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

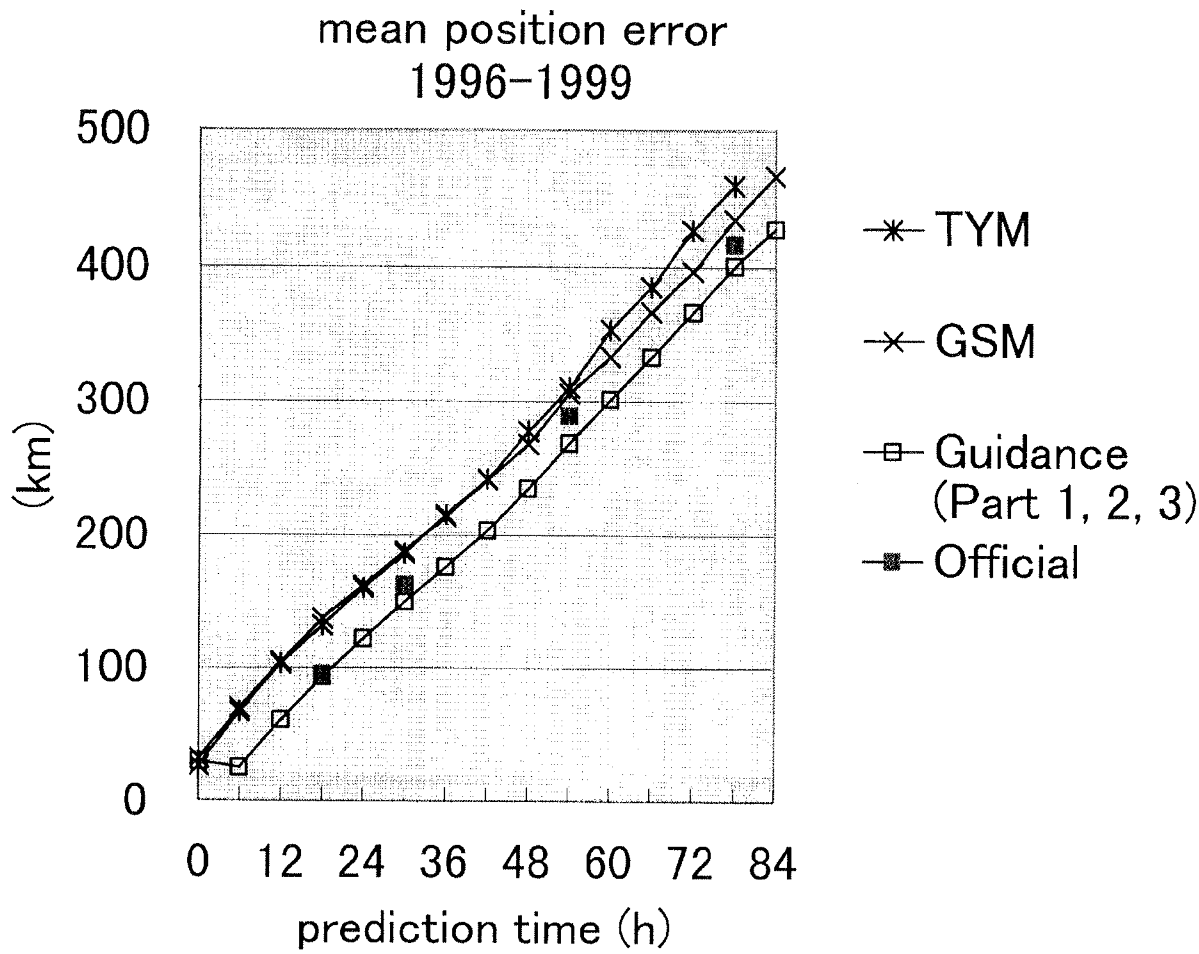

Fig. 1 Mean position errors of TYM, GSM, and the guidance for the dependent four-year period (1996-1999). Those of JMA's official forecast for 12, 24, 48, 72 hours are also plotted with its time frame set forward by 6 hours with respect to that of the numerical models.

