Improvement of the JMA Typhoon Model by Using New Physical Processes

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Abstract

The Typhoon Model (TYM) with a new physical process package was operationally implemented in July 2003 at the Japan Meteorological Agency (JMA). In this package, (1) a prognostic cloud scheme based on Smith (1990) and (2) a radiation scheme including the direct effect of aerosols were newly introduced. In addition to these effect, (3) a prognostic Arakawa-Schubert cumulus parameterization scheme and (4) estimation of the roughness length on the sea surface were modified. The schemes (1) to (3) had already been implemented into the Global Spectral Model (GSM) by Kuma et al. (2001). Preliminary experiments with three typhoons in 2002 were carried out for 108 cases. The results showed remarkable improvements in track prediction and neutral skill in intensity prediction of typhoon.

1. Introduction

JMA operates TYM four times a day for the prediction of tropical cyclones in the western North Pacific. In recent years, TYM has been improved by changing the typhoon bogus system (e.g., Sakai et al. 2002), while the GSM has been improved by changing the physical processes and succeeds to reduce the typhoon positional error (e.g., Kuma et al. 2001). Based on the above improvement in GSM, the physical processes of TYM are changed by introducing a physical process package, which was implemented in GSM in December 1999 (GSM9912).

In this paper, the new physical process package for TYM and its performance are presented. First, the modifications on physical processes from the previous TYM are introduced in section 2. The result of the experiment is shown in section 3. Finally, a summary of the result and concluding remarks are presented in section 4.

2. Improvements on the physical processes

The improvements on the physical processes of TYM consist of two components:

(1) Introduction of the physical process package of GSM9912

The new physical process package includes

(a) Introduction of a prognostic cloud water scheme (Smith 1990),
(b) Introduction of the direct effect of aerosols on short-wave radiation,
(c) Modification of the prognostic Arakawa-Schubert cumulus parameterization scheme.

Hosomi (2002) reported that by introducing the physical process package of GSM9912 into the Regional Spectral Model (RSM), the skill of the upper-tropospheric wind became better and meso-scale lows spuriously generated by intensive false rain were suppressed. Since TYM has the same dynamical frame and physical processes as RSM, the new TYM is expected to improve the track prediction of typhoon in the same way as RSM.

(2) Modification of the roughness length on the sea surface

Preliminary experiments showed, however, that TYM with the new physical processes mentioned above often overestimated typhoon intensity. It is known that simulated typhoon intensity is sensitive not only to the cumulus parameterization but also to the parameterization of heat (and water vapor) and momentum fluxes from the sea surface. Some recent studies indicate that the intensity of a simulated tropical cyclone is sensitive to the ratio of the exchange coefficients Ch/Cm, where Ch the exchange coefficient of heat (and water vapor) and Cm the exchange coefficient of momentum. The lower the value of Ch/Cm, the weaker a intensity of the simulated tropical cyclone (Emanuel 1995; Bao 2002). In order to suppress the overestimation in typhoon intensity forecasts, the parameterization of roughness length on the sea surface is changed so that the heat and moisture fluxes on the sea surface are decreased (Lower value of Ch/Cm). For this purpose,

(d) The roughness length formulae in TYM are changed from Kondo (1975) to Garratt (1992) and Beljaars (1995). Garratt (1992) is used for the heat (and water vapor) exchange coefficient, Beljaars (1995) is used for the momentum exchange coefficient.

Details of the change to the roughness length on the sea surface are described in APPENDIX.

3. Results

In order to examine the forecast performance for various typhoons, the following three typhoons are selected by considering the seasonal condition and the typhoon track (Fig. 1):

- T0206 (CHATAAN): 29 June to 11 July 2002 with recurvature.
- T0216 (SINLAKU): 29 August to 7 September 2002 without recurvature.
- T0221(HIGOS): 27 September to 2 October 2002 with recurvature.

