Outline of the New Typhoon Prediction Models at JMA

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Abstract

Aiming at improving tropical cyclone (TC) track and intensity forecasts as well as general weather forecasts, the Japan Meteorological Agency (JMA) started the operation of a new suite of numerical prediction models on 1 March 2001 on the occasion of the installation of an advanced computer system (Computer System for Meteorological Services: COSMETS) in place of the 5-year-old predecessor. Both horizontal and vertical resolutions have been enhanced by 1.67 times in the Typhoon Model (TYM) while only the vertical resolution has been by 1.33 times in the Global Spectral Model (GSM). The new TYM runs four times a day to produce 84-hour predictions for each of a maximum of two TCs in the western North Pacific while the new GSM runs twice a day to produce 90-hour predictions for all tropical cyclones of tropical storm intensity or higher in the same basin.

Since TYM and a simple guidance scheme based on it have been shown to produce 48-hour TC intensity predictions with fairly high accuracy, JMA will start 48-hour TC intensity forecasts in June 2001. JMA has a plan to extend intensity forecasts up to 72 h, soon after it confirms that the combination of the new TYM and the guidance scheme makes 72-hour intensity predictions with enough accuracy for TCs in the coming 2001 season.

During the 5-year period of the new computer system, a further enhancement of the resolutions of TYM by 1.20 times, the introduction of variational data assimilation schemes into global analysis, and the coupling of TYM with an ocean mixed-layer model are scheduled. These are expected to further improve performance of the numerical models in TC track and intensity predictions.

1. Introduction

There have been increasing requests for extended forecasts of tropical cyclone (TC) intensity as well as improved track forecasts of RSMC Tokyo - Typhoon Center, one of the Regional Specialized Meteorological Centers (RSMC) for TC analysis and forecast. The Japan Meteorological Agency (JMA) installed a new computer system: Computer System for Meteorological Services (COSMETS) to meet the growing demand for atmospheric and oceanic analyses and forecasts with higher accuracy. On this system a new suite of numerical analysis and prediction models started their operations on 1 March 2001. Among these the Typhoon

Table 1 Specifications and operations of the Typhoon Model (TYM) and the Global Spectral Model (GSM) at JMA

Model		TYM			GSM		
Version	identifier	TYM9603 (40km, L15)	TYM0103 (24km, L25)	TYM0303 (20km, L30)	GSM9603 (T213, L30)	GSM0103 (T213, L40)	GSM0303 (TL319, L40)
	in operation	1 Mar. 1996 – 28 Feb. 2001	1 Mar. 2001 – early 2003	early 2003 – early 2006	1 Mar. 1996 – 28 Feb. 2001	1 Mar. 2001 – early 2003	early 2003 – early 2006
Domain	area and setting	limited-area, relocatable			global		
	num. of grid points	163 x 163	271 x 271	325 x 325	640 x 320	←	←
	map projection	Mercator (S. of 20N) / Lambert (N. of 20N)				N/A	
Discretization and Resolution							
	horizontal	spectral (double Fourier)			spectral (spherical harmonics)		
	grid size/wave num.	40km	24km	20km	T213	←	TL319
	vertical	finite difference (σ –p hybrid)			finite difference (σ –p hybrid)		
	num. of vert. levels	15	25	30	30	40	←
Dynamics	governing equations	primitive (hydrostatic)			primitive (hydrostatic)		
	progn. variables	u, v, Tv, q, ln(Ps)			ζ, D, T, q, qc*, Ps		
	time integration	semi-implicit			semi-implicit		
	initialization	nonlinear normal-mode with physics			nonlinear normal-mode with physics		
Physics	moist phys. processes						
	grid scale	instant fallout of condens. with evap. of rain	←, then progn. cloud water cont.		progn. cloud water cont. with evap. of rain		
	cumul. parameteriz.	progn. Arakawa–Schubert			progn. Arakawa–Schubert		
	mid–level conv.	moist conv. adj.			mass–flux type		
Operation	length of prediction	78h	84h	←	84h / 192h	90h / 216h	←
	initial time	0600, 1800UTC	0000, 1200UTC / 0600, 1800UTC	← ←	0000 / 1200UTC	0000 / 1200UTC	←
Initial field	analysis	Gobal (T213 grid)	←	Gobal (TL319 grid)	Gobal (T213 grid)	←	Gobal (TL319 grid)
	data cut–off time	1.5h	2.5h / 1.5h	←	2.5h / 3.0h	2.5h	←
	assimilation scheme	3–D stat. Interpol on hybrid σ –p levels	←, then 3–D var. (late 2001)	3–D var., then 4–D var. (early 2004)	3–D stat. Interpol on hybrid σ –p levels	←, then 3–D var. (late 2001)	3–D var., then 4–D var. (early 2004)
Lateral boundary conditions		GSM prediction 3–hourly			N/A		
Bogusing	symmetric component	synthetic vortex based on Pc and R30**			synthetic vortex based on Pc and R30**		
	asymmetric component	derived from TYM prediction, adjusted so that initial track matches latest analysis			derived from GSM prediction		

