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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 $\times$ 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

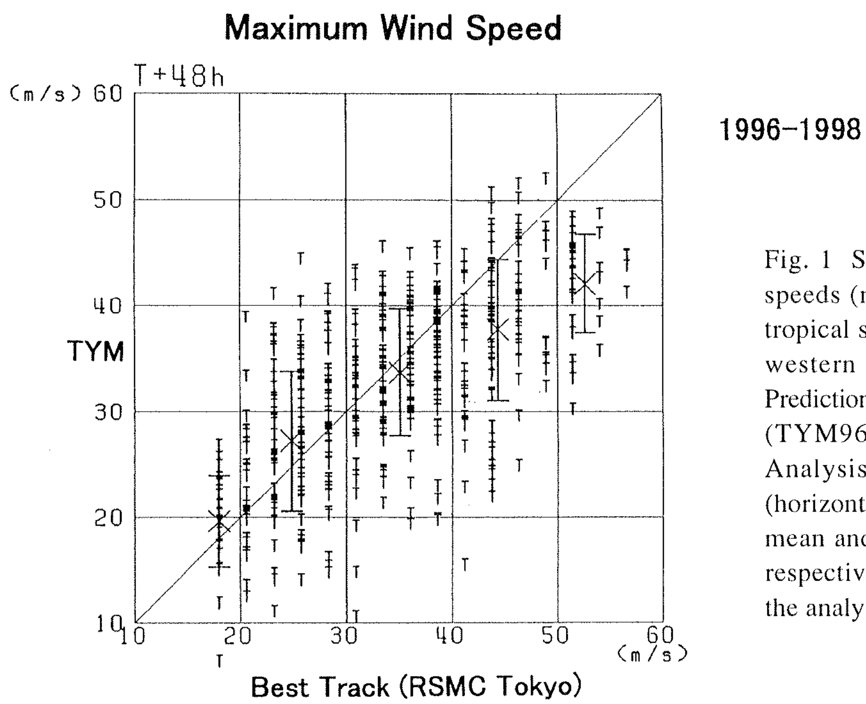

Fig. 1 Scatter plot of maximum wind speeds (m s^{-1}) for tropical cyclones of tropical storm intensity or higher in the western North Pacific in 1996-1998. Prediction by the previous Typhoon Model (TYM9603) at T+48h (vertical) vs. Analysis (RSMC Tokyo Best Track) (horizontal). Cross and error bar denote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

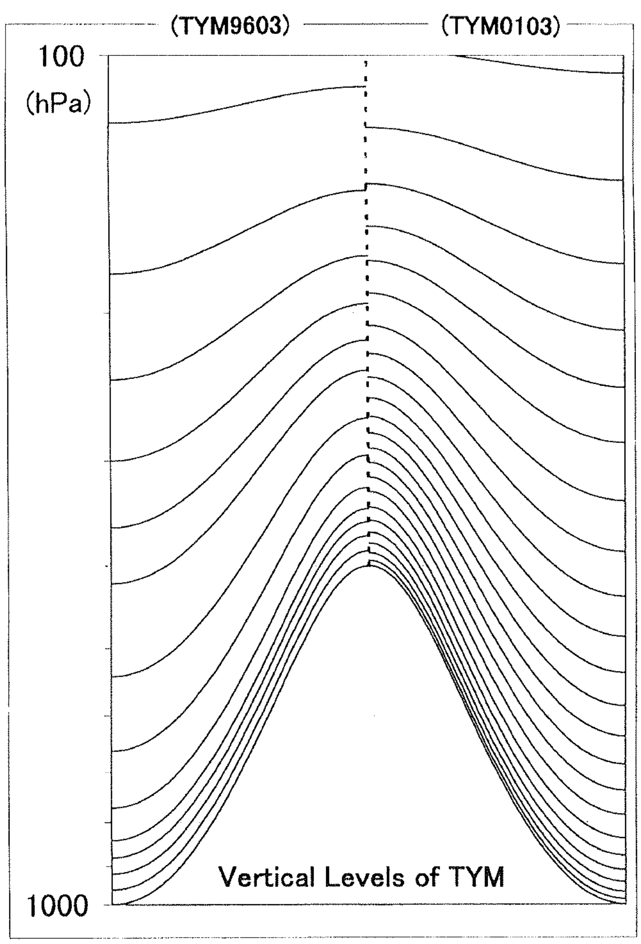

Fig. 2 Distributions of vertical levels up to 100 hPa in the former TYM (TYM9603) (left) and in the new TYM (TYM0103) (right).

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.

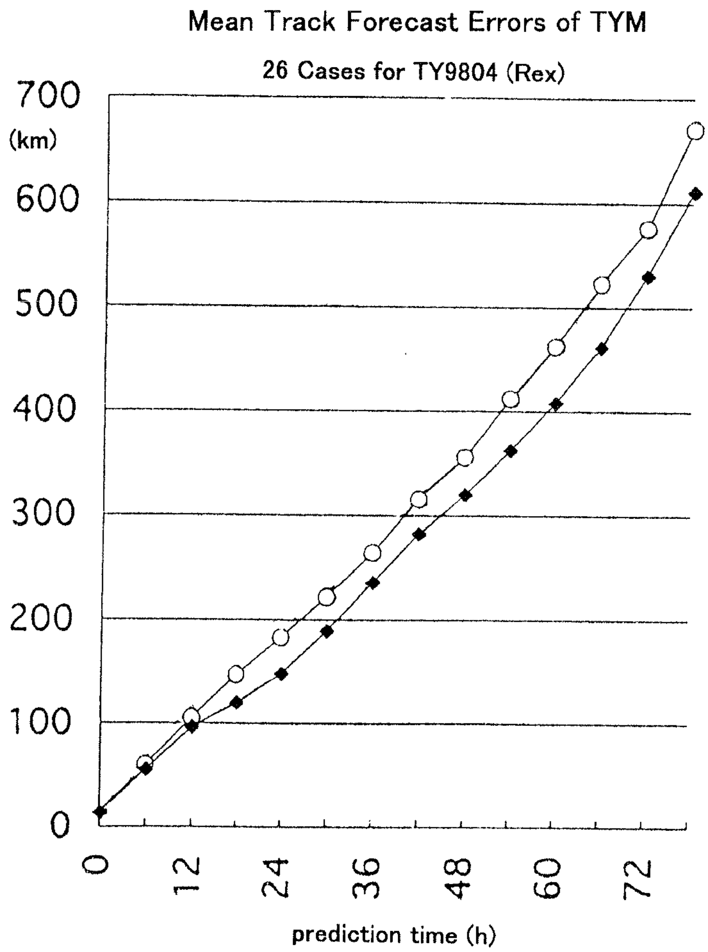

Fig. 3 Mean track prediction errors for 26 cases of Typhoon 9804 (Rex). Line with open circles indicates the former TYM (9603) and line with solid squares its higher-resolution version (23.5 km grid, 27 vertical levels).