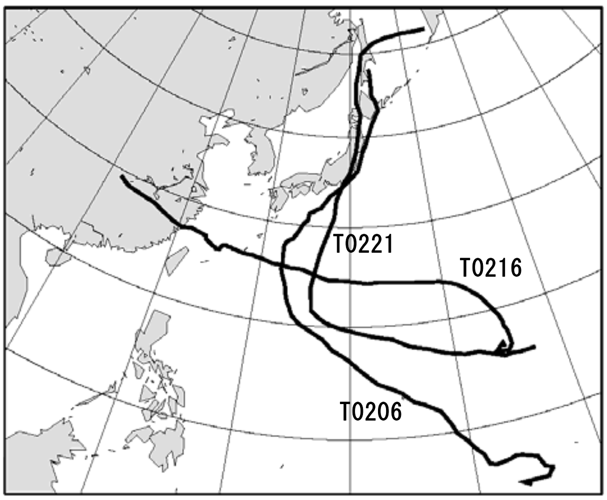

Fig. 1 Track of the target typhoons for the experiment. T0206 (CHATAAN), T0216 (SINLAKU), T0221(HIGOS).

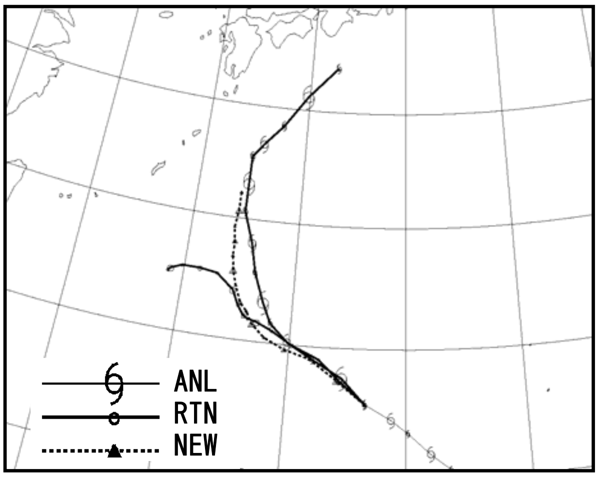

Fig. 2 Predicted track for the T0206 (CHATAAN) by TYM. (Initial time: 2002/07/06 00 UTC) ANL: Analysis, RTN: Control, NEW: New TYM. Plotted every 6 hour.

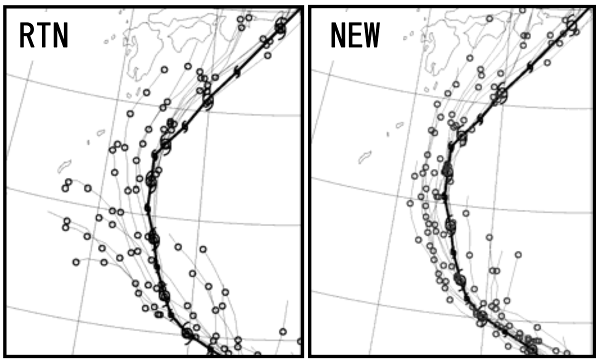

Fig. 3 Analyzed and predicted tracks around recurvature stage. The control (left panel) and the new TYM (right panel). Bold line is analyzed typhoon track. Thin lines are predicted typhoon track in each initial time. 6-hourly positions are plotted each line.