←: same as the column on the nearest left

* qc: cloud water content

** Pc: central pressure of tropical cyclone
R30: radius of 30kt (~15m/s) winds

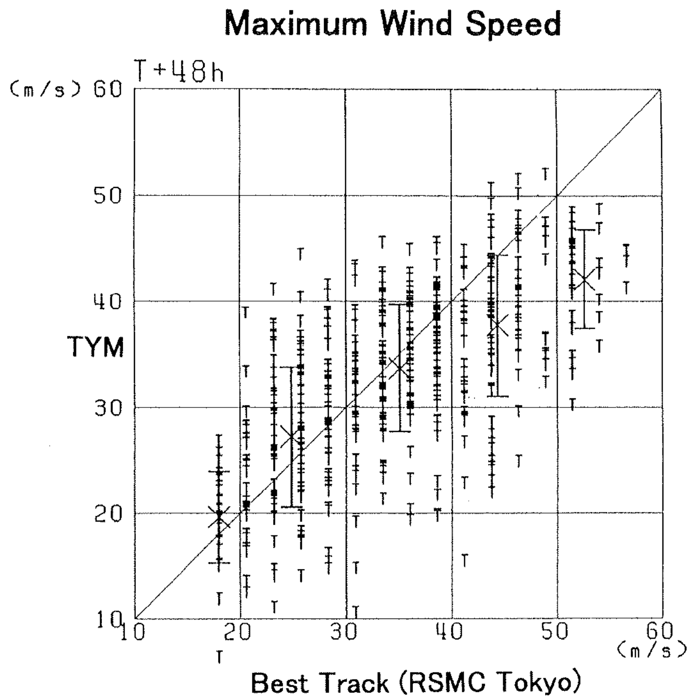
Model (TYM) and the Global Spectral Model (GSM) have been used for tropical cyclone forecasting. Both horizontal and vertical resolutions of TYM were enhanced on this occasion while only the vertical resolution of GSM was increased.

The former Typhoon Model (TYM9603) of JMA had large negative biases for intense TCs and slight positive biases for weak TCs in the prediction of maximum wind speed (Nagata and Mino, 2000) (Fig. 1). Its relatively coarse grid size of 40km probably explains a major part of the large negative biases, since it is far below (above) the marginal resolution (grid size (5-10km)) to represent inner-core structure of TC, which is highly correlated with TC intensity. As shown by Nagata et al. (2001) in a mesoscale model intercomparison study, COMPARE Case III, we can expect that the enhanced model resolutions reduce the errors significantly in intensity prediction, especially the negative biases in maximum wind speed for intense TCs.

This paper first describes specifications of the new typhoon prediction models (TYM and GSM) in some detail (Section 2), and then focuses on the performance of TYM in TC predictions; the impact of higher resolutions in TYM on TC track predictions of a particular typhoon in 1998 (Section 3), and that on a TC intensity prediction of an intense TC in 1999 (Section 4), followed by an example of the prediction of a TC by the new TYM (Section 5). The reader is referred to companion papers (Kuma et al., 2001; Nagata and Tonoshiro, 2001) for the performance of GSM in TC predictions. These are believed to help the reader learn major features of the new typhoon prediction models to use its products effectively and efficiently. At the end, future plans aiming for further improvement of numerical TC predictions are briefly presented (section 6).

2. Specifications and operations of the new TYM

Specifications of the new TYM and GSM are shown in Table 1. Major frameworks of the models follow the predecessors' both in dynamics and in physics while their codes have been changed to optimize computational efficiency on the massive parallel processors computer with distributed memory. TYM is a spectral limited-area model whose domain of about 6,480km × 6,480km square is re-locatable and fixed during integration according to the expected track of a target TC. The most important changes were made in resolutions as well as in operations of the models. TYM increased its horizontal resolution by 1.67 times from 40km to 24km and vertical resolution by the same ratio from 15 to 25 σ-p hybrid levels (Fig. 2). The enhanced resolutions, especially the horizontal one, are believed to improve not only TC track predictions but also intensity predictions through better representation of inner-core



1996-1998

Fig. 1 Scatter plot of maximum wind speeds (m s^{-1}) for tropical cyclones of tropical storm intensity or higher in the western North Pacific in 1996-1998. Prediction by the previous Typhoon Model (TYM9603) at T+48h (vertical) vs. Analysis (RSMC Tokyo Best Track) (horizontal). Cross and error bar denote mean and standard deviation of errors, respectively, for each 10 m s^{-1} range of the analysis.

