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Verifications of Tropical Cyclone Predictions of the New Numerical Models at JMA

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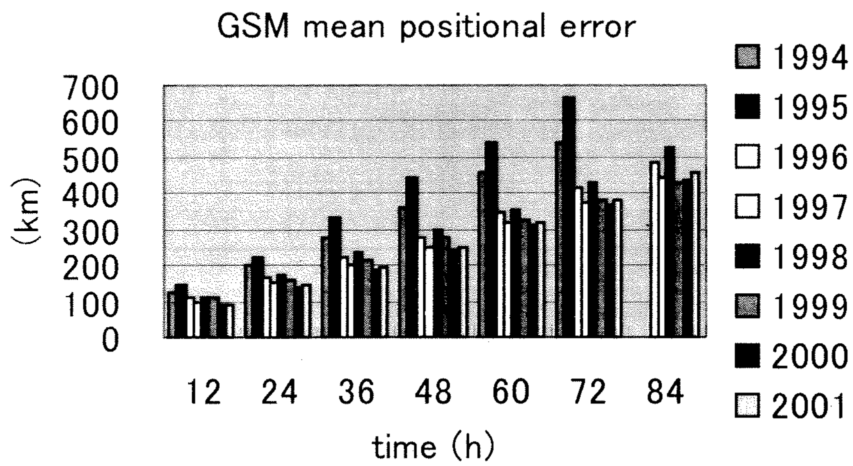
1. Introduction

The Japan Meteorological Agency (JMA) started operations of a new suite of numerical analysis and prediction models on a new computer system (Computer System for Meteorological Services, COSMETS) on 1 March 2001, including the Typhoon Model (TYM) and the Global Spectral Model (GSM) which make tropical cyclone predictions in the area of responsibility in the western North Pacific as an operation of the tropical cyclone (TC) Regional Specialized Meteorological Center (RSMC) Tokyo - Typhoon Center. The reader is referred to Mino and Nagata (2001) and JMA (2002) for the specifications of the numerical models. Both horizontal and vertical resolutions were enhanced in TYM while only the vertical resolution was increased in GSM. These upgrades were expected to produce a higher performance of the models in tropical cyclone track and intensity predictions. However, verifications show that the track prediction performance of both models worsened, while the intensity prediction performance of TYM improved but that of GSM deteriorated. This paper summarizes major features of the verifications of tropical cyclone track and intensity predictions by TYM and GSM for the western North Pacific in the 2001 season.

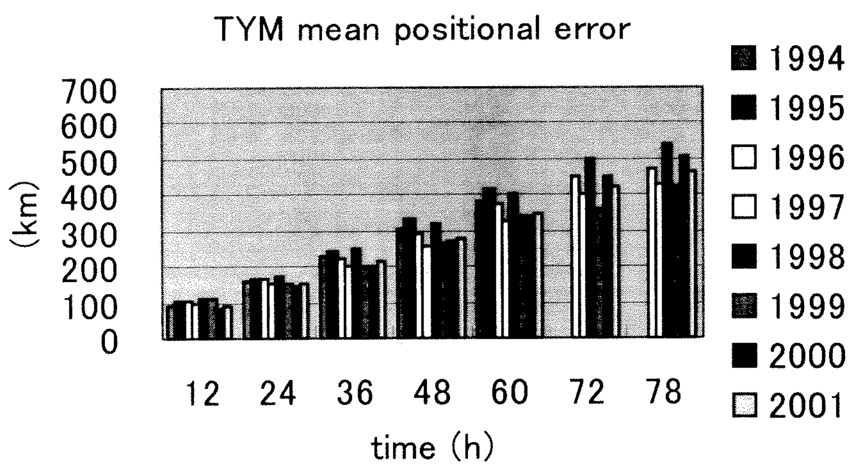
Sections 2 and 3 deal with the track and intensity prediction performances, respectively. In Section 4, tunings of the TC bogusing scheme in TYM for alleviating a systematic track error for larger storms are discussed. Summary and some comments are provided in Section 5.

2. Track prediction performance

All the verifications in this paper are conducted against the RSMC Tokyo - Typhoon Center's best track data. Figure 1 shows year-to-year variations of mean positional errors for GSM and TYM from 1994 to 2001. Apparently, the performances of both models for the 2001 season were approximately the same as the averages for the previous five-year period (1996-2000) when the old suite of numerical models had been in

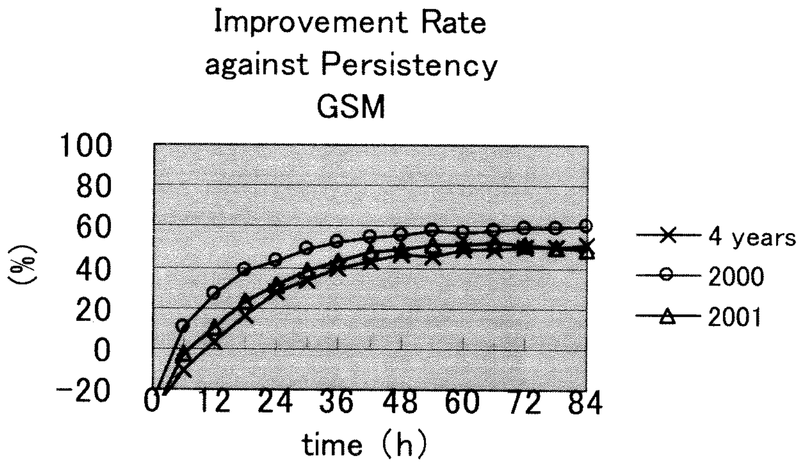


(a)

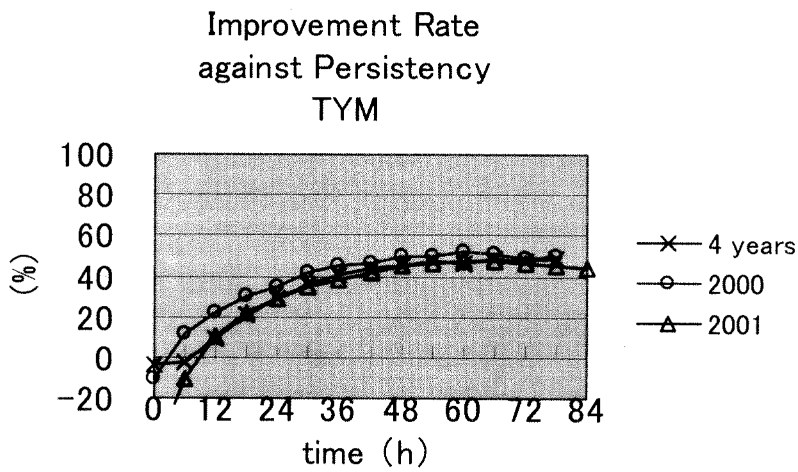


(b)

Fig. 1 Annual mean errors in distance of center positions predicted by (a) GSM and (b) TYM for 1994-2001. Note that major version-ups of the models were made in March 1996 and March 2001.