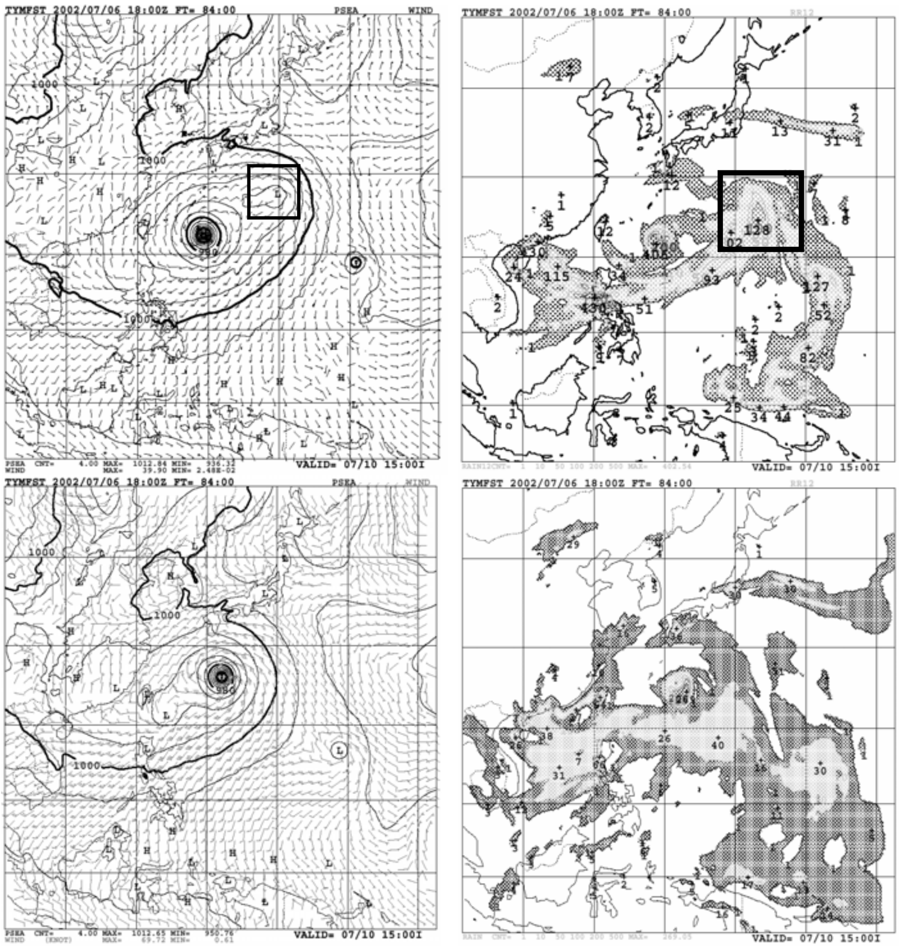

Fig. 4 84-hour forecast of the control (upper panels) and new (lower panels) TYMs. Initial time: 2002/07/06 18 UTC. Target typhoon: T0206 (CHATAAN). Mean sea level pressure (left panels) and 12-hour accumulated precipitations (right panels).

A false low and associated intensive precipitation are indicated with squares.

The operational TYM forecasts with the old physical process package are used as the control to evaluate the impact of the new physical processes.

Figure 2 shows the track for T0206 predicted by the new TYM starting from 00UTC 6 July 2002 along with those of the control and the analysis. In this forecast period, the typhoon changed its direction from north-westward to north-eastward (recurvature stage). In the control, the recurvature is not predicted and the typhoon continues to move to the northwest. In the case of the new TYM, though the moving speed is slower than the analysis, the recurvature is well predicted. Similar results are obtained from other forecasts starting from different initial times (Fig. 3). Figure 4 shows surface pressure and precipitation of the 84-hour forecast starting from 18UTC 6 July 2002. In the control, a small low and associated intensive precipitation are predicted to the northeast of the typhoon (between the sub-tropical high and the typhoon). The low moves to northeast along the western edge of the sub-tropical high following the anti-cyclonic flow.