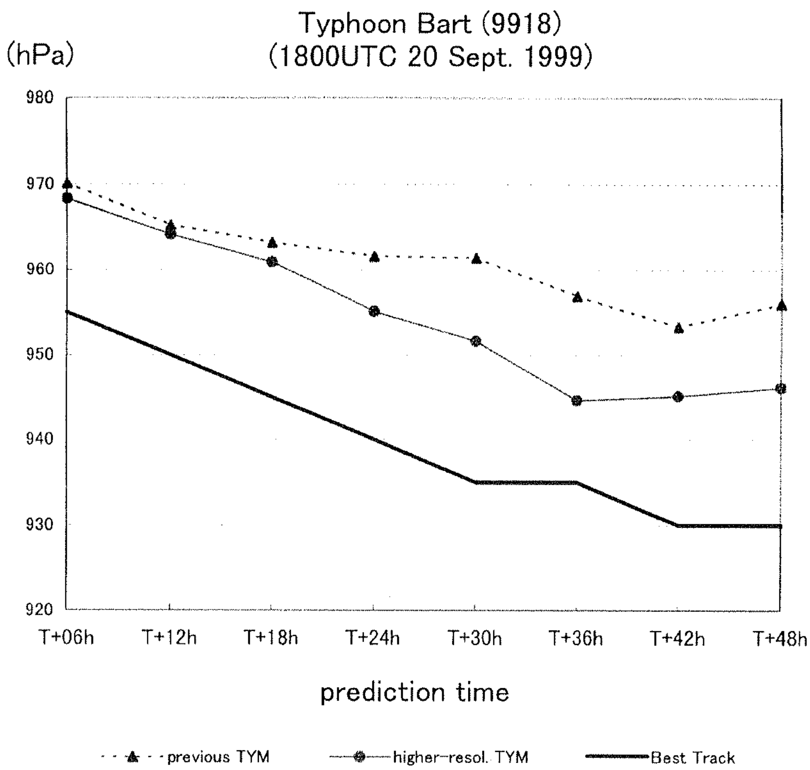

Fig. 4 Impact of doubled horizontal and vertical resolutions for a case of Typhoon Bart (9918). Predicted central pressures for the former TYM (40 km grid, 15 levels) (dashed line with solid triangles) and its higher-resolution version (20 km grid, 30 levels) (thin solid line with solid circles) are 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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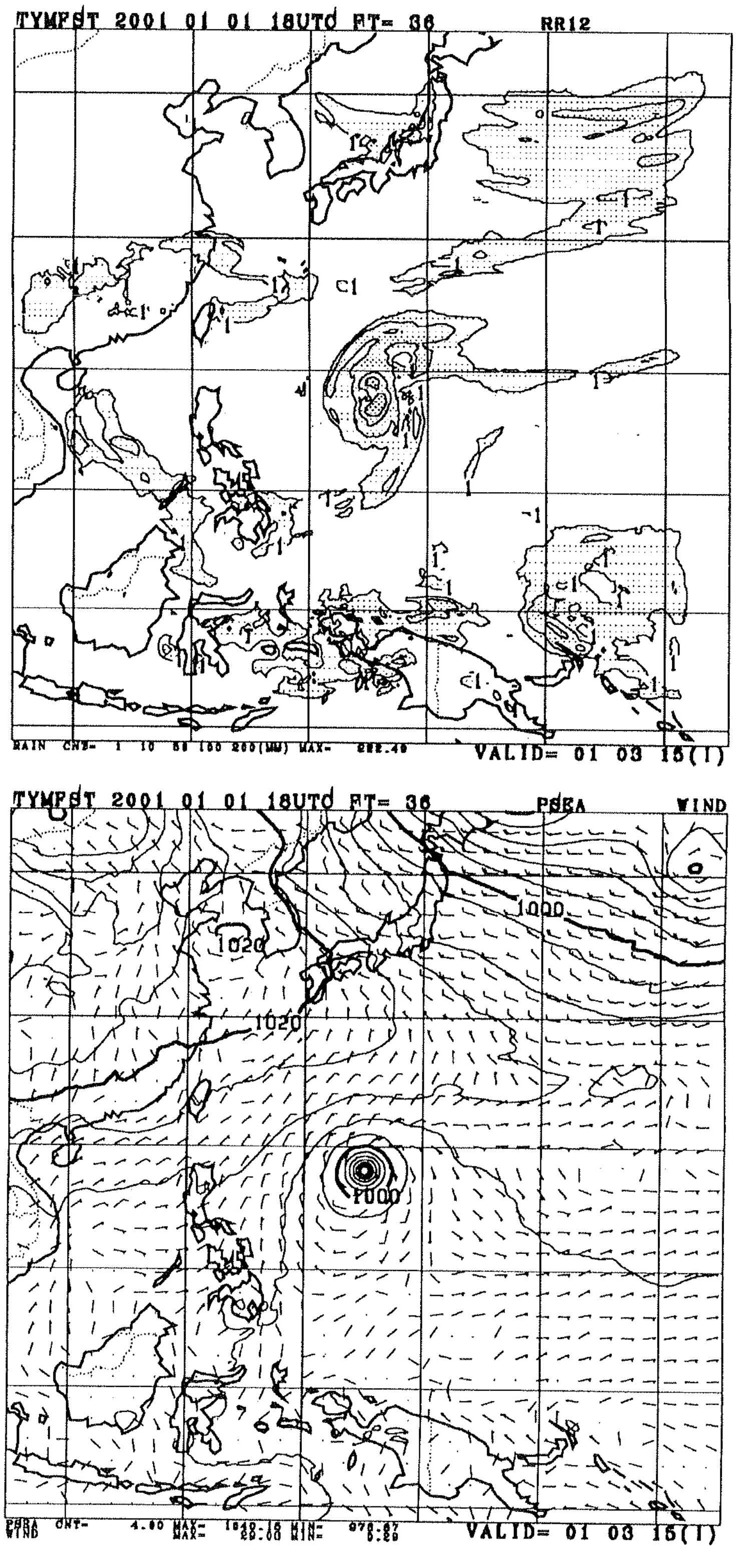

Fig. 5 An example (snapshot) of predicted fields of a TC (Typhoon Soulik, 0023) by the new TYM initialized at 1800UTC 01 January 2001. (a) 12-hour accumulated precipitation at T+36h (valid at 0600UTC 03 January 2001). Contours are 1, 10, 50, 100, 200 mm. Maximum is 222 mm. (b) Sea-level pressure and 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.

GMS-V IR 0600UTC 03 January 2001

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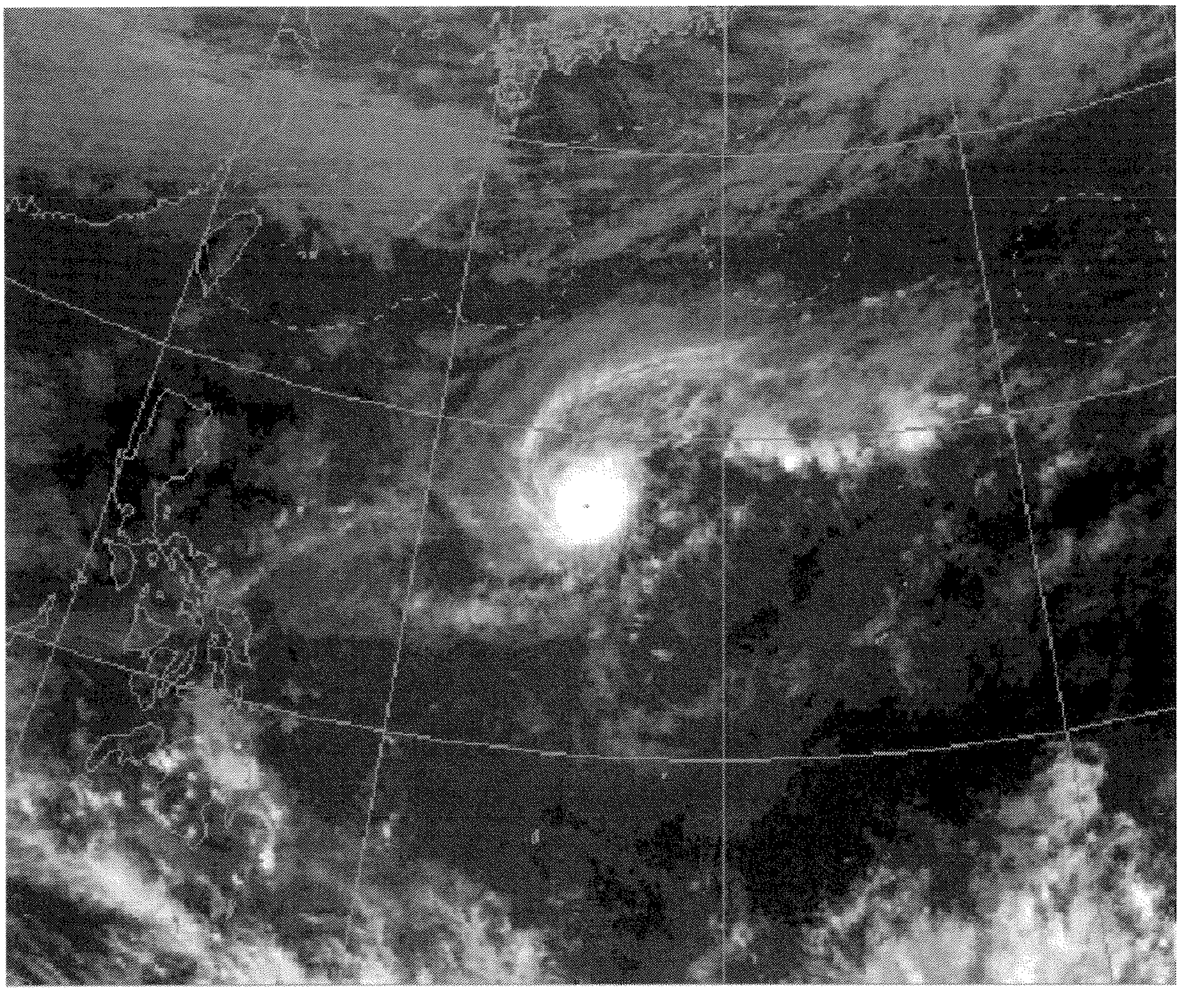

Fig. 5 (cont'd)

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

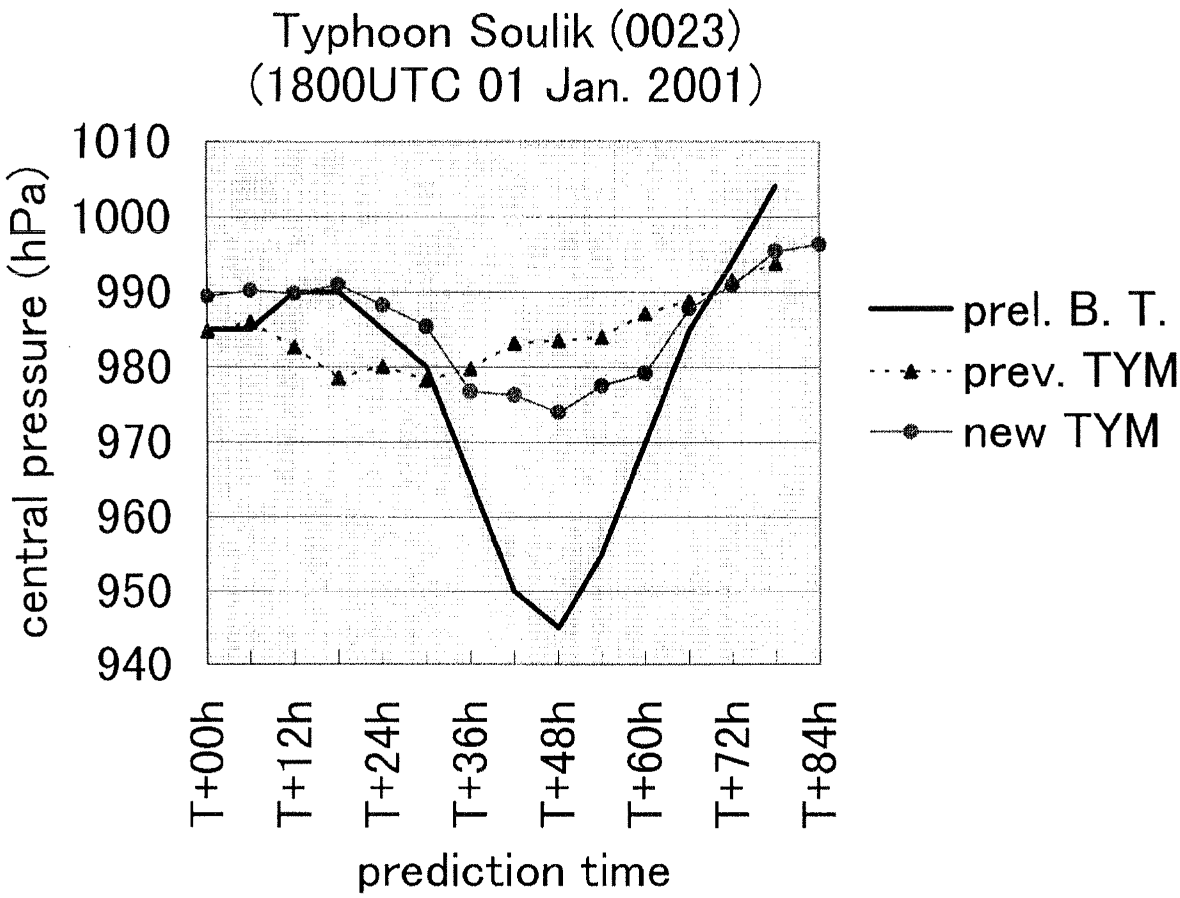

Fig. 6 Time evolutions of central pressure of Typhoon Soulik (0023) predicted by the former TYM (dashed line with solid triangles) and the new TYM (thin solid line with solid circles) in comparison with the preliminary Best Track data (thick solid line). The models are initialized at 1800UTC 01 January 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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Impact of a Recent Major Version-up of the Global Spectral Model (GSM) at JMA on Tropical Cyclone Predictions

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Abstract

The Global Spectral Model (GSM) at the Japan Meteorological Agency (JMA) underwent a major version-up in December 1999. The version-up included the incorporation of cloud water content as a prognostic variable, a modification of the prognostic Arakawa-Schubert cumulus parameterization, and the calculation of direct effect of aerosols on short-wave radiation. A verification against a best track data has been made of predictions of tropical cyclones (TCs) in the western North Pacific by GSM for all the cases in the year 2000 and has been compared with those for the previous four-year period (1996-1999). Results show that the version-up produced significant improvements both in track and intensity predictions of TCs: the mean track error relative to that of the persistency forecast has been reduced by about 20 (10) % for 24 (72) h predictions, while the bias and the root-mean-square error (RMSE) of maximum wind speed have been reduced drastically from 14 (17) m s^{-1} to 8 (6) m s^{-1} and from 15 (19) m s^{-1} to 10 (11) m s^{-1} for 24 (72) h predictions, respectively.