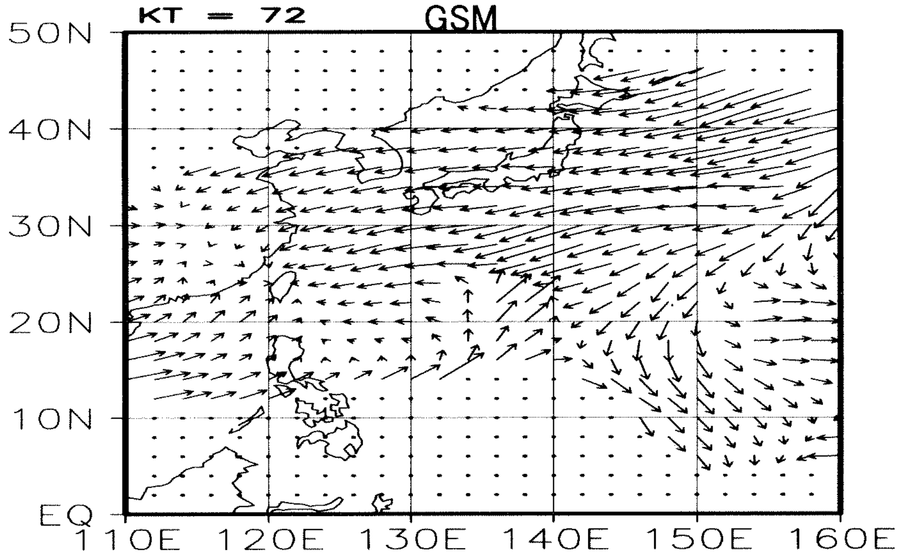


(a)

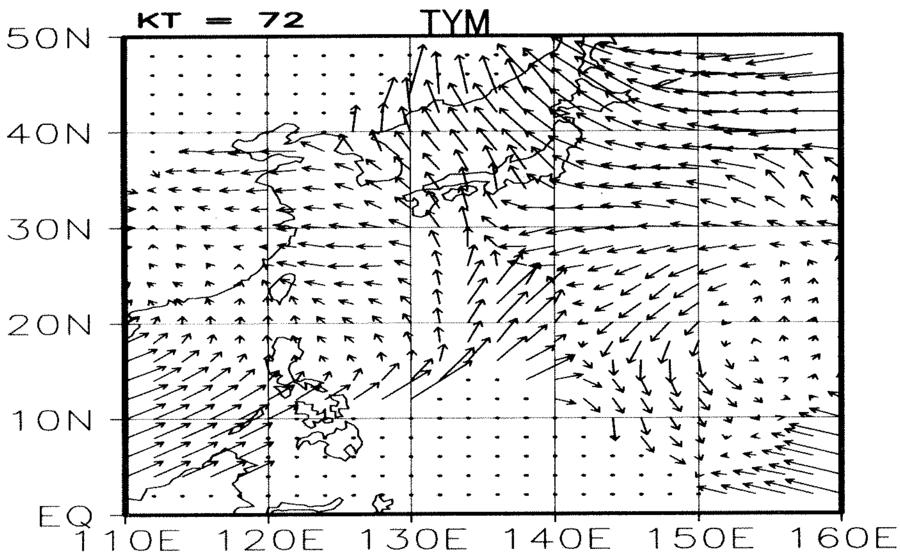


(b)

Fig. 2 Improvement (error reduction) rates against the persistency method for the four-year period (1996-1999), the year 2000, and the year 2001. (a) GSM, (b) TYM. The definition of the rate is found in the text.



(a)



(b)

Fig. 3 Regional distribution of systematic track error vectors (Prediction - Analysis) at T_0+72h. (a) GSM, (b) TYM. One grid interval is 200km in the scaling of error vectors. The large systematic error vectors seen around 20N, 136E both in TYM and GSM mostly originated from several cases of Typhoon Pabuk (0111), as shown in Section 4.

operation. To evaluate year-to-year variability of actual performance by eliminating the influence of year-to-year variability in prediction difficulty, we normalize the mean positional errors with those of the persistency method by calculating error reduction rate (called "improvement rate", hereafter), which is defined as:

$$\textit{improvement rate} = (P - M) / P,$$

where P and M denote the mean errors of the persistency method and those of the numerical model, respectively (Fig. 2). Results show that improvement rates of both models for the year 2001 were lower than those for the year 2000 and were close to those for the previous four-year period (1996-1999).

The deterioration of GSM's performance in 2001 from 2000 could be attributed to a revision of physical processes, which was made at the major upgrade of the model on 01 March 2001. In the upgrade, the cumulus parameterization of GSM was modified in the following two points, aiming at better performance in the medium- and long-range predictions of tropical precipitation and associated circulation.

1) Moist static energy of the cumulus updraft was increased according to the intensity of planetary boundary layer turbulence.
2) Evaporation of cumulus precipitation was incorporated.

This revision, however, produced significant systematic errors in early forecast days in GSM (figures not shown). One is that negative biases in geopotential height field appeared northeast off the Philippines in the western portion of the subtropical high pressure in the western North Pacific in the three-month average of June-July-August 2001. Another systematic error in GSM is that positive biases in geopotential height field appeared in a fairly large mid-latitude region spanning from 125E to 170E along the latitudinal belt between 35N and 55N in the two three-month averages of June-July-August and September-October-November 2001. These positive biases in the north and those negative biases in the south produced easterly wind biases in between, which presumably account for westward biases in tropical cyclone track predictions broadly seen in mid-latitudes both in GSM and TYM (Fig. 3). It is speculated here that the systematic errors of GSM prediction fields affected TYM's TC predictions through initial field and lateral boundary conditions of TYM, which were provided by the Global Data Assimilation system and GSM, respectively.

Besides these, a large portion of the worse performance of TYM in 2001 than in 2000 came from several cases for Typhoon Pabuk (0111), which headed to the west-northwest in low latitudes before recurvature, against the predicted tropical cyclone heading to the north. A sea surface wind field derived from scatterometer data suggests that the size of the bogus TC was too large in these cases. We, therefore, made some modifications in the TC size specification portion of the TC bogusing scheme for TYM as trials and examined the modified schemes for alleviating the systematic track error for larger storms. Results are presented in Section 4.