The new TYM is superior to the control in the prediction of synoptic pattern in tropics. Figure 5 shows the 72-hour forecast for T0216 starting from 06UTC 2

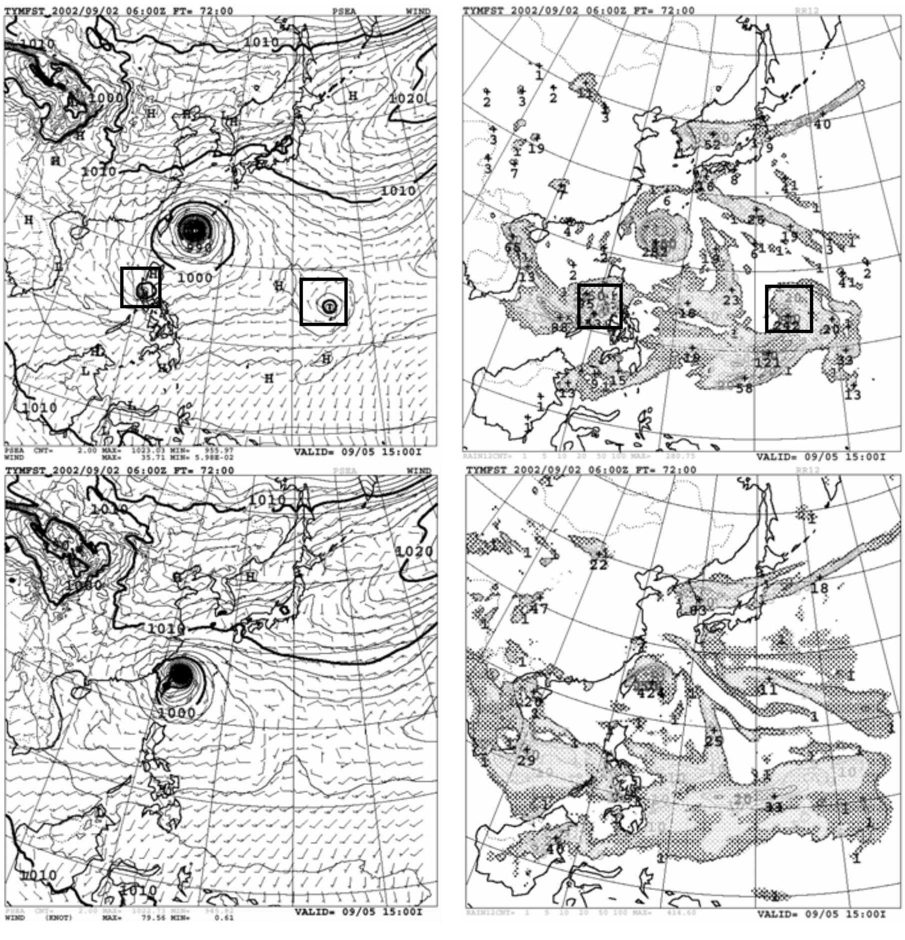

Fig. 5 72-hour forecast of the control (upper panels) and new (lower panels) TYMs. Initial times: 2002/09/02 06 UTC. Target typhoon : T0216 (SINLAKU). Mean sea level pressure (left panels) and 12-hour accumulated precipitations (right panels).

A false lows and associated intensive precipitation area are indicated with squares.

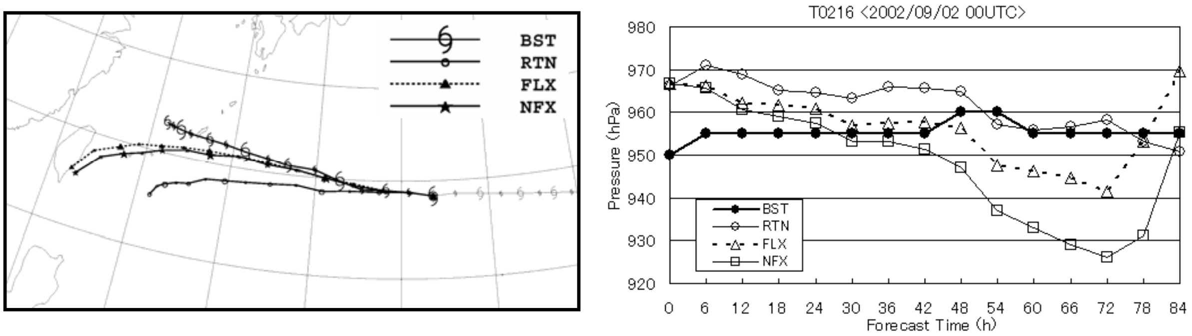

Fig. 6 Track (left panel) and intensity (right panel) forecast comparisons between the control and new TYM. Initial time: 2002/09/06 00UTC. Target typhoon: T0206 (CHATAAN).
ANL: Analysis, RTN: Control, NFX: Kondo(1975), FLX: Garratto (1992) and Beljaars(1995).
6-hourly intensity and position are plotted.

