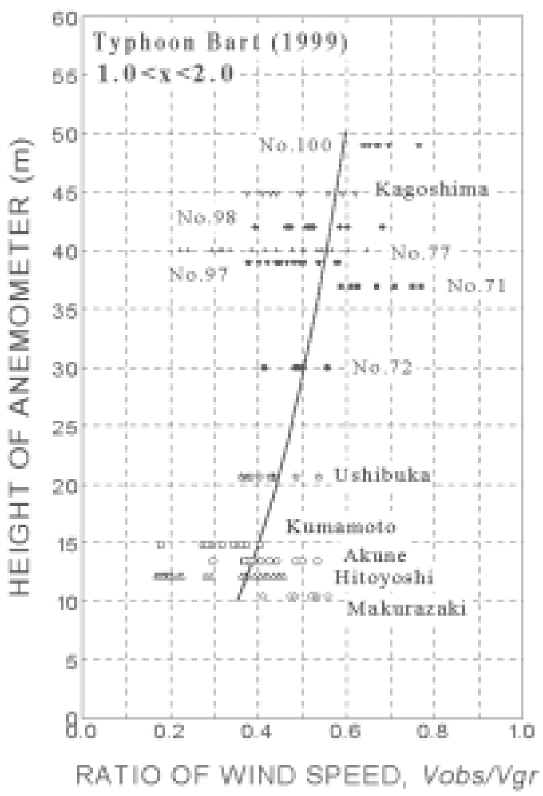

Fig.6 A relation between the ratio of wind speed ratio and anemometer height

Acknowledgements

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Key Words: typhoon; pressure profile; gradient wind; surface wind, NeWMeK