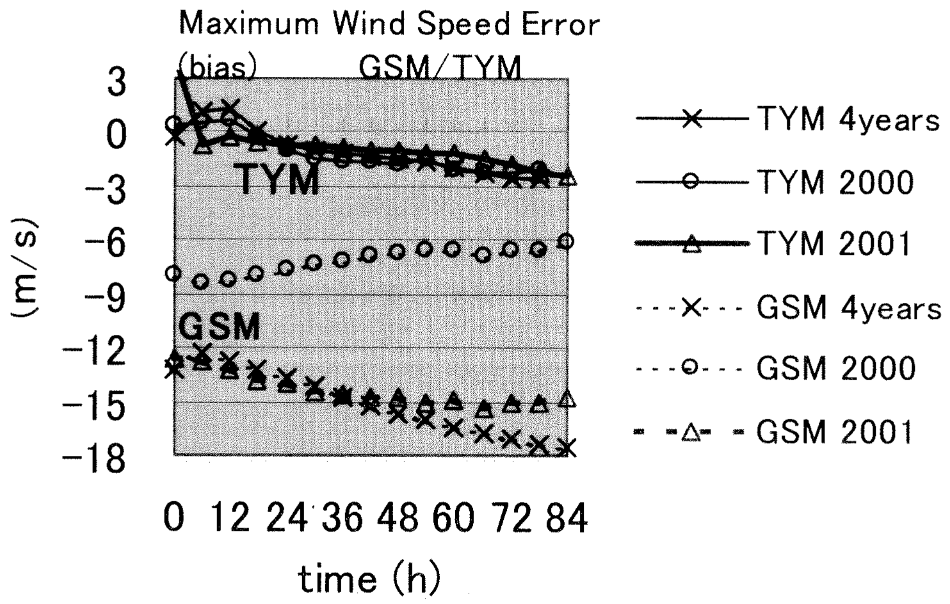
3. Intensity prediction performance

We choose maximum wind speed for the verification of TC intensity. Figure 4 shows biases and root mean square errors (RMSEs) of maximum wind speeds predicted by TYM and GSM for the previous four-year period (1996-1999), the year 2000, and the year 2001. GSM's weakening bias and RMSE both increased in 2001 nearly to the averages for the four-year period from those for the year 2000. These could also be attributed to the revision of physical processes in the model mentioned in the previous section.

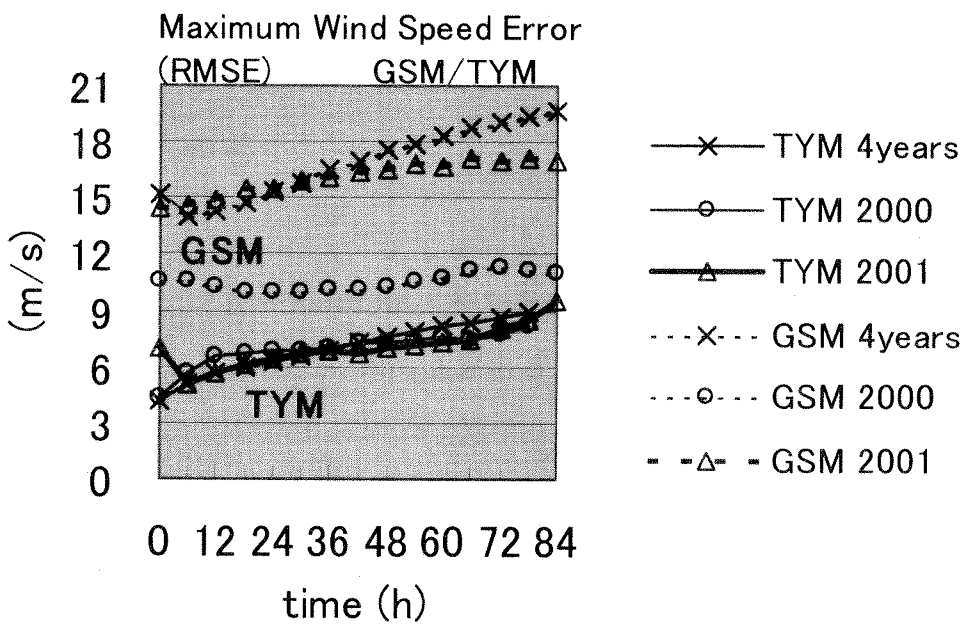
TYM's weakening bias noted during and before the year 2000 was somewhat reduced in 2001. Considering that higher horizontal resolution is crucial for better presentation of inner core structure of TCs, which is essential to realistic TC intensity simulation (Nagata et al., 2001), this reduction of the weakening bias must be owing to the enhanced horizontal resolution in TYM. RMSE for 2001 was reduced after T_0+36h in comparison with the four-year period while it was reduced from T_0+0h through T_0+66h in comparison with the year 2000. The fact that there appeared no decrease in RMSE from 2000 to 2001 after T_0+66h was mostly contributed to by several cases for Typhoon Nari (0116). This is demonstrated in Fig. 5, which compares biases and RMSEs between Typhoon Nari and all the other tropical cyclones in 2001. Negative bias and RMSE rapidly grew after T_0+60h for Typhoon Nari while they did not for the other tropical cyclones. Furthermore, cases where TYM predicted landfall were the major contributor to this rapid growth of intensity error after T_0+60h, as shown in Fig. 6, which compares biases and RMSEs between cases with and without landfall of Typhoon Nari. Negative bias and RMSE rapidly increased after T_0+60h in the cases with landfall. Examination of individual cases suggests that major portions of the intensity errors arose from track errors accompanied by false (or too early) landfall. In other words, the intensity errors in these Typhoon Nari's cases are combinations of intensity errors themselves and intensity errors arising from track errors.

When another verification is conducted confining to only cases without landfall for all tropical cyclones in 2000 and in 2001, respectively (Fig. 7), we find a reduction of RMSE (improvement of intensity prediction) from 2000 to 2001 throughout the prediction period. This means that the basic ability of TYM in predicting intensities of TCs located over the ocean was improved at its upgrade between the 2000 and the 2001 season.

To investigate error characteristics, cases are categorized by



(a)



(b)

Fig. 4 (a) biases and (b) root-mean-square errors (RMSEs) of maximum wind speed for the four-year period (1996-1999), the year 2000, and the year 2001. Dashed lines for GSM and solid lines for TYM.