September 2002. Whereas intensive rain areas and small-scale lows are predicted around the Luzon Island and the Saipan Island in the control, these features are suppressed in the new TYM.

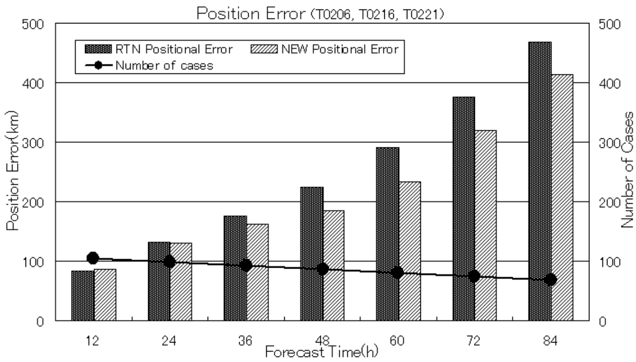

Fig. 7 Mean positional error of TYM.
Dark bar (RTN) is the control. Light bar (NEW) is the new TYM. Line is the number of cases.

Figure 6 shows the impact of the different roughness length formulae on the intensity forecast for T0216 using the physical process package of GSM9912. Both of the experiments improve the track forecast compared to the control. In the experiment using the old (Kondo) roughness length formulae (thin solid line), the predicted central pressure of the typhoon is about 30 hPa lower than that of the analysis. In the experiment using the new (Garratt and Beljaars) roughness length formulae (broken line), the overestimation is suppressed and the predicted central pressure is closer to the analysis.

The comparison of the mean positional error between the control and the new TYM is shown in Figure 7. A remarkable improvement in mean positional error is seen at the later stage of the forecast time. The mean positional error is reduced by 56 km in 72-hour forecast (74 cases). Figure 8 shows scatter diagrams of the typhoon positional error in 72-hour forecasts. The south-westward bias after the recurvature stage is slightly reduced. The dispersion of the positional error in the new TYM is smaller than that in the old one.

The mean error (ME) and the root mean square error (RMSE) of the typhoon central pressure forecasts are shown in Fig. 9. Though RMSE varies with the forecast time, the new TYM has almost the same performance in RMSE as the old TYM. ME is reduced at the early stage of the forecast time. ME of the new TYM scarcely varies (2–3 hPa) during the forecast period.