1. Introduction

The Japan Meteorological Agency (JMA), one of the Regional Specialized Meteorological Centers (RSMCs), made a major version-up of the Global Spectral Model (GSM) in December 1999 to reduce systematic errors and produce better predictions. The version-up included the incorporation of cloud water content as a prognostic variable, a modification of the prognostic Arakawa-Schubert cumulus parameterization, and the calculation of direct effect of aerosols on short-wave radiation.

Before the version-up, GSM showed a relatively large error in the tropical upper troposphere. It was speculated that inconsistency in the treatments of latent heat release and radiative heating/cooling associated with clouds in the upper troposphere was the major source of the error. More specifically, in the previous GSM, cloud cover was diagnosed from relative humidity and cloud water content was diagnosed from temperature with a lower limit set at 240K. While these diagnostic schemes produced clouds leading to a good mean value of outgoing long-wave radiation (OLR) for the entire tropics, they caused unreasonable cloud water contents in some regions, which harmed diabatic heating distribution and wind fields. Another systematic error of GSM was pointed out in the distribution of rainfall in the Asian monsoon region, especially in the Bay of Bengal. The maximum of predicted rainfall was located in the southern part of the bay while actual rainfall is concentrated near the northern coasts and inland on the southern slope of the Himalayas. The prognostic Arakawa-Schubert cumulus parameterization scheme was suspected to produce this discrepancy in rainfall. The cloud-base mass flux in the scheme was mainly determined by an overall stratification of a layer represented by the cloud work function (Arakawa and Schubert, 1974). This tended to excessively prevent the scheme from activating in the neighborhood of the Tibetan Plateau where the upper troposphere is heated both by sensible heat supply and latent heat release.

To resolve these problems causing the systematic errors, three changes were made in GSM (Kuma, 2000a; Kitagawa, 2000). Firstly, to eliminate the inconsistency between cloud properties and radiative processes, cloud water content was changed from a diagnostic variable into a prognostic variable which was consistently coupled with both moist physical processes and radiative processes. Secondly, to better represent the Asian monsoonal rainfall, the equation prognosing cloud-base mass flux was changed in such a way that the following three factors alter the threshold value of cloud work function for triggering an increase of cloud-base mass flux for a particular entraining cumulus updraft:

- turbulence in the planetary boundary layer (PBL);
- grid-scale ascent near the cloud base;
- energy of convective inhibition ("negative area" in the vertical profile of temperature) .

Thirdly, to increase accuracy in the calculation of short-wave radiation, the direct effect of aerosols on short-wave radiation was incorporated into the model.

The changes on the version-up of the model actually alleviated the systematic errors, leading to improvements in verification scores of prediction fields (Kuma, 2000b). This paper focuses on impacts of the changes on tropical cyclone predictions.

2. Impacts on TC track and intensity predictions

Since the version-up was made near the end of the year 1999, we compare mean errors of tropical cyclone track predictions between the year 2000 and the previous four-year period (1996-1999) for all the cases of tropical cyclone available in the western North Pacific. To eliminate the influence of year-to-year variability, we normalize the track prediction errors with those for the persistency method.

The result is shown in Fig. 1a, in which improvement rates of track predictions by the model from the persistency forecasts are calculated. It shows that the mean improvement rates increased by about 20 (10) % for 24 (72) h predictions, in other words, the mean track errors relative to those of the persistency forecasts were reduced by the same amounts. Note this error reduction was achieved only by the changes in the prediction model.

Besides, they presumably influenced the global analyses through the "forecast-analysis" cycle. In Fig. 1b are shown improvement rates of track predictions by the Typhoon Model (TYM) from the persistency forecasts. Those for the year 2000 are slightly better than those for the previous four-year period (1996-1999). This slight improvement in the track predictions of TYM should be attributed to better initial fields which are prepared from the global analyses, since TYM itself experienced none of such changes as GSM experienced.

A verification has been made also for tropical cyclone intensity predictions with regard to maximum wind speed (Figs. 2 and 3). Results show that absolute values of the bias and the root-mean-square error (RMSE) of maximum wind speed for GSM have been reduced drastically from 14 (17) m s^{-1} to 8 (6) m s^{-1} and from 15 (19) m s^{-1} to 10 (11) m s^{-1} for 24 (72) h predictions, respectively, even though they are still larger than those for TYM. Thus the changes at the version-up of GSM produced large improvements in tropical cyclone track and intensity predictions as well as the reductions of the specific systematic errors mentioned previously.

3. Summary and a remark

JMA installed a new version of GSM with some major changes including the incorporation of cloud water content as a prognostic variable, a modification of the prognostic Arakawa-Schubert cumulus parameterization, and the calculation of direct effect of aerosols on short-wave radiation. Verifications have shown that the version-up produced significant improvements both in track and intensity predictions of TCs. The mean track errors relative to those of the persistency forecasts have been reduced by about 20 (10) % for 24 (72) h predictions. Besides this, the new version of GSM might have exerted a good influence on TYM's track predictions by providing initial and lateral boundary conditions of higher quality. As for TC intensity prediction, bias and root-mean-square error (RMSE) of maximum wind speed in GSM has been reduced drastically from 14 (17) m s^{-1} to 8 (6) m s^{-1} and from 15 (19) m s^{-1} to 10 (11) m s^{-1} for 24 (72) h predictions, respectively, even though the errors are still larger than those of TYM.

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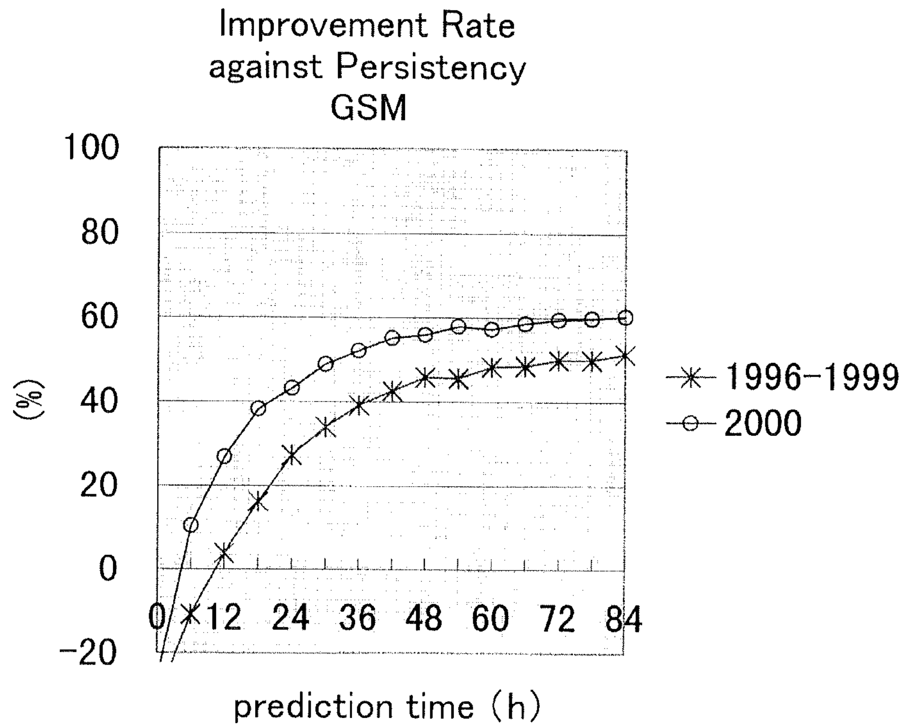

b

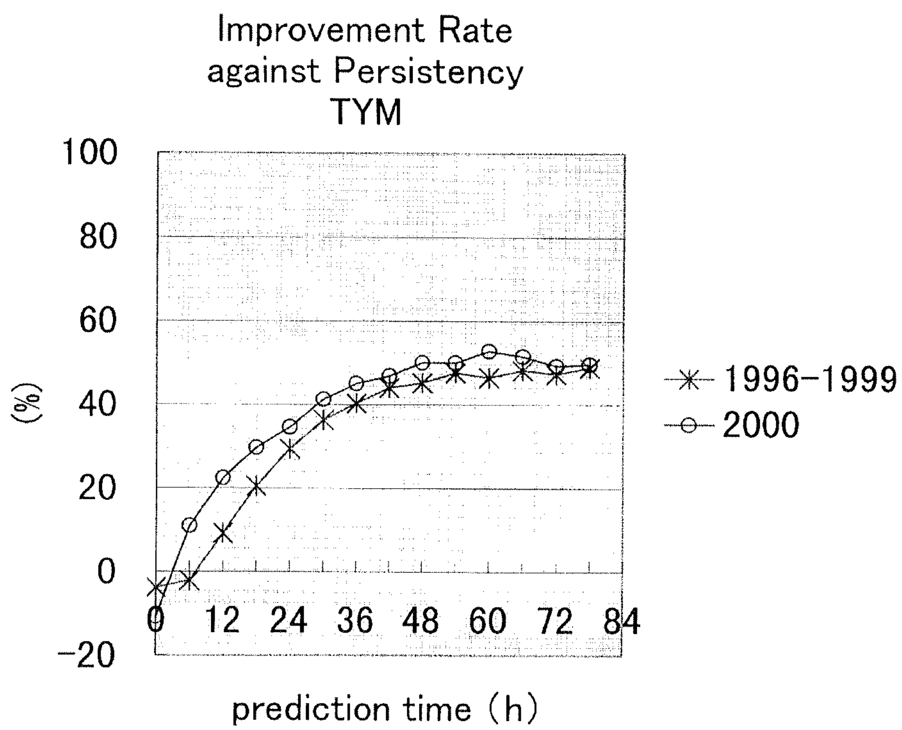

Fig. 1 Improvement rates of track predictions by the models from those by the persistency method for the 4-year period 1996-1999 (line with asterisks) and for the year 2000 (line with open circles). Improvement rates are defined as (PER-MDL)/PER*100 (%), where PER and MDL denote mean position errors of the persistency method and the numerical model, respectively. (a): GSM, (b): TYM.