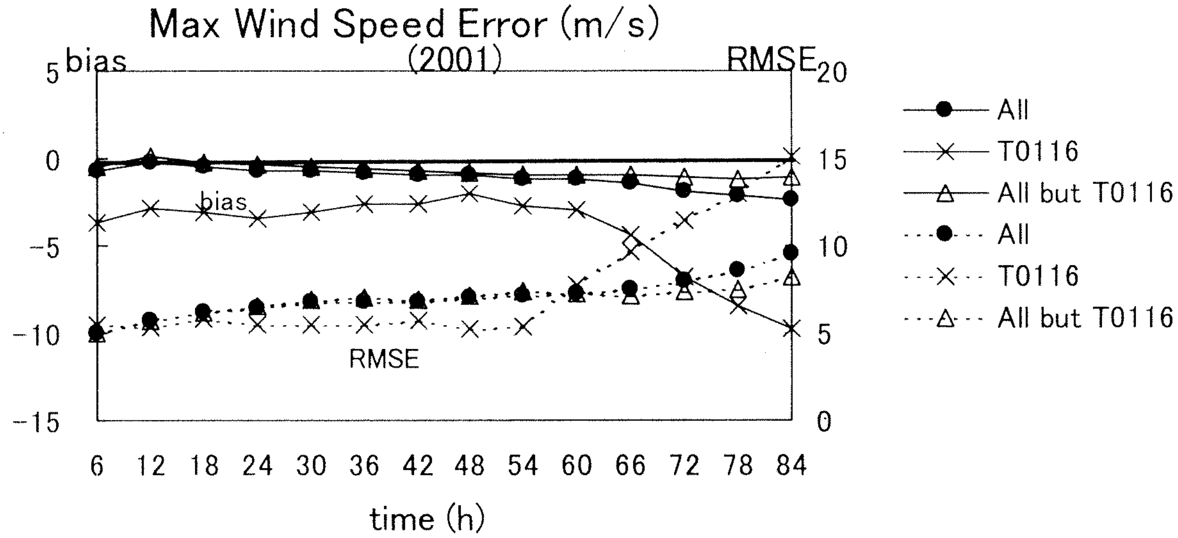


Fig. 5 Biases (solid lines) and root-mean-square errors (RMSEs) (dashed lines) of TYM's maximum wind speed for all tropical cyclones (solid circles), for Typhoon Nari (0116) (crosses), and for all tropical cyclones but for Typhoon Nari (0116) (open triangles), in 2001.

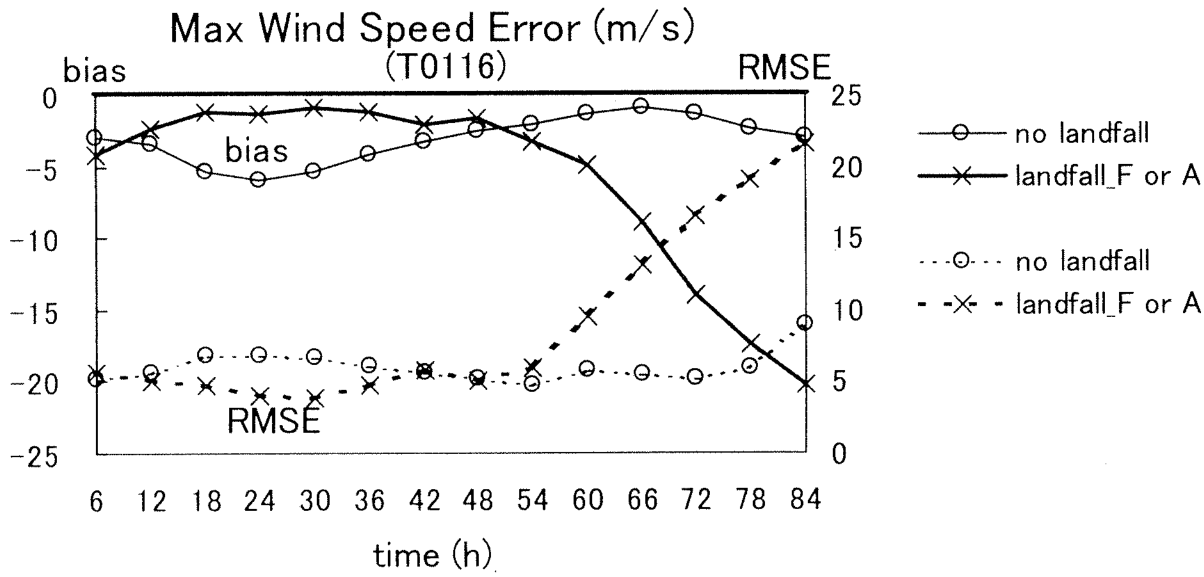


Fig. 6 Biases (solid lines) and root-mean-square errors (RMSEs) (dashed lines) of TYM's maximum wind speed for cases of Typhoon Nari (0116) with landfall predicted by the model or analyzed (crosses), and those without landfall (open circles).

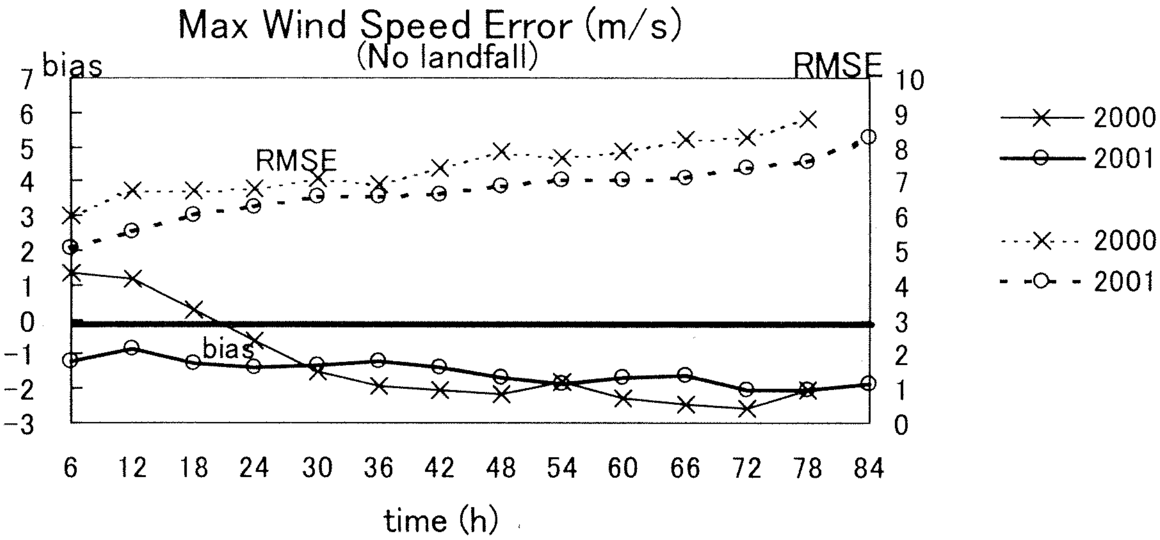


Fig. 7 Biases (solid lines) and root-mean-square errors (RMSEs) (dashed lines) of TYM's maximum wind speed for only cases of tropical cyclones without landfall predicted by the model or analyzed for the year 2000 (crosses) and for the year 2001 (open circles).