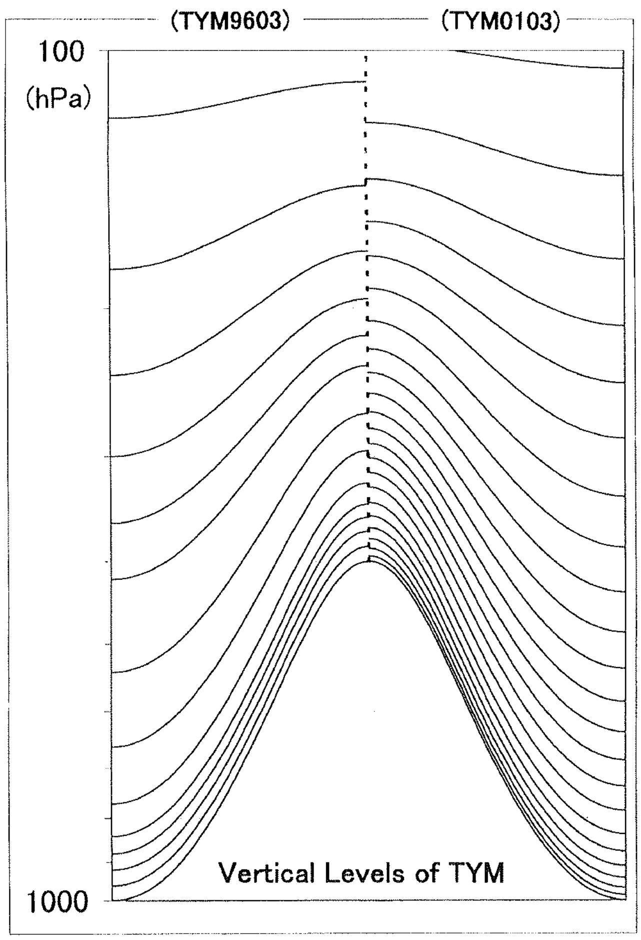


Fig. 2 Distributions of vertical levels up to 100 hPa in the former TYM (TYM9603) (left) and in the new TYM (TYM0103) (right).

structure of TCs. GSM increased only its vertical resolution by 1.33 times from 30 to 40 σ -p hybrid levels, with most of the additional levels (8 out of 10) put into the stratosphere (figure not shown). As regards physical processes including cumulus convection, GSM had a major version-up in December 1999, which has been producing positive impacts on TC track and intensity predictions, as described in a companion paper (Kuma et al., 2001). Its prognostic Arakawa-Schubert cumulus parameterization experienced further tuning on 1 March 2001 to alleviate excessive feedback mechanism.

The former TYM and GSM had been operated alternately at 6-hour intervals, providing 78 h and 84 h predictions, respectively, for making RSMC's official 72-hour TC track forecasts. Since 1 March 2001, TYM has been operated four times a day at 6-hour intervals (at 0000, 0600, 1200 and 1800UTC). It produces 84-hour predictions for each of a maximum of two TCs, whenever a TC of tropical storm intensity or higher is expected to exist in the area of responsibility (AOR) of RSMC Tokyo within 24 hours. This operation enables providing TC forecasters with two consecutive TYM predictions with different initial fields covering the official 72-hour forecast periods. GSM has been operated twice a day (at 0000/1200UTC) as it had been. Its predictions have been extended to 90 h to provide lateral boundary conditions to TYM initialized 6 hours later (at 0600/1800UTC). Now TC forecasters at the RSMC Tokyo - Typhoon Center have three (2 TYMs + 1 GSM) and four (2 TYMs + 2 GSMs) predictions available for making 72-hour track forecasts to be issued at 0600/1800UTC and at 0000/1200UTC, respectively.

Schemes of implantation of synthetic tropical cyclone structure (tropical cyclone bogusing) remain the same as the previous ones (NPD/JMA, 1997; Nagata et al. 1998). Both TYM and GSM employ asymmetric bogusing, in which asymmetric components are derived from prediction fields of respective models. In TYM the derived asymmetric components are crudely adjusted (rotated and amplified) so that initial TC tracks match better latest analyzed tracks (Nagata, 1997). Synthetic TC vortices are then implanted into initial fields (TYM) or first guess fields (GSM).

For both models, initial fields are prepared from the Global Analysis made on the T213 Gaussian grid of GSM with three-dimensional statistical interpolation. The assimilation scheme is scheduled to be replaced with three-dimensional variational scheme (3D-VAR) during the year 2001 so that satellite measurements can be directly assimilated.