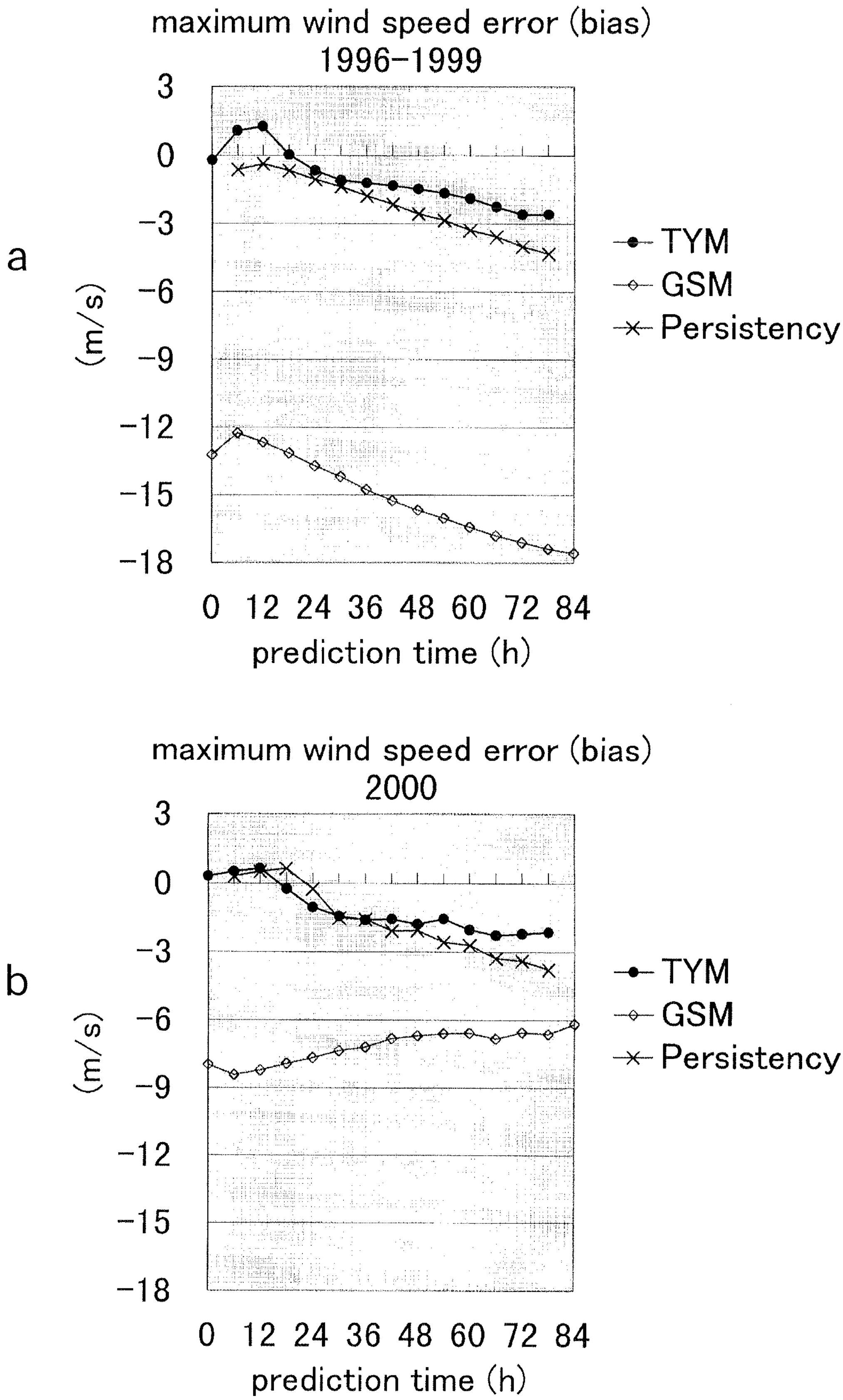

Fig. 2 Biases of maximum wind speed of tropical cyclones in the western North Pacific for TYM and GSM against the persistency method. (a): 1996-1999, (b): 2000.

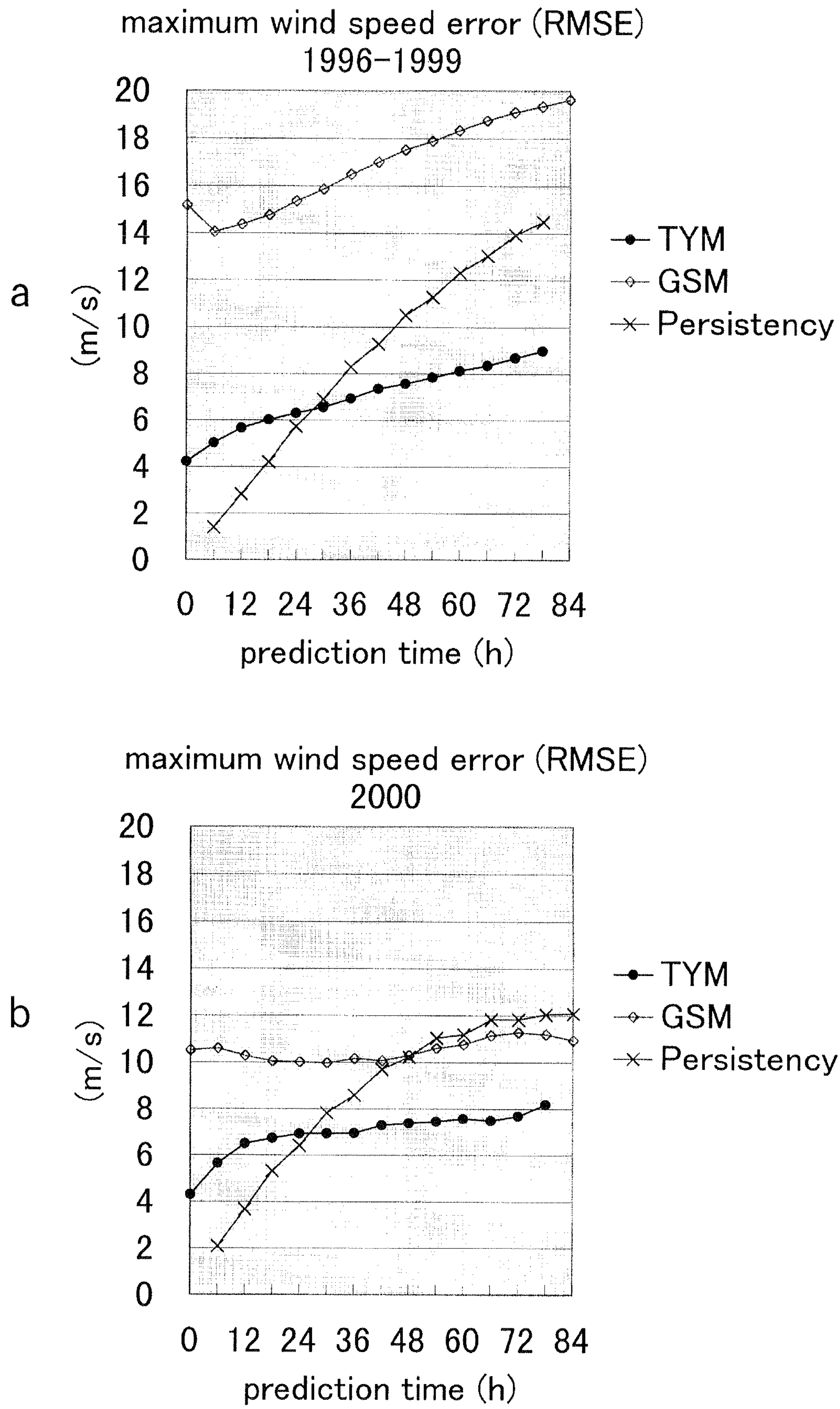

Fig. 3 Same as Fig. 2 but for root-mean-square errors (RMSEs).

On the occasion of starting the operations of the new suite of numerical models on 1 March 2001 (Mino and Nagata, 2001), the prognostic Arakawa-Schubert cumulus parameterization in GSM experienced further tuning. It aimed at alleviating an excessive feedback mechanism, which had lead to overprediction of precipitation along the ITCZs in the Pacific and the Indian Ocean and underprediction of precipitation on the west coast of the Indian Sub-continent in the extended range of forecast.

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A Simple Guidance Scheme for Tropical Cyclone Predictions

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Abstract

A simple guidance scheme has been developed for tropical cyclone (TC) track forecast. The scheme consists of bias correction, initial adjustment, and ensemble averaging of numerical model TC track predictions. The bias correction is based on a verification of numerical model track predictions for a four-year period of 1996-1999. The scheme is tested with independent data in the year 2000 as well as with dependent data in the four-year period of 1996-1999. Results show that initial adjustment works well to reduce track prediction errors while bias correction does not work well in 2000 presumably because of a significant change in systematic error between the four-year period and the year 2000. Ensemble averaging of two numerical models does not work well in 2000, which is probably due to a difference in performance between the two models: the Global Spectral Model (GSM) performed much better in 2000 than in the four-year period while the Typhoon Model (TYM) performed only slightly better in 2000.

Another simple guidance scheme similar to that for track forecast has been developed for TC intensity forecast. It consists of bias correction and initial adjustment of numerical model TC intensity predictions but does not employ ensemble averaging of numerical model TC intensity predictions because of a large difference in performance between the two numerical models. The same kind of test as that for track forecast is performed. Results show that both initial adjustment and bias correction work well to reduce intensity prediction errors in 2000.

In consideration of the verifications above and probable changes in TC prediction performance expected to result from the version-ups of GSM and TYM in March 2001, forecasters at the RSMC Tokyo - Typhoon Center will use a guidance scheme which employs only initial adjustment both for track and intensity forecasts in the coming 2001 season. Further investigation is required at the Center before the forecasters at the Center make a decision on if they should adopt bias correction and/or ensemble averaging besides initial adjustment in the guidance scheme.