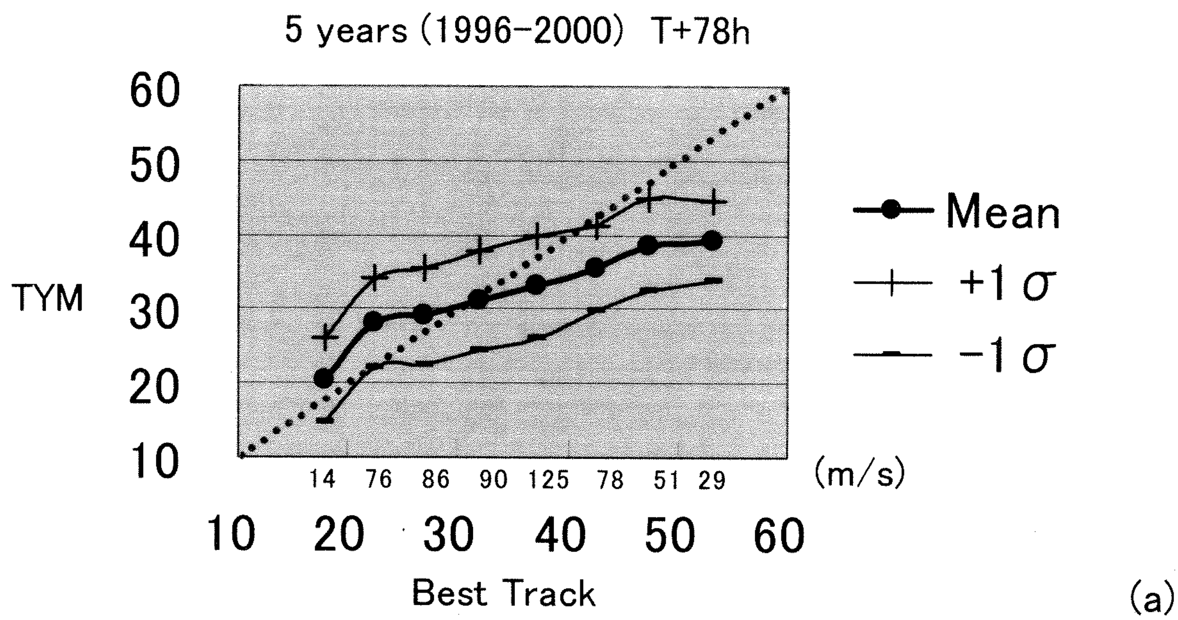
maximum wind speed and a bias and a standard deviation (SD) of errors are calculated for each category (Fig. 8). Results show that biases were reduced significantly in 2001 from the previous five year period (1996-2000) for maximum wind speeds of 35 - 40 and 40 - 45 m s^{-1}, so that biases are now very small from minimal tropical storm intensity through these categories. In contrast, for maximum wind speeds of 45 - 50 and 50 m s^{-1} <, negative biases somewhat increased. However, the number of cases for these categories were so small in 2001 that a general conclusion can not be drawn for very intense storms falling into these categories.

We should note here that JMA changed its process of deriving surface (10 m) wind speeds from TYM's prediction data. In the previous five year period (1996-2000), surface wind speed was derived simply by multiplying the lowest model level (~ 20 hPa above surface) wind speed by a constant (0.8). Meanwhile, in 2001 it was calculated with the planetary boundary layer physics incorporated in the model. This means that data compared between the two periods in Fig. 8 are not homogeneous in an exact sense. However, the impact of the model change is so obvious that it is highly probable that an actual improvement occurred in TYM's performance in TC intensity prediction.

4. Tunings of TC bogusing scheme in TYM

A large portion of the worse performance of TYM in TC track prediction in 2001 than in 2000 came from several cases of Typhoon Pabuk (0111). In these cases, the actual TC headed to the west-northwest in low latitudes before recurvature, against the predicted tropical cyclone heading to the north (Fig. 9b). Notably, in contrast, such systematic track errors were rarely seen in GSM's predictions when the initial TC position was west of the 140E longitudinal line (Fig. 9a). Since both prediction models used the same Global Analysis for their initial fields and physical processes were similar between the two models, we suspect that the difference in TC bogusing scheme was responsible for the difference in track predictions for Typhoon Pabuk between TYM and GSM. Actually when we did not use the TC bogusing scheme in TYM in an experiment (Fig. 10), the systematic track error was reduced considerably in these cases of Typhoon Pabuk.

In order to examine how realistic the current bogus TC is, we investigate an ocean surface wind field derived from SeaWinds microwave Scatterometer aboard the QuikSCAT satellite for a typical case of large track error for Typhoon Pabuk (Fig. 11). The wind field shows a large azimuthal variation in radius of 30kt winds around the TC center. In the west and east quadrants, areas of 30kt winds or stronger were confined near the TC center while in the north and south quadrants, they were broad. In the south quadrant, a fairly broad belt of strong southwesterly winds existed in association with ITCZ clouds far south of the typhoon, while in