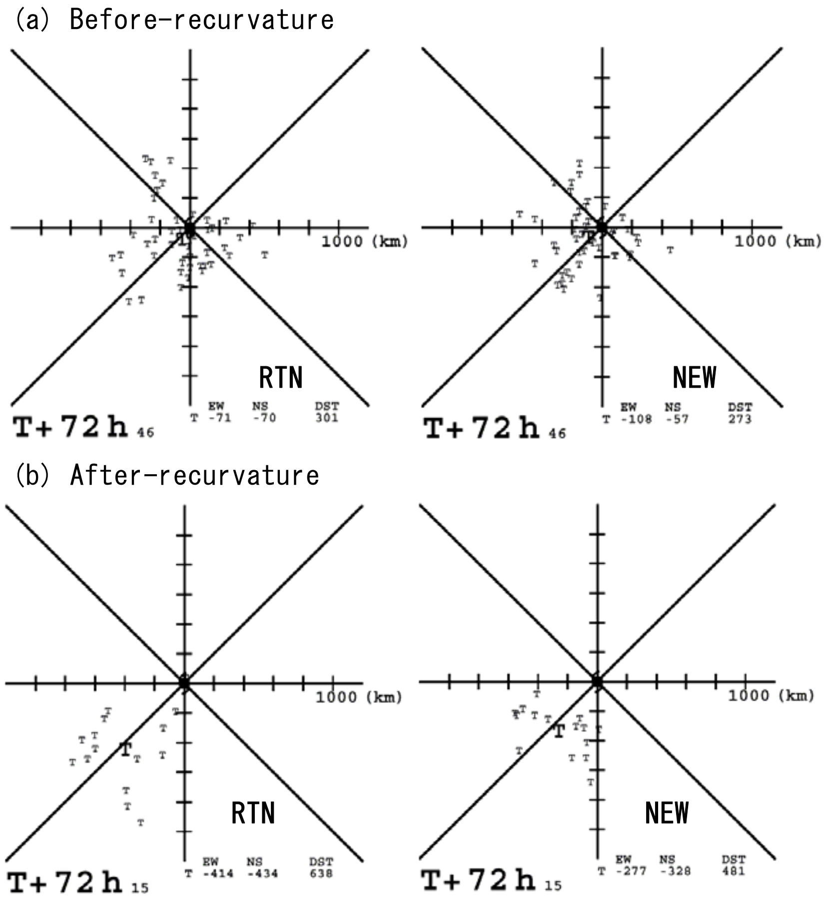

Fig. 8 Scatter diagram for 72-hour forecast error of typhoon position

The upper panels show the before-recurvature stage and the lower panels show the after-recurvature stage. The left panels show the control. The right panels show the new TYM. The predicted typhoon positions relative to the analysis are plotted. Up-direction shows the northward error and right-direction shows eastward error. Bold character '**T**' shows the mean positional bias.

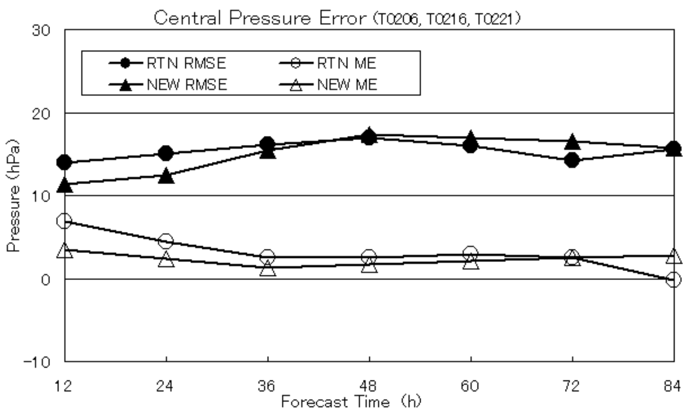

Fig. 9 Central pressure error of TYM.

RTN: control, NEW: new TYM. Black marks show root mean square error (RMSE). White marks show mean error (ME).

4. Summary

JMA has implemented a major version-up for TYM in July 2003. The version-up includes an introduction of precipitation and radiation processes based on those implemented in GSM in 1999. The roughness length formulae in calculating the heat (and water vapor) and momentum fluxes on the sea surface are also modified. False intensive rain areas associated with spurious small-scale lows in the tropics are suppressed. The typhoon track forecast is remarkably improved in the new TYM. As for typhoon intensity forecast, the new TYM produces almost same performance as the old one.