1. Introduction

Although numerical models have been steadily improved to produce tropical cyclone (TC) track and intensity predictions with increasing accuracy, errors still can be large and normally grow with prediction time. Errors may be decomposed into two parts, systematic errors (biases) and random errors. Systematic errors can be eliminated with bias correction based on long-term statistics. Random errors in individual cases often persist throughout the prediction period. We call such persisting random errors "coherent errors (with regard to time)". Coherent errors in middle and late forecast hours can be eliminated if we obtain information on them within early forecast hours by verifying early portions of predictions with latest analyses available. Besides these, if we have two or more numerical model predictions available whose random errors vary independently at least to some degree, simple ensemble averaging of the model predictions may lead to a reduction of errors. Based on these considerations, we have developed a guidance scheme for numerical model predictions, which consists of the following three simple procedures, to make predictions with possibly smaller errors:

Part 1: bias correction based on statistics,
Part 2: initial adjustment (parallel shift of a model prediction),
Part 3: ensemble averaging of two or more different numerical model predictions.

Firstly we apply the guidance scheme to tropical cyclone track forecast, using predictions by the Global Spectral Model (GSM) and the Typhoon Model (TYM). In Part 1, we calculate systematic errors (biases) of center position predictions in the four-year period (1996-1999) and subtract them from center position predictions in each case so that systematic errors are eliminated. If systematic errors are dominant in total errors and they are stable for years, this part of the scheme is expected to reduce total errors considerably. In Part 2, we shift a predicted track without any modification in its shape and orientation (i.e., just translate a track) in such a way that the position error at the latest analysis time (T+06h or T+12h of a model prediction) vanishes. If the predicted track has a coherent error throughout the entire prediction period, this part of the scheme effectively reduces a total error. In Part 3, we simply make an ensemble average of track predictions by the two numerical models. If systematic errors of the two models are compensating and/or random errors vary independently between the two models, this part of the scheme reduces total errors.

Secondly a similar kind of guidance scheme is applied to TC intensity forecast. In this case, the scheme consists of bias correction and initial adjustment of numerical model TC intensity predictions but does not employ ensemble averaging of predictions because of a large difference in performance between the two numerical models.

In this study, we evaluate the performance of the guidance scheme with independent data in the 2000 season to see if each of the above procedures should be adopted at the RSMC Tokyo - Typhoon Center in the coming 2001 season.

2. Performance of guidance

We should discriminate data between the two periods, dependent data in the four-year period (1996-1999) and independent data in the year 2000, for Part 1 of the guidance scheme (bias correction). Meanwhile, for the other parts (Part 2 and Part 3), data are independent in any time period because of their natures.

a) Track predictions in the dependent four-year period (1996-1999)

Figure 1 shows mean position errors of TYM, GSM, and the guidance for the dependent four-year period (1996-1999). In this figure, those of JMA's official forecast for T+12h, T+24h, T+48h, and T+72h are also shown for comparison. The time frame for JMA's official forecast is set forward by 6 hours with respect to that for the numerical models and the guidance based on them. This is because we should take into account the time spent by various processings until numerical model predictions become available for forecasters to use. The figure shows that the guidance works well to reduce mean position errors by 29 (32) % for 18-h predictions <for 12-h official forecasts> and 13 (8) % for 78-h predictions <for 72-h official forecasts> against TYM (GSM) predictions, respectively.

To separate contributions of individual parts of the scheme, we calculate mean position errors of TYM and GSM predictions with only bias correction and those of TYM and GSM predictions with both bias correction and initial adjustment and compare them with those of the original TYM and GSM predictions (Figs. 2 and 3). The figures indicate that the contribution of bias correction gradually increases from nearly zero at early prediction hours to about one half (TYM) or two thirds (GSM) of the total improvement near the end of the prediction period. Meanwhile the contribution of initial adjustment shows a reverse tendency: it dominates in early prediction hours and gradually decreases to about one half (TYM) or one third (GSM) of the total improvement near the end of the prediction period. As regards ensemble averaging, it also makes some contribution to reducing position errors, suggesting that random errors vary independently at least to some degree between the two numerical models.

b) Track predictions in the independent one-year period (2000)

Figure 4 shows mean position errors of TYM, GSM, and the guidance for the independent one-year period (2000), just in the same way as Fig. 1. It shows that the guidance works well only in early prediction hours but does not perform better than both models in the rest of the prediction period. To explore which part(s) of the scheme is responsible for this poor

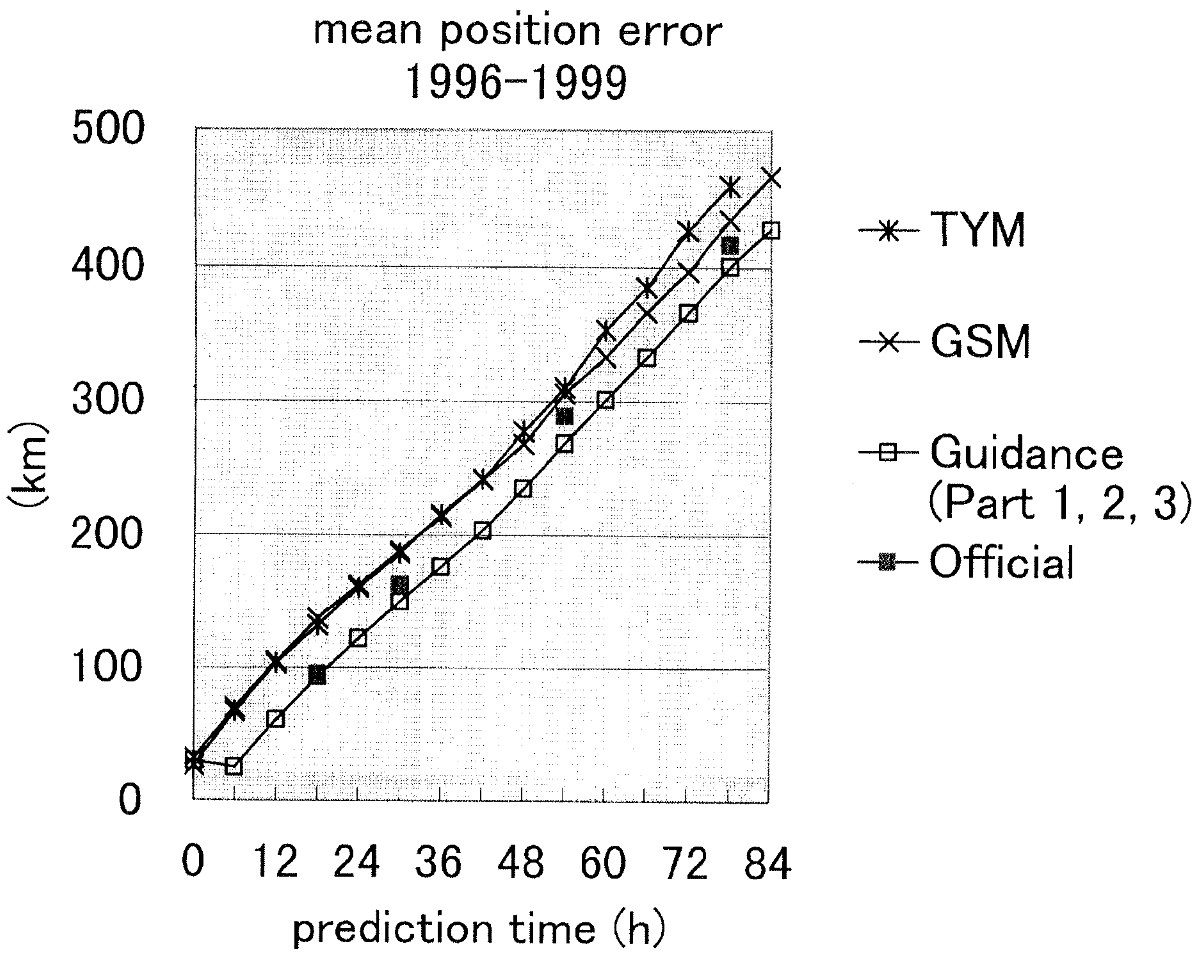

Fig. 1 Mean position errors of TYM, GSM, and the guidance for the dependent four-year period (1996-1999). Those of JMA's official forecast for 12, 24, 48, 72 hours are also plotted with its time frame set forward by 6 hours with respect to that of the numerical models.

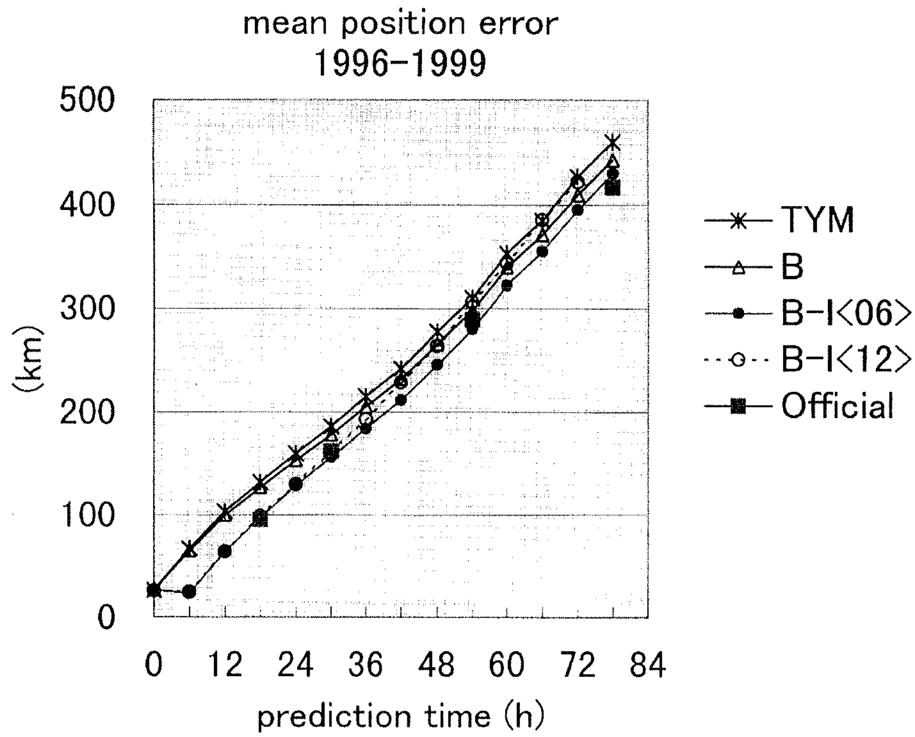

Fig. 2 Same as Fig. 1 but for TYM, TYM with bias correction (B), TYM with both bias correction and initial adjustment at the latest analysis time which is corresponding to prediction at T+06h (12h) of the model (B-I<06> (B-I<12>)).