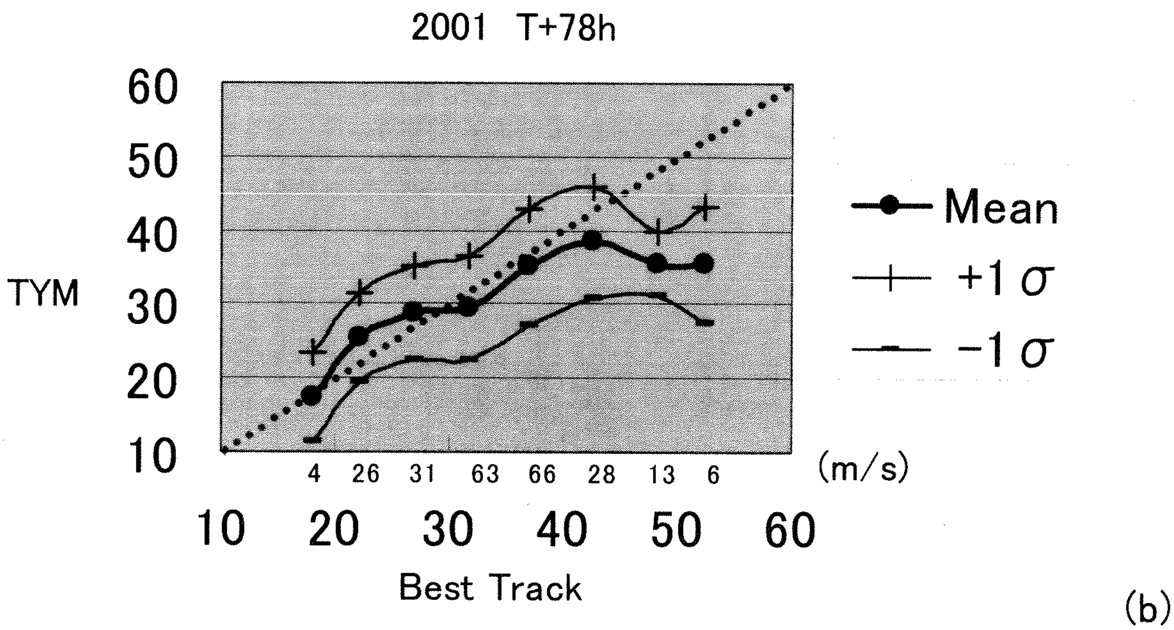
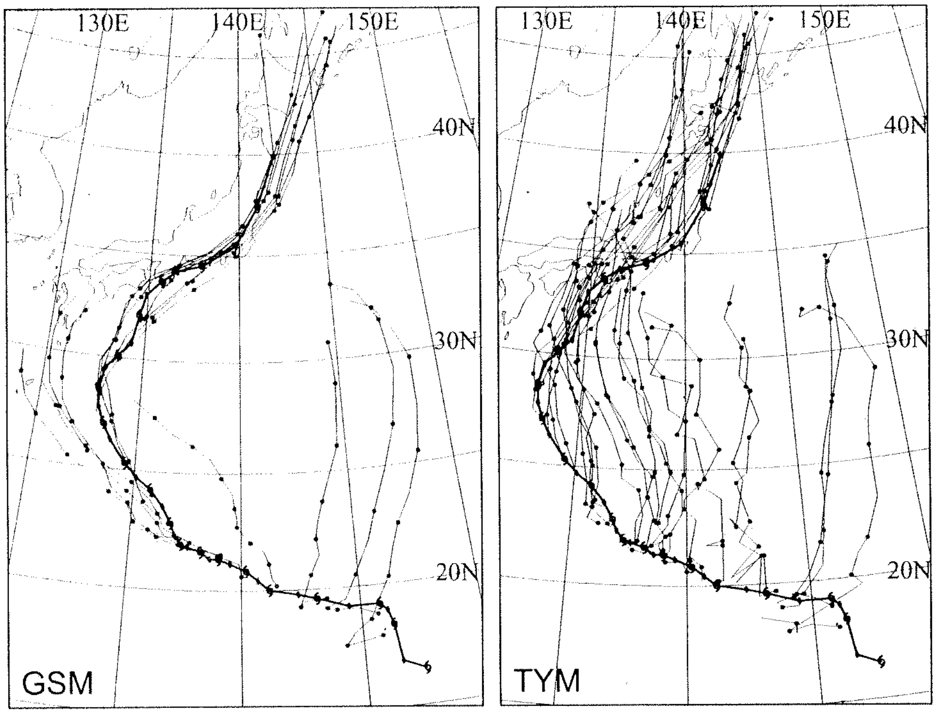


Fig. 8 Mean values (solid circles) and those plus/minus one standard deviation (plus/minus signs, respectively) of errors of TYM's maximum wind speed at T_0+78h categorized by maximum wind speed at 5 m s^{-1} intervals (a) for the five-year period (1996-2000), and (b) for the year 2001. Number of cases falling into each category is put along the lower periphery of each panel.



(a) (b)

Fig. 9 Tracks of Typhoon Pabuk (0111) predicted by GSM (a) and TYM (b) compared with the analyzed one.

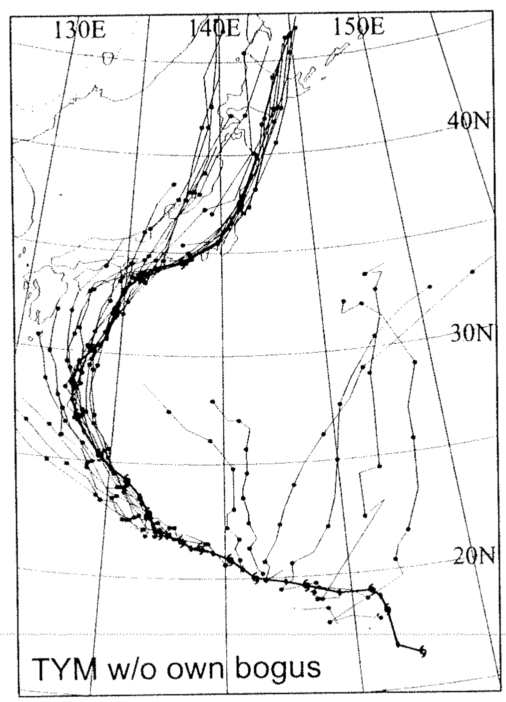


Fig. 10 Tracks of Typhoon Pabuk (0111) predicted by TYM without its own bogusing scheme. Note here that even if we do not use the TC bogusing scheme of TYM, we are still using another TC bogusing scheme, which is adopted in the Global Data Assimilation system and thus used in GSM.