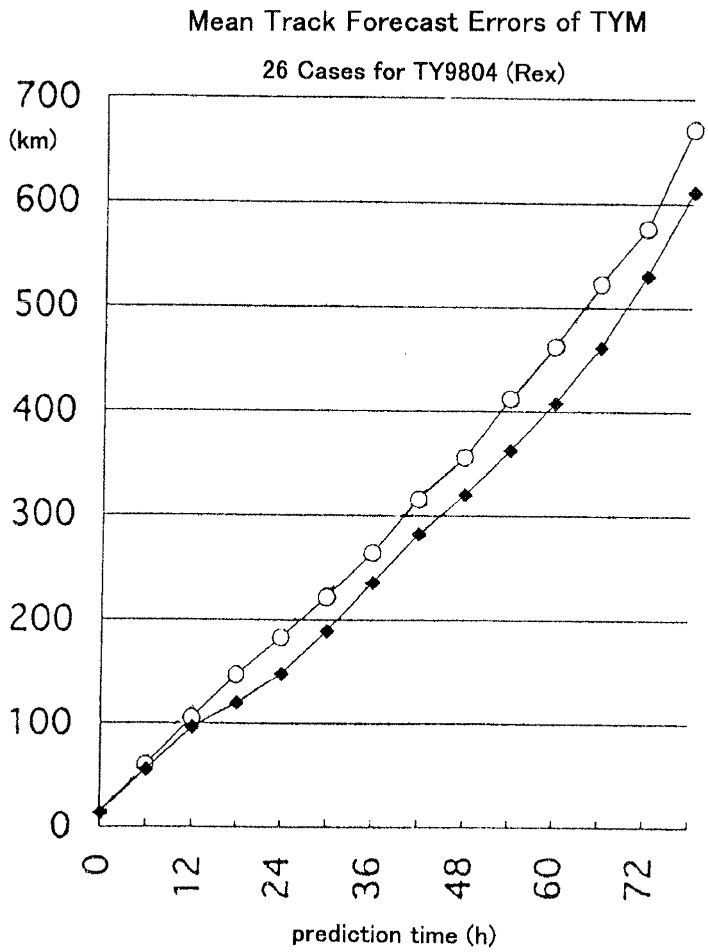


Fig. 3 Mean track prediction errors for 26 cases of Typhoon 9804 (Rex). Line with open circles indicates the former TYM (9603) and line with solid squares its higher-resolution version (23.5 km grid, 27 vertical levels).

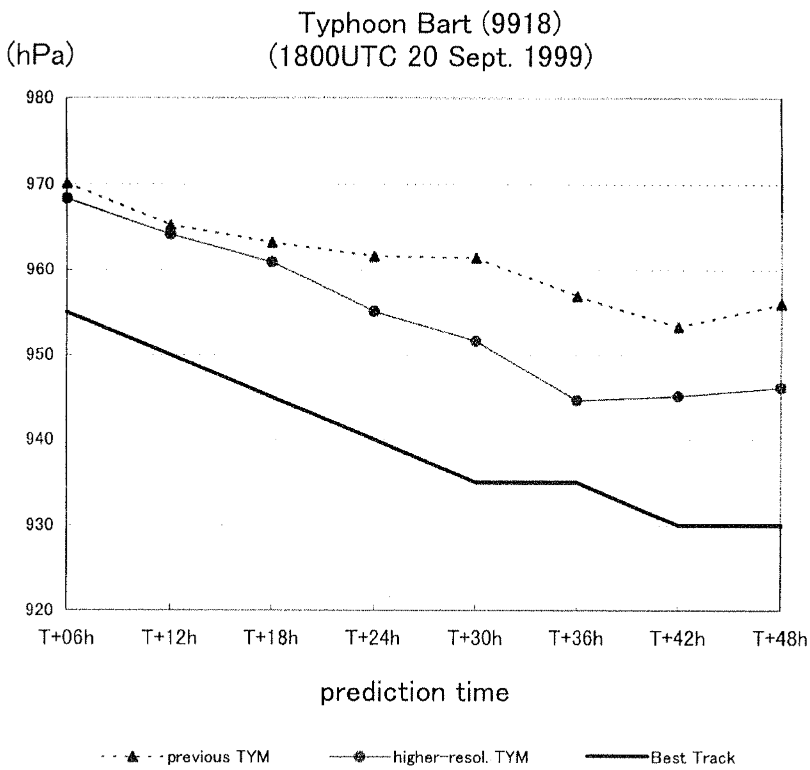


Fig. 4 Impact of doubled horizontal and vertical resolutions for a case of Typhoon Bart (9918). Predicted central pressures for the former TYM (40 km grid, 15 levels) (dashed line with solid triangles) and its higher-resolution version (20 km grid, 30 levels) (thin solid line with solid circles) are shown in comparison with the Best Track data (thick sold line). Time frame is initialized at 1800UTC 20 September 1999.