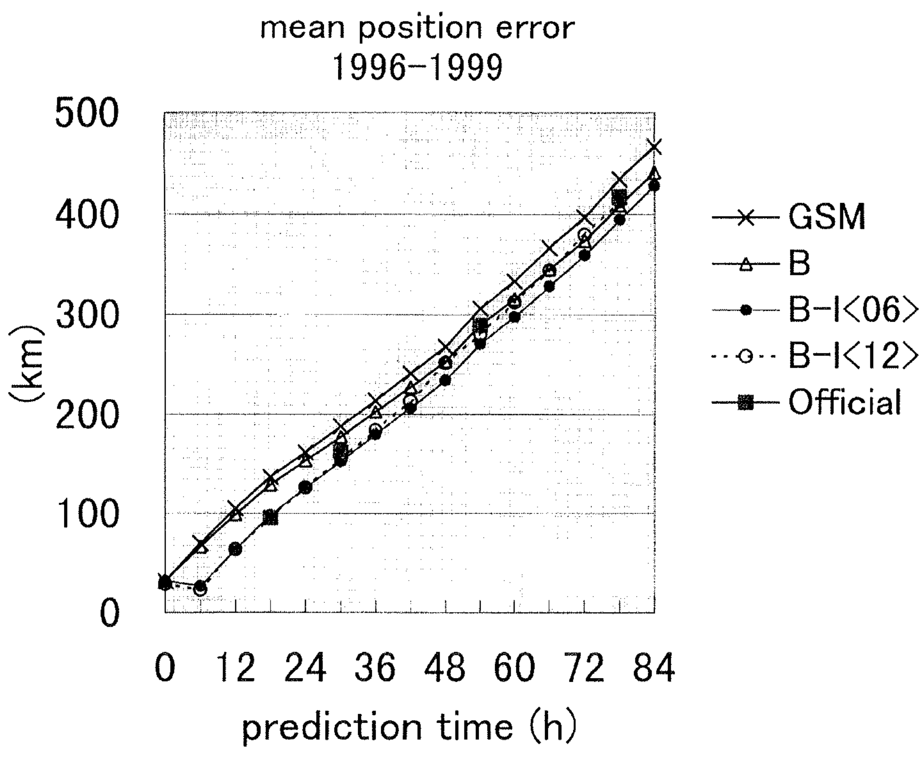

Fig. 3 Same as Fig. 2 but for GSM.

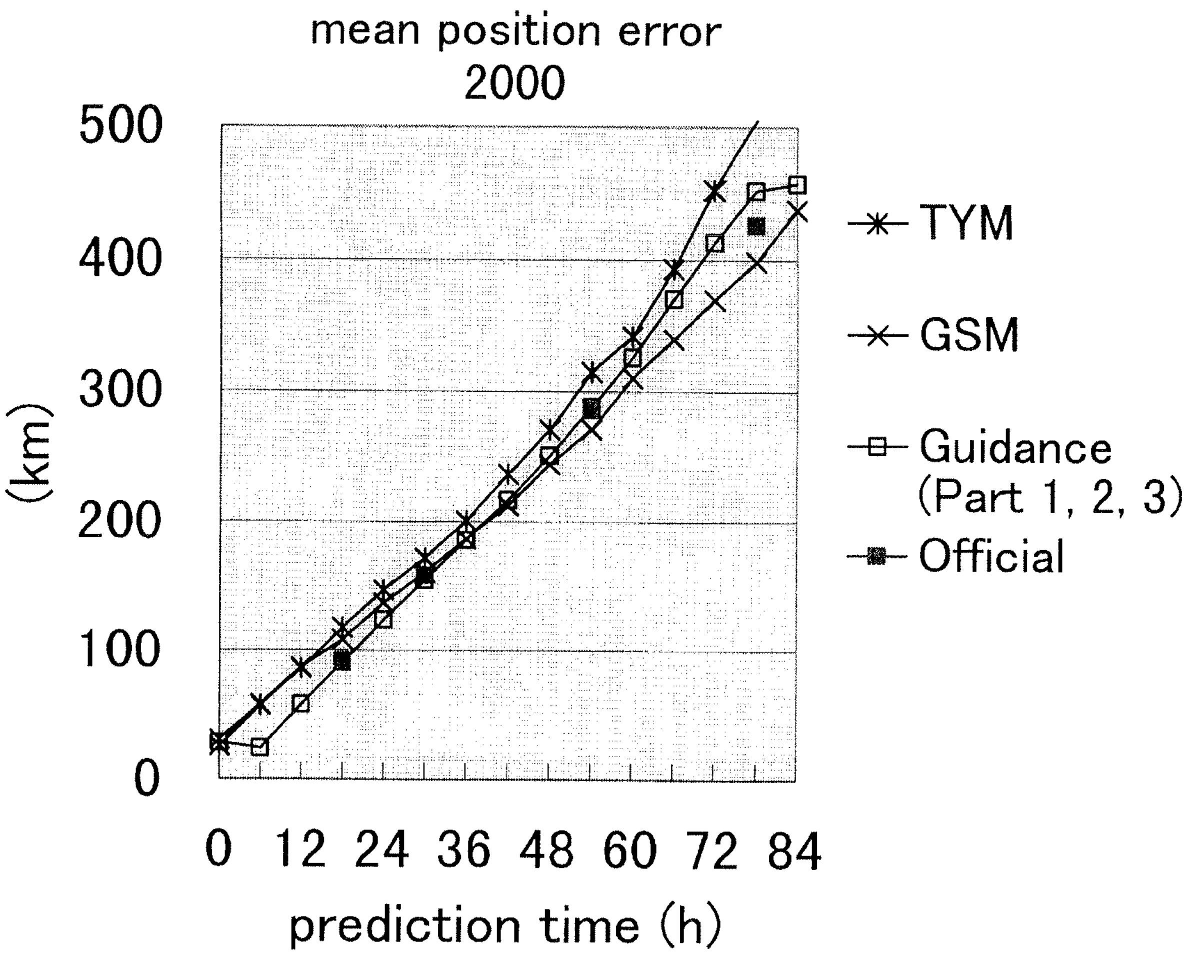

Fig. 4 Same as Fig. 1 but for the independent one-year period (2000).

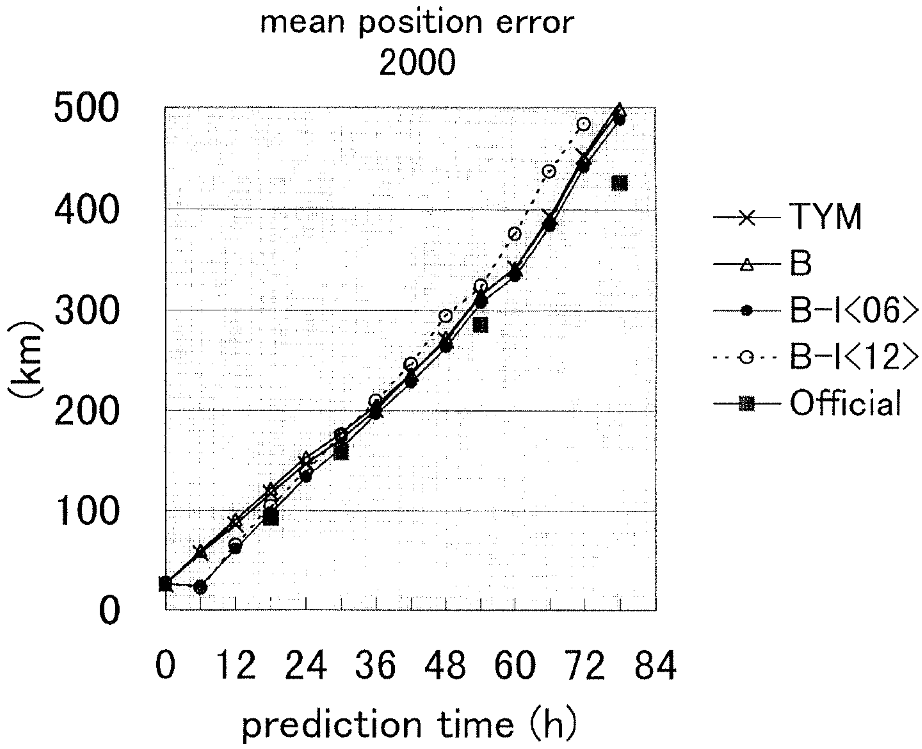

Fig. 5 Same as Fig. 2 but for the independent one-year period (2000).

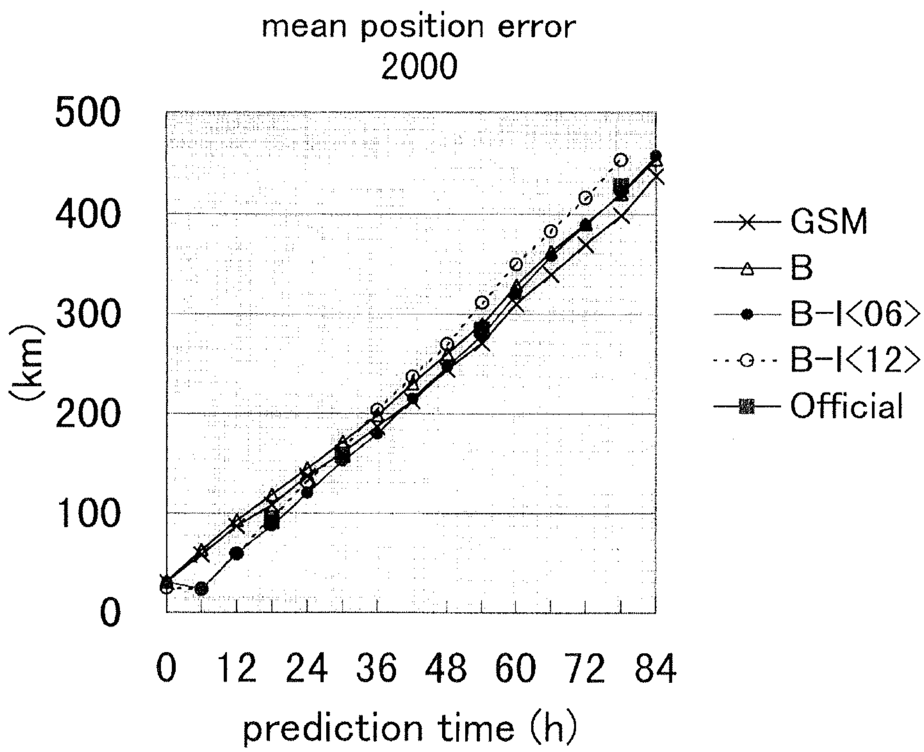

Fig. 6 Same as Fig. 3 but for the independent one-year period (2000).