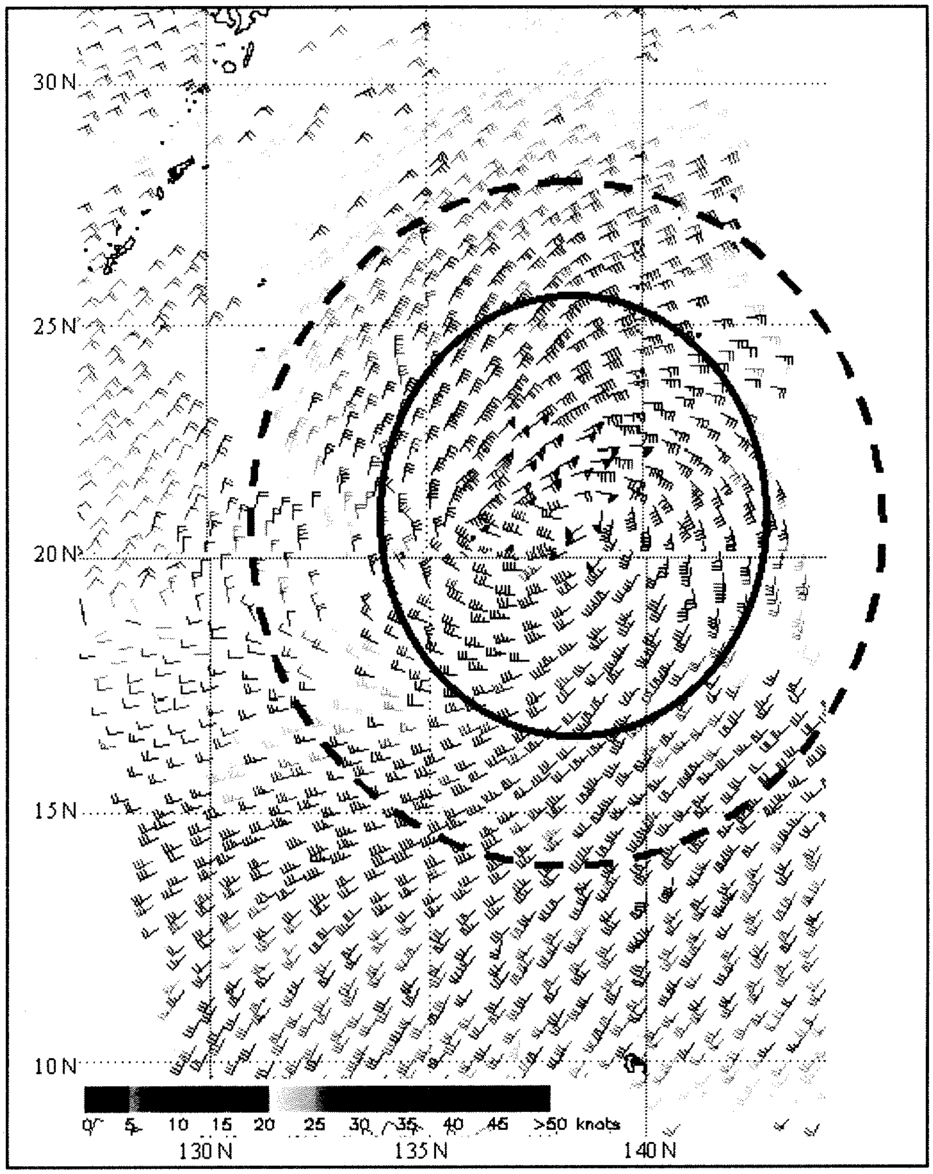


Fig. 11 Ocean surface winds processed by NOAA/NESDIS from near real-time data collected by NASA/JPL's SeaWinds Scatterometer aboard the QuikSCAT at 2042UTC 16 August 2001. The thick dashed circle indicates the area of 30kt winds according to the quick analysis of JMA and the thick solid one does that used in a modified bogusing scheme in an experiment. The radius of the latter circle is 57% of the former.

the north quadrant, large pressure gradients existed between the typhoon and a mid-latitude high pressure, accounting for the broad area of strong winds in between. Therefore, it is speculated that strong winds originating from the typhoon itself were confined near the typhoon center, as indicated by the areas of 30kt winds or stronger in the west and east quadrants. If this speculation is correct, the operational analysis of the radius of 30kt winds (denoted by the thick dashed line in Fig. 11) was too large for use in generating a bogus TC, resulting in the systematic track error in TYM.

To confirm the hypothesis mentioned above, we modified the TC bogusing scheme of TYM in the following two ways as trials on a research basis and conducted two sets of prediction experiments for those cases of Typhoon Pabuk with the two modified schemes, respectively:

a) Radius of 30kt winds was reduced to 57% of the analyzed value.
The reduction rate of 57% was determined by comparing the radius of 30kt winds in the west and east quadrants of the TC (thick solid circle in Fig. 11) analyzed with the QuikSCAT scatterometer sea surface winds and the radius of 30kt winds analyzed operationally (thick dashed circle in Fig. 11) in the particular case and fixed.

b) An upper bound (800km) was set to the outer radius of the annular zone for blending the bogus TC with the global analysis.
In the original TC bogusing scheme, the radius of the annular zone for blending the bogus TC with the global analysis is determined in proportion to the operationally analyzed value of the radius of 30kt winds and there is no upper bound set to it. Because of this, the annular zone can be too large when the radius of 30kt winds is overestimated in the operational analysis, leading to the systematic track error in TYM.

Results of the experiments (Fig. 12) show that the modified TC bogus a) worked to reduce the systematic track error drastically. Thus, in the cases of this particular TC, track prediction was very sensitive to the size of the bogus TC represented by the radius of 30kt winds. Therefore, accurate analysis of the radius of 30kt winds is crucial for better TC track predictions in such cases. Considering the current situation where the QuikSCAT is the major provider of ample ocean surface wind data, we should emphasize that operational use of the QuikSCAT ocean surface wind data in the analysis of the radius of 30kt winds is very important for improving TC track predictions. JMA has a plan to start using QuikSCAT ocean surface wind data in the manual analysis of wind radii of TCs and also in the Global Data Assimilation System by the beginning of the 2002 TC season in the western North Pacific.