3. Impact of higher resolutions on track prediction

To examine the impact of higher resolutions of TYM by comparison with the former TYM, a higher-resolution version of the former TYM was tested in a total of 26 cases of Typhoon 9804 (Rex). In this test, the higher-resolution version of the former TYM adopted a horizontal resolution of 23.5 km and 27 vertical levels, which were very close to those of the new TYM. The former TYM showed far above-average track errors for this particular typhoon, whose complicated track with several opposite curvatures was obviously affected by two or more tropical upper-tropospheric lows (TUTLs) passing east of it.

Figure 3 compares mean track prediction errors between the former TYM and its higher-resolution version. Note that differences existed only in resolutions of the prediction models and neither in initial fields nor in lateral boundary conditions in this examination. The figure shows that the mean track error was reduced by about 10 % for 72-h prediction when horizontal and vertical resolutions were enhanced by a factor of 1.7 ~ 1.8.

4. Impact of higher resolutions on intensity prediction

In this section we show impact of higher resolutions of the prediction model on TC intensity prediction for a case of a rapidly developing typhoon. In this prediction experiment, we compared two models: one was the former TYM and the other was its higher-resolution version which had exactly doubled horizontal and vertical resolutions (20km grid and 30 vertical levels). The target was Typhoon Bart (9918) on a developing stage in September 1999, which eventually hit the western part of Japan causing a severe storm surge claiming a toll of 12 lives.

Figure 4 compares predictions of central pressure between the two models against the RSMC Tokyo Best Track data. It shows that both models predicted the deepening of the typhoon to some extent. However, in the former TYM the error grew faster with time to reach +25 hPa at T+48h. Meanwhile the higher resolution version produced a time evolution of central pressure which was closer to the analysis, even though it still had a positive bias. Thus, the model of higher resolutions showed a better performance at least in this particular case. In this connection, Nagata et al. (2001) showed a significant impact of horizontal resolution on TC intensity prediction for a case of an explosive development of a TC in the western North Pacific in 1990 in the third case of the mesoscale model intercomparison study (COMPARE III). Taking this into consideration, we can expect that weak biases in intensity prediction for a

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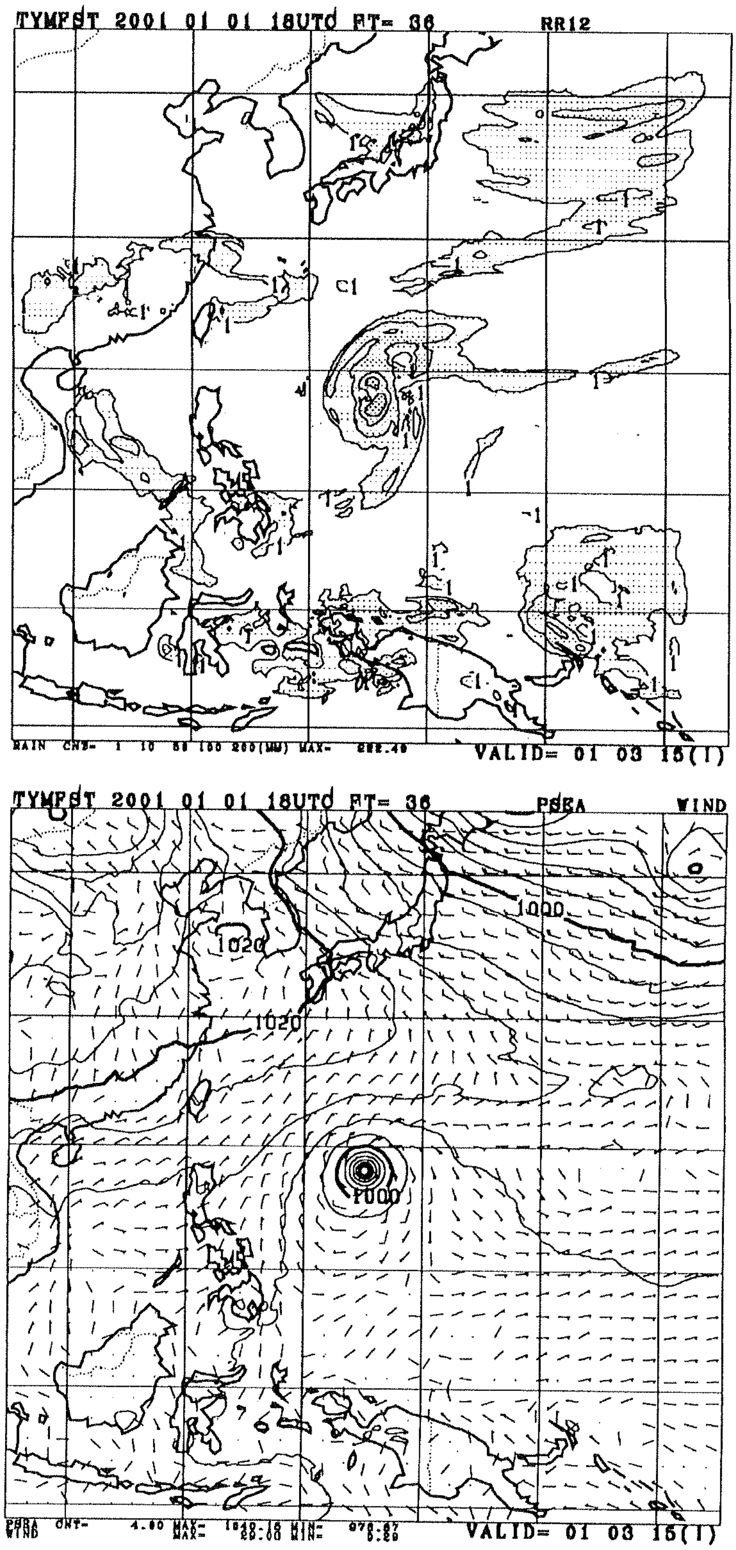