Bias (Systematic Error) of Track Forecast

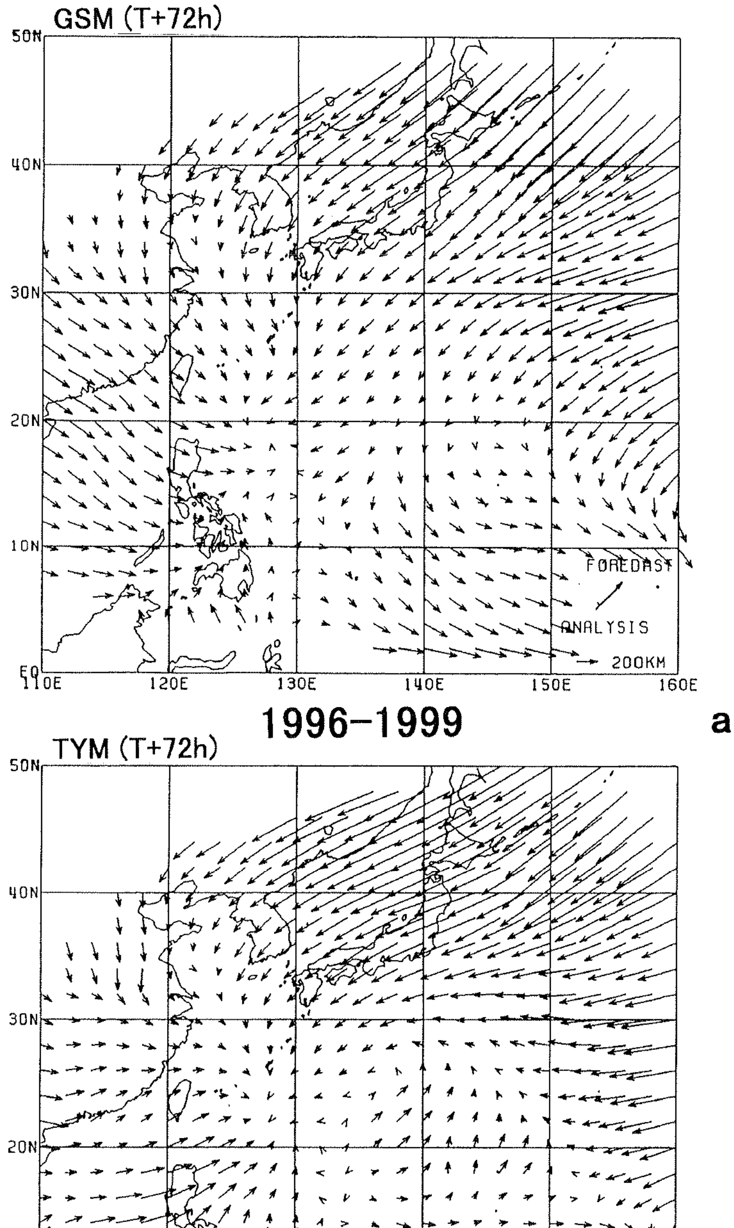

Fig. 7 Regional distribution of systematic track error vectors (Forecast - Analysis) at T+72h of prediction. Top panel for GSM and bottom one for TYM. Scale of vectors is shown in the down right corner in each panel. (a) the four-year period (1996-1999) and (b) the one-year period (2000). The large systematic errors seen around the Mariana Islands in both models in the year 2000 mostly originated from several consecutive cases of Typhoon Saomai (0014) where both numerical models failed to predict its unusual sudden southward turn.

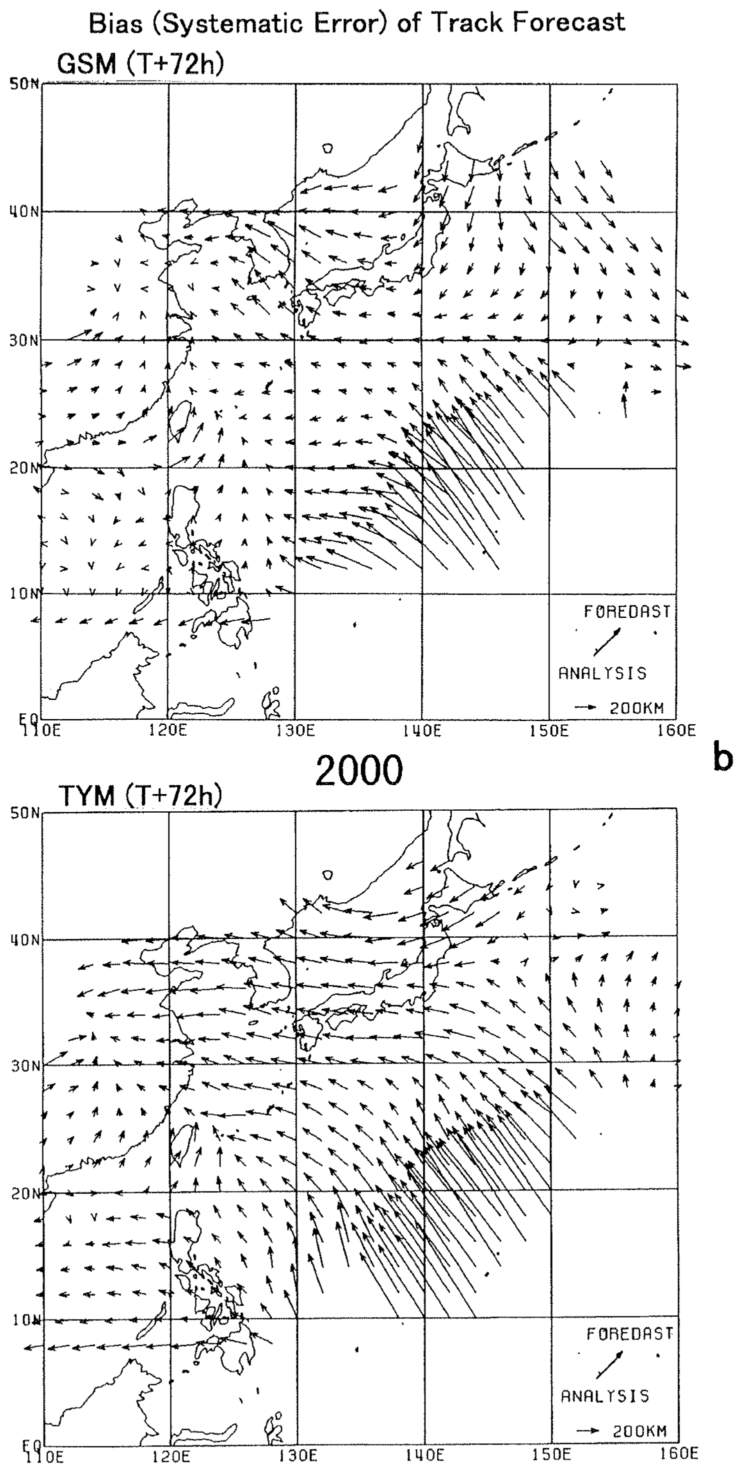
Bias (Systematic Error) of Track Forecast
GSM (T+72h)
50N
40N
30N
20N
10N
EQ
110E
120E
130E
140E
150E
160E
FORECAST
ANALYSIS
200KM
2000
b
TYM (T+72h)
50N
40N
30N
20N
10N
EQ
110E
120E
130E
140E
150E
160E
FORECAST
ANALYSIS
200KM

Fig. 7 (cont'd)

performance of the guidance, we calculate mean position errors of TYM and GSM predictions with only bias correction and those of TYM and GSM predictions with both bias correction and initial adjustment and compare them with those of the original TYM and GSM predictions (Figs. 5 and 6). The figures indicate that bias correction has an adverse effect on track predictions in large portions of the prediction period. This must be due to inter-annual variations of systematic errors of track predictions (Fig. 7). The differences in systematic errors between 2000 and 1996-1999 are presumed to originate mainly from inter-annual natural variability but not from changes in numerical models. This presumption is based on the facts that the systematic errors in the year 2000 are still similar between the two models and that GSM has had significant changes (Kuma et al., 2001) while TYM has had no significant change between the two periods.

Meanwhile initial adjustment works well throughout the prediction period just in the same way as in the dependent four-year period. Ensemble averaging does not work to reduce mean position errors in the independent one-year period in which the Global Spectral Model (GSM) performed much better than in the previous years while the Typhoon Model (TYM) performed only slightly better, resulting in a significant difference in track prediction performance in late prediction hours between the two models.

c) Intensity predictions in the dependent four-year period

Figure 8 compares mean intensity errors, i.e., biases and root-mean-square errors (RMSEs) of maximum wind speed predictions by TYM, GSM, and the guidance based only on TYM with both bias correction and initial adjustment with those by the persistency method (assuming invariable intensity) for the dependent four-year period. JMA's official forecasts only for 24 hours are available and included with its time frame set forward by 6 hours for the same reason mentioned in Section 2a. TYM outperforms GSM throughout the period and does the persistency method in middle and late prediction hours. The guidance works to reduce errors effectively, especially in early prediction hours, which is a result mainly of initial adjustment. Slight error reductions in late prediction hours are created by bias correction. The resultant guidance improves intensity predictions of TYM to a good extent and its errors are much smaller than those of the persistency method in middle and late prediction hours and they are almost the same in early prediction hours.

d) Intensity predictions in the independent one-year period

Figure 9 is the same as Fig. 8 but for independent data in the 2000 season. All the

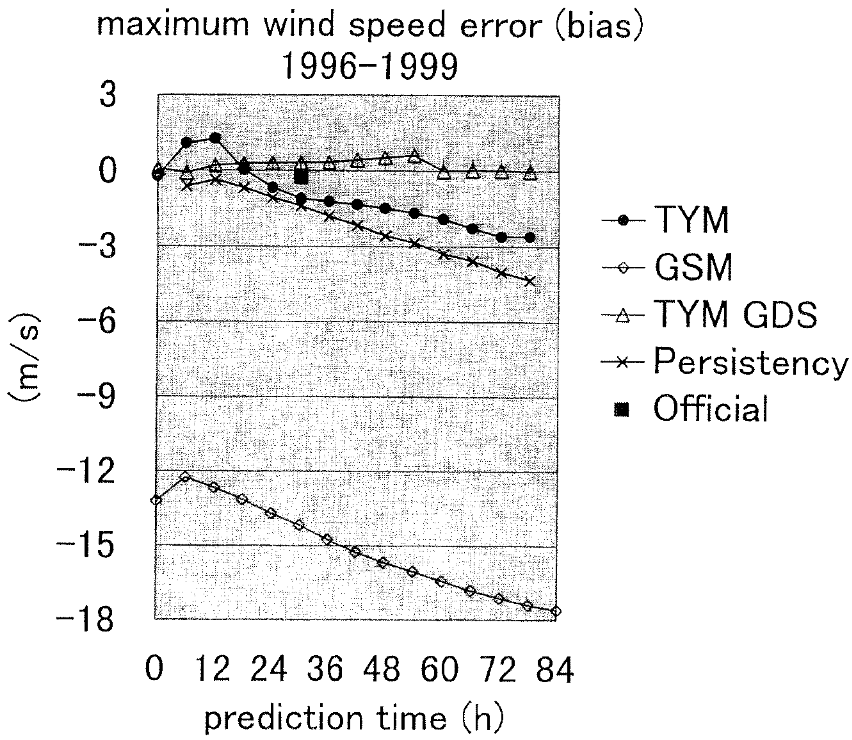

Fig. 8a Mean intensity errors (biases of maximum wind speed) of predictions by TYM, GSM, the guidance based only on TYM with bias correction and initial adjustment (TYM GDS), and the persistency method assuming no intensity change, for the dependent four-year period (1996-1999). Those of JMA's official forecast for 24 hours are also plotted with its time frame set forward by 6 hours with respect to that of the numerical models.