[APPENDIX] The formulae of the roughness length on the sea surface in the new TYM

The surface fluxes based on the Monin-Obukhov similarity theory are calculated with the following formulae :

$$\tau_x / \rho = -C_m |\mathbf{V}_a| u_a \qquad (1)$$

$$\tau_y / \rho = -C_m |\mathbf{V}_a| v_a \qquad (2)$$

$$H = -\rho c_p C_h |\mathbf{V}_a| (\theta_a - \theta_s) \qquad (3)$$

$$LE = -L \rho C_h |\mathbf{V}_a| (q_a - q_s) \qquad (4)$$

$$|\mathbf{V}_a| = \sqrt{u_a^2 + v_a^2}$$

where τ_x and τ_y are the momentum flux, H the sensible heat flux, LE the latent heat flux, θ the potential temperature, q the specific humidity, ρ the density of air, C_p the heat capacity at constant pressure of the air, L the latent heat of vaporization. Subscripts a and s denote the values at the lowest vertical level of the atmospheric model and the ground surface respectively. The exchange coefficient of momentum flux (C_m) and that of heat flux (C_h) proposed by Louis et al. (1981) are as follows:

$$C_m = \left\{ \frac{k}{\ln(z_a / z_{0m})} \right\}^2 \mathrm{fm}(Ri, z_a / z_{0m}) \qquad (5)$$

$$C_h = \frac{k}{\ln(z_a / z_{0m})} \frac{k}{\ln(z_a / z_{0h})} \mathrm{fh}(Ri, z_a / z_{0m}, z_a / z_{0h}) \qquad (6)$$

where k is the von Karman's constant (=0.4), z_{0m} the roughness length for momentum, z_{0h} the roughness length for heat, R_i the Richardson number, and fm and fh the functions decided by stability (Refer to JMA (2002) for the details). Different values of the roughness length are used for the land from that for the sea surface. Only the roughness length on the sea surface is changed in the experiments.

In the old TYM, the roughness length on the sea surface is calculated by following formulae derived from Kondo (1975):

$$
\begin{aligned}
&u_{10} \leq 25m/s \\
&\quad z_0 = -34.7\times10^{-6} + 8.28\times10^{-4}u^* \\
&u_{10} > 25m/s \\
&\quad z_0 = -0.227\times10^{-2} + 3.39\times10^{-3}u^*
\end{aligned} \tag{7}
$$

where u^* is a friction velocity and u_{10} is a wind speed at 10 m height above sea level, z_0 is used for z_{0m} and z_{0h}.

In the new TYM, the roughness length for momentum flux proposed by Beljaas (1995) and that for heat flux proposed by Garratt (1992) are used respectively:

$$z_{0m} = \frac{0.11\nu}{u^*} + \frac{\alpha}{g}u^{*2} \tag{8}$$

$$z_{0h} = \exp\left\{-2.48\times\left(\frac{u^*\times z_{0m}}{\nu}\right)^{0.25} + 2.0\right\} \tag{9}$$

where ν is the kinematic viscosity of air (=1.5x10^{-5}m^2/s), g the acceleration of gravity and α = 0.018.

Emanuel (1995) indicates that the intensity of simulated tropical cyclones depends on the value of Ch/Cm. In the case of large values of Ch/Cm, the simulated typhoon is intensified, and vice versa. The value of Ch/Cm for the new TYM is smaller than that for the old one (Fig. A), and the overestimation of typhoon intensity is suppressed.

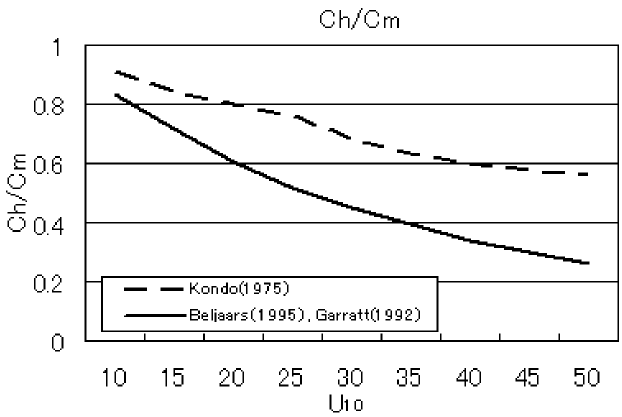

Fig. A The ratio of Ch to Cm, as a function of wind speed at 10m height. The ratio calculated under the stable condition at the surface boundary layer.

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