Fig. 5 An example (snapshot) of predicted fields of a TC (Typhoon Soulik, 0023) by the new TYM initialized at 1800UTC 01 January 2001. (a) 12-hour accumulated precipitation at T+36h (valid at 0600UTC 03 January 2001). Contours are 1, 10, 50, 100, 200 mm. Maximum is 222 mm. (b) Sea-level pressure and surface winds at T+36h. Contour intervals of pressure are 4 hPa and wind notation is conventional. (c) Verifying GMS-V infrared imagery at 0600UTC 03 January 2001.

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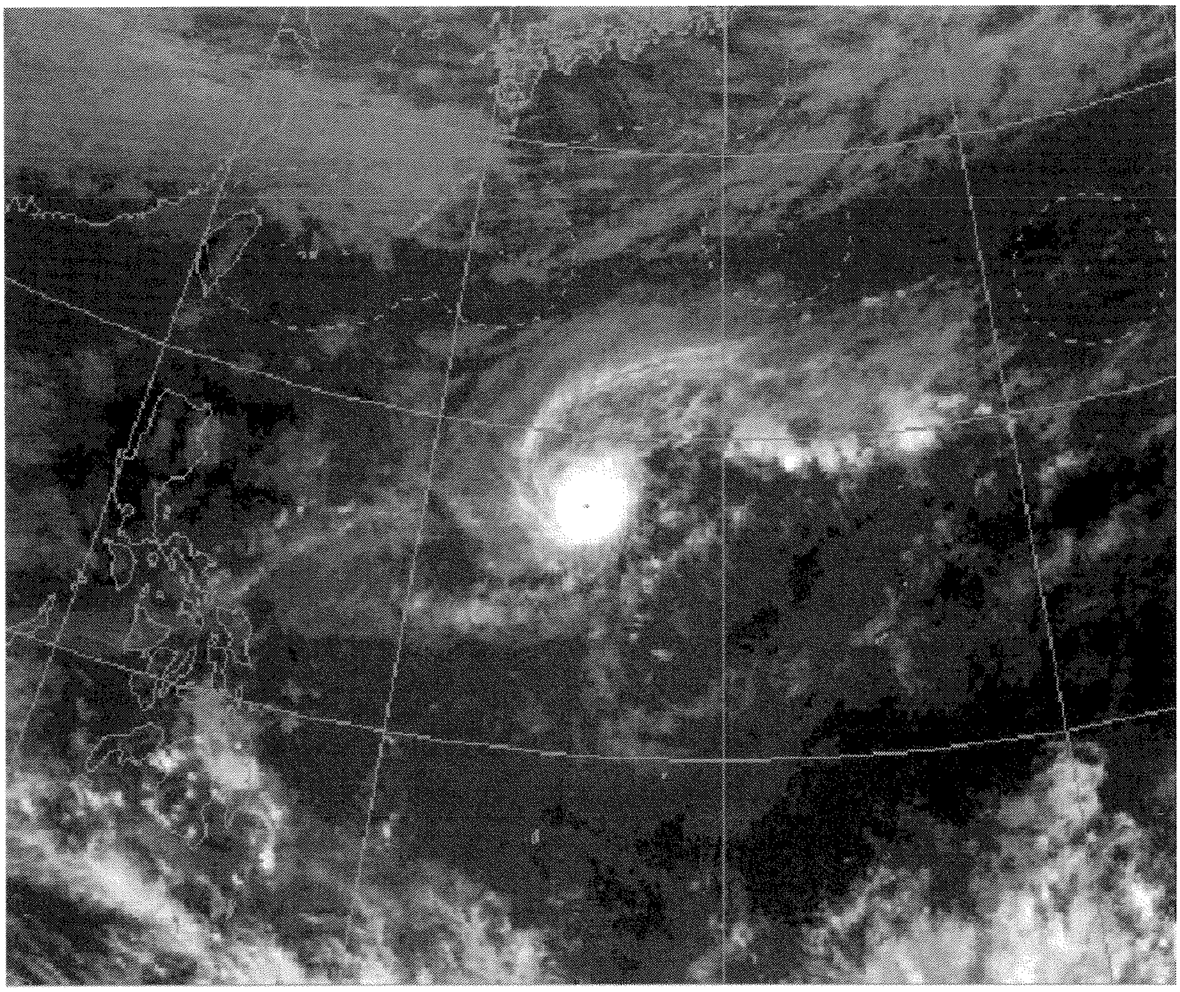