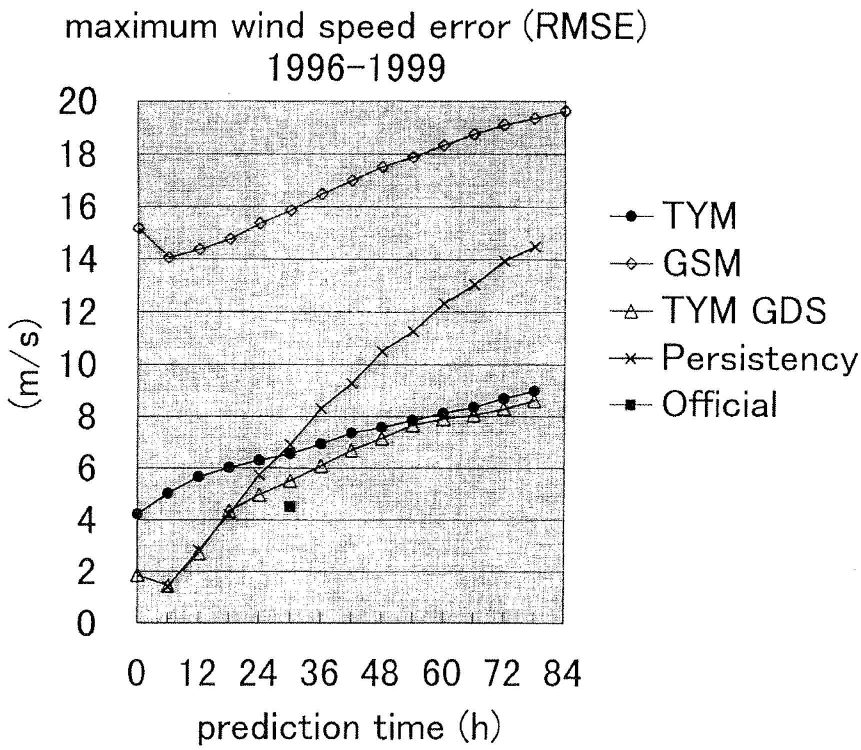

Fig. 8b Same as Fig. 8a but for root-mean-square errors (RMSEs) of maximum wind speed.

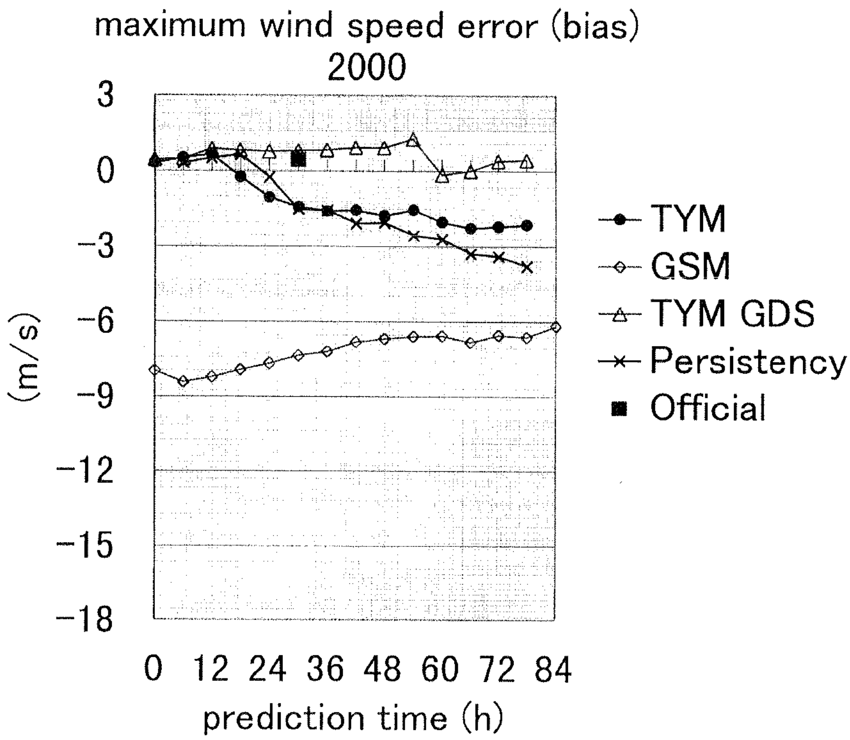

Fig. 9a Same as Fig. 8a but for the independent one-year period (2000).

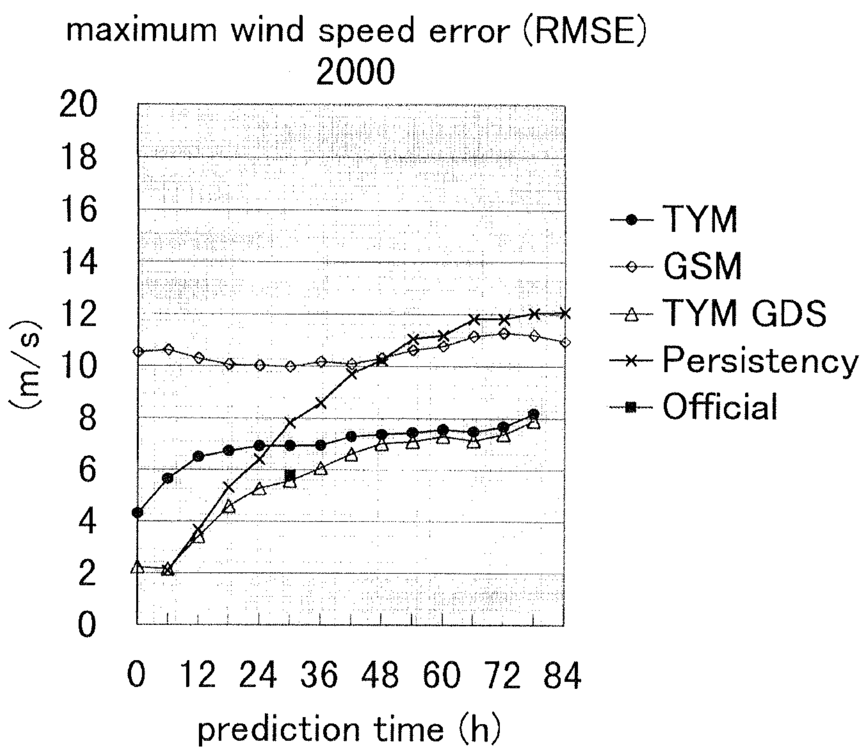

Fig. 9b Same as Fig. 8b but for the independent one-year period (2000).

predictions as well as JMA's official forecast show nearly the same performances as those for the previous four-year period (1996-1999), respectively, except for GSM. GSM performed much better in 2000 than in the previous four-year period. GSM's biases of maximum wind speed predictions have been drastically reduced to make RMSEs much smaller than in the previous period, even though they are still larger than those of TYM. This improvement in the performance of GSM in intensity prediction may probably be explained by the major version-up in December 1999 (Kuma et al., 2001).

3. Guidance to be employed at the RSMC Tokyo - Typhoon Center

The verifications presented in the previous section have shown that initial adjustment works well to reduce track prediction errors while neither bias correction nor ensemble averaging does not work well for data in the year 2000. As regards intensity prediction, both initial adjustment and bias correction work well to reduce intensity prediction errors for data in the same period. Besides these, we should expect that the version-ups of GSM and TYM in March 2001 (Mino and Nagata, 2001) will create changes in performance of numerical model track and intensity predictions more or less. This may invalidate the bias correction based on the verification statistics for the previous numerical models. Considering these circumstances, forecasters at the RSMC Tokyo - Typhoon Center will employ only initial adjustment (Part 1) of the scheme, for both track and intensity predictions in the coming 2001 season. Further investigation, such as extensive validation study of predictions of the new models, is required at the Center before the forecasters at the Center make a decision on if they should adopt bias correction and/or ensemble averaging besides initial adjustment in the guidance scheme.

4. Summary

The simple guidance scheme for tropical cyclone (TC) track and intensity predictions employs bias correction and initial adjustment (for both track and intensity predictions), and ensemble averaging of numerical models (for track prediction). The scheme has been tested for the independent 2000 season besides the dependent 1996-1999 seasons. The result shows that initial adjustment works well in both track and intensity predictions in 2000 while bias correction only works well in intensity prediction but not in track prediction in 2000. The reason why bias correction does not work well in track prediction in 2000 is attributed to a significant change in systematic error between the four-year period 1996-1999 and the year 2000, which is presumably originating mainly from year-to-year natural variability. Ensemble averaging of the two numerical models does not have a positive impact on track prediction in 2000 because of the difference in performance between the two numerical models.

In consideration of the verifications made and probable changes in TC prediction performance expected to result from the version-ups of GSM and TYM in March 2001, forecasters at the RSMC Tokyo - Typhoon Center will use a guidance scheme which employs only initial adjustment both for track and intensity forecasts in the coming 2001 season. Further investigation is required at the Center before the forecasters at the Center make a decision on if they should adopt bias correction and/or ensemble averaging besides initial adjustment in the guidance scheme.

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Mino, H., and M. Nagata, 2001: Outline of the new typhoon prediction models at JMA. *RSMC Tokyo-Typhoon Center Technical Review*, No. 4, 1-13.