The error reduction rate of bogus b) from the operational predictions

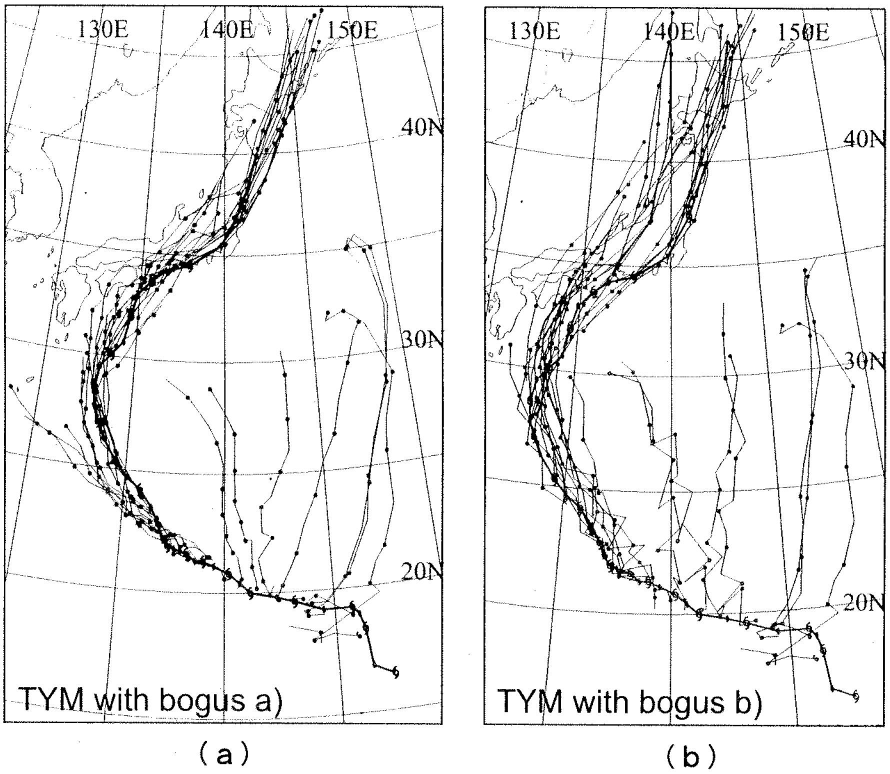


Fig. 12 (a) Tracks of Typhoon Pabuk (0111) predicted by TYM with the modified TC bogusing scheme a) in which the radius of 30kt winds is reduced to 57% of the analyzed value, (b) same as (a) but for the modified TC bogusing scheme b) in which an upper bound (800km) is set to the outer radius of the annular zone for blending the bogus TC with the global analysis.

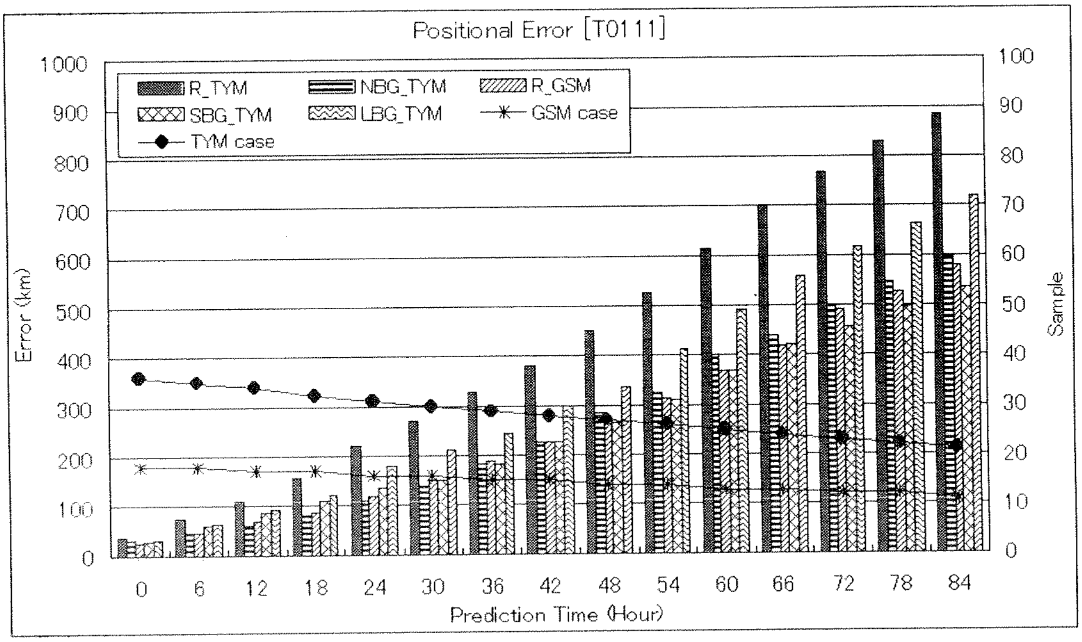


Fig. 13 Comparison of mean position errors in distance for Typhoon Pabuk (0111) among TYM (R_TYM), TYM without its bogusing scheme (NBG_TYM), GSM (R_GSM), TYM with the modified bogusing scheme a) (SBG_TYM), and TYM with the modified bogusing scheme b) (LBG_TYM) from left to right. Note that the numbers of GSM predictions verified are about half of those for TYM and, therefore, verifications are not homogeneous between the two models GSM and TYM.

was about half of that of bogus a) (Fig. 13). This seems to show bogus a) works better than bogus b). Yet we still need to continue exploring tunings of the bogusing scheme to find the best performing bogus.

5. Summary and comments

Tropical cyclone track and intensity predictions of the new numerical prediction models at JMA were verified against the RSMC Tokyo - Typhoon Center's Best Track data for the 2001 season.

GSM and TYM both showed lower performance in track prediction in 2001 than in 2000, when examined in terms of improvement (or error reduction) rates from the persistency method. The deterioration of GSM's performance in 2001 could be attributed to a revision of physical processes, which was introduced at the major upgrade of the model on 01 March 2001. A large portion of the worse performance of TYM in 2001 than in 2000 came mostly from several cases for Typhoon Pabuk (0111). The size of the bogus tropical cyclone, which was too large in several cases, is suspected of being responsible for the track prediction errors of this particular tropical cyclone. Revisions of the physical processes in GSM and the tropical cyclone bogusing scheme in TYM are now intensively explored for better performance in the coming 2002 season.

The performance of GSM in intensity prediction worsened, while TYM's improved from T_0+0h through T_0+66h presumably owing to the enhanced resolutions. RMSEs of TYM's intensity predictions for T_0+72h and T_0+78h remained nearly the same in 2001 as those in 2000. Examination of individual cases suggests that major portions of intensity errors arose from the Typhoon Nari (0116)'s track errors including false (or too early) landfall. However, verifications for selected cases show that TYM's intensity prediction performance for tropical cyclones over ocean, i.e., without landfall, was improved throughout the forecast period at its upgrade in March 2001. Besides this, intensity prediction error statistics categorized by maximum wind speed show that biases are now very small from minimal tropical storm intensity through the maximum wind speed of 40 - 45 m s^{-1}.

As described in Mino and Nagata (2001), several improvements of the numerical prediction system, besides the tunings of the TC bogusing scheme of TYM, are planned for the 5-year operation period (2001-2006) of the new computer system:

< TYM >

a) Improvement of physics: prognostic cloud water content
during the 2002 season

b) Enhancement of resolutions: 24km --> 20km grid, 25 levels --> 30 levels early 2003

c) Coupling with an ocean mixed layer model

early 2004

< GSM >

a) Improvement of physics: modification of cumulus parameterization

early 2002

b) Introduction of QuikSCAT SeaWinds ocean surface wind data to Global Analysis

early 2002

c) Introduction of semi-Lagrangian scheme with a linear grid

early 2003

d) Introduction of 4D-VAR

early 2004

Before the introduction of those improvements, three-dimensional variational method (3D-VAR) was already introduced into the Global Data Assimilation System in late September 2001. It has been shown that this change produces better performance in TC track predictions not only in GSM but also in TYM (Takeuchi and Narui, 2001).

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