Fig. 5 (cont'd)

intense TCs (see Fig. 1) will be reduced much in the new Typhoon Model.

Besides these, in a companion paper (Nagata and Tonoshiro, 2001), it is shown that intensity prediction errors can be reduced to some extent with a simple guidance scheme which includes initial adjustment with latest analysis. It works well in cases like the one in Fig. 4 where error is highly consistent in time. Since TYM combined with the simple guidance scheme based on it produces 48-hour TC intensity predictions with fairly high accuracy, JMA has decided to start 48-hour TC intensity forecasts in June 2001. JMA has a plan to extend intensity forecasts up to 72 h, soon after it confirms that the combination of the new TYM and the guidance scheme makes 72-hour intensity predictions with enough accuracy for TCs in the coming 2001 season.

5. Example of prediction of a TC with the new TYM

In this section we present an example of prediction of a TC with the new numerical analysis and prediction system which includes the new TYM (24 km grid, 25 levels) and the new Global Data Assimilation System (T213, 40 levels). The new system was tested for a case of Typhoon Soulik (0023), which was marked by an abrupt deepening of central pressure followed by a rapid filling with an interval of only 24 hours.

Figure 5 shows prediction fields for Typhoon Soulik on its developing stage at T+36h (valid at 0600UTC 03 January 2001) made by the new Typhoon Model initialized at 1800UTC 01 January 2001. Not only inner-core precipitation maxima associated with eye-wall ascents but also outer spiral rainbands were simulated in fair agreement with corresponding satellite imagery. Besides these, sharp pressure gradients were simulated near the center, which are typical of intensifying tropical cyclones. Probably owing to this fair prediction of subsynoptic-scale features, the new TYM succeeded in predicting a time evolution of central pressure which is fairly close to the actual evolution of central pressure (the preliminary RSMC Best Track data) including the abrupt deepening followed by the rapid filling with the minimum at T+48h (valid at 1800UTC 03 January 2001) (Fig. 6). Meanwhile the former TYM produced a much worse time evolution of central pressure which had minima at T+18h and T+30h. Thus in this case the new TYM performed much better than the former one in the prediction of central pressure evolution, though errors were still large probably partly because of insufficient resolutions for representing subsynoptic-scale inner-core structure. It is speculated that not only higher resolutions of the new TYM but also better initial fields produced through the analysis and forecast cycle with the new Global Data Assimilation System might have contributed

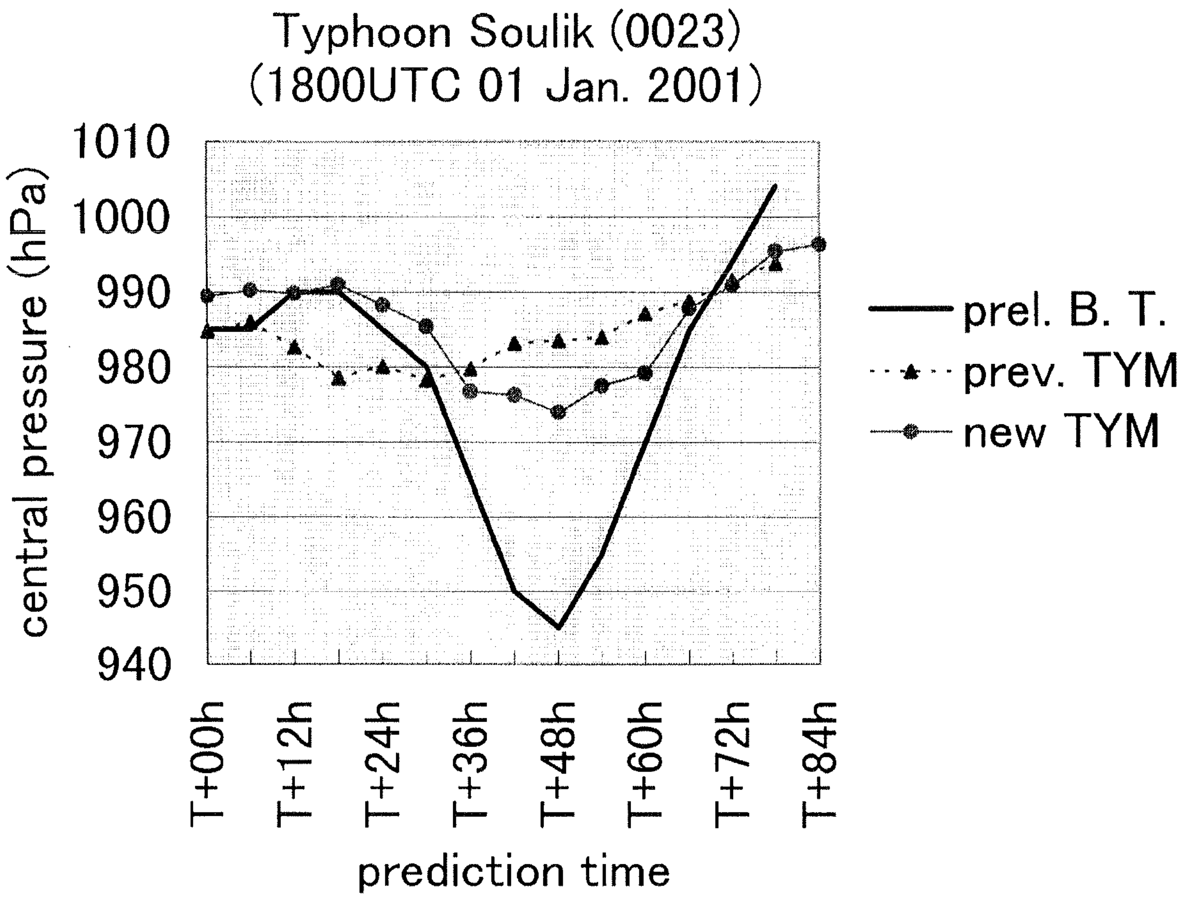

Fig. 6 Time evolutions of central pressure of Typhoon Soulik (0023) predicted by the former TYM (dashed line with solid triangles) and the new TYM (thin solid line with solid circles) in comparison with the preliminary Best Track data (thick solid line). The models are initialized at 1800UTC 01 January 2001.

to this improved prediction.

6. Future plans for numerical TC predictions

There are several improvements of the numerical prediction system to be made during the 5-year period of the new computer system. One is further enhancement of the resolutions of TYM by a factor of 1.20 from 24 km to 20 km in horizontal grid size and from 25 to 30 vertical levels, scheduled tentatively early 2003. This will not be operational until GSM is converted from the current Eulerian framework with T213 resolution into a semi-Lagrangian framework with a linear grid of TL319 resolution and a two-time-level scheme, which is expected to bring a drastic improvement in computational efficiency.

Another improvement is implementation of four-dimensional variational data assimilation scheme (4D-VAR) for global analysis as well as for analyses for mesoscale models, which enables direct assimilation of asynoptic, non-prognostic-variable data, such as radiance measured from polar-orbiting satellites, atmospheric (moisture) delay of GPS satellite signals, and radial component of wind observed with Doppler radar. Although the variational scheme (4D-VAR) requires huge computer resources, it is expected to produce initial fields of high quality which have sufficient physical consistency and derive a maximum amount of information from observational data. It is sure to lead to improved accuracy of TC predictions. The implementation is scheduled in 2004.

The other thrust into TC intensity predictions would be coupling of TYM with an ocean mixed-layer model. There have been a number of studies which show large impacts of the coupling of a tropical cyclone model with an ocean mixed layer on TC intensity (Bender et al., 1993; Falcovich et al., 1995; Ginis et al., 1997). An ocean model to be coupled with TYM is now under development at the Meteorological Research Institute, JMA Tsukuba. The coupling is scheduled in 2004.

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