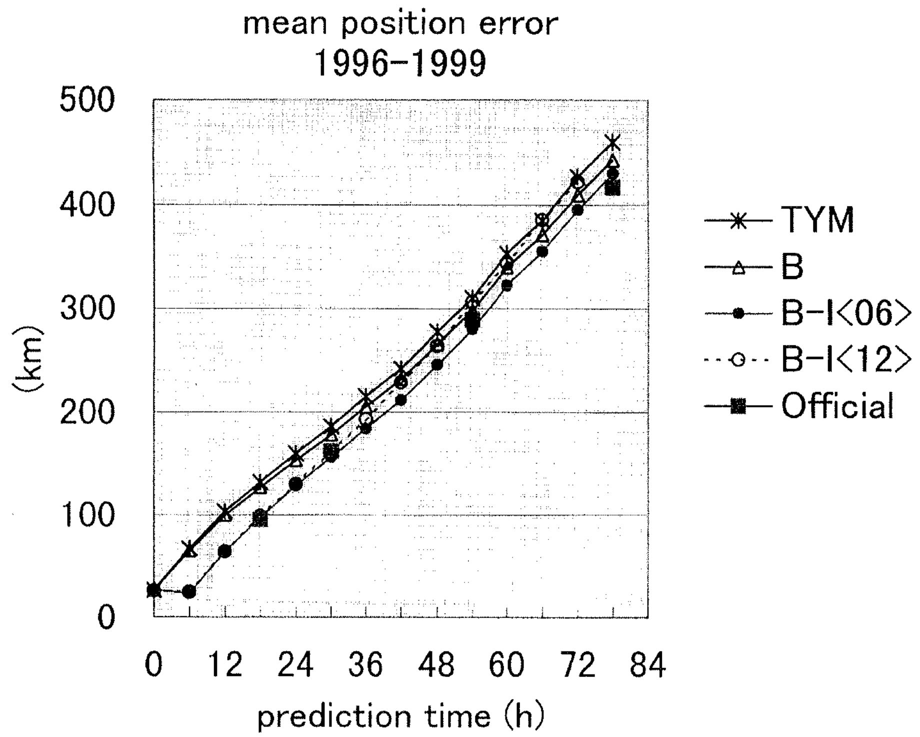

Fig. 2 Same as Fig. 1 but for TYM, TYM with bias correction (B), TYM with both bias correction and initial adjustment at the latest analysis time which is corresponding to prediction at T+06h (12h) of the model (B-I<06> (B-I<12>)).

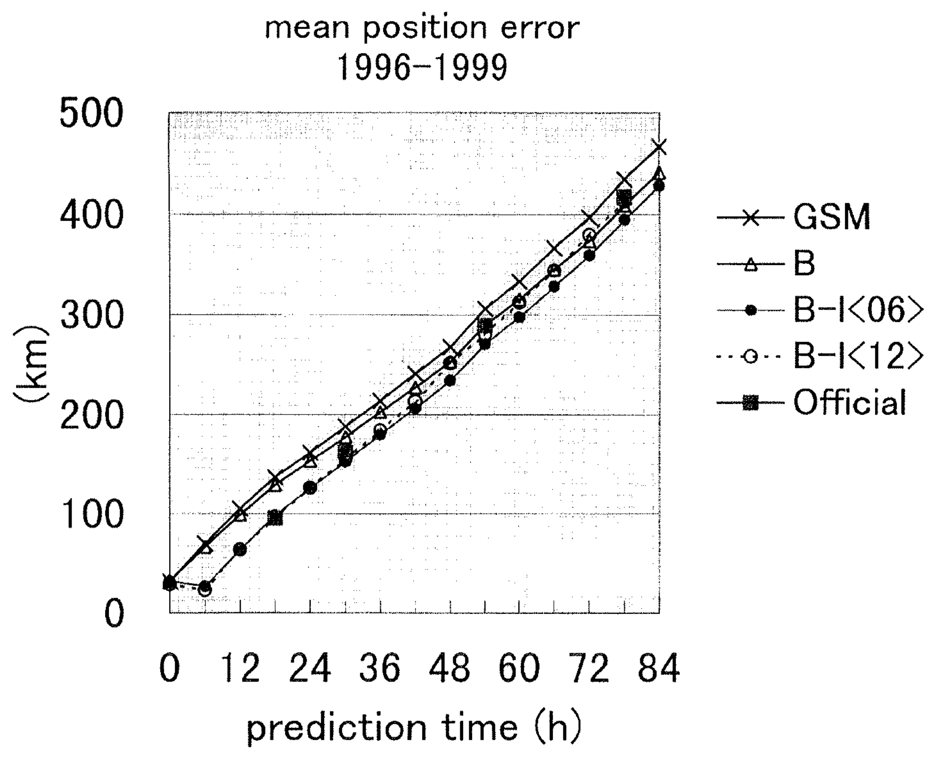

Fig. 3 Same as Fig. 2 but for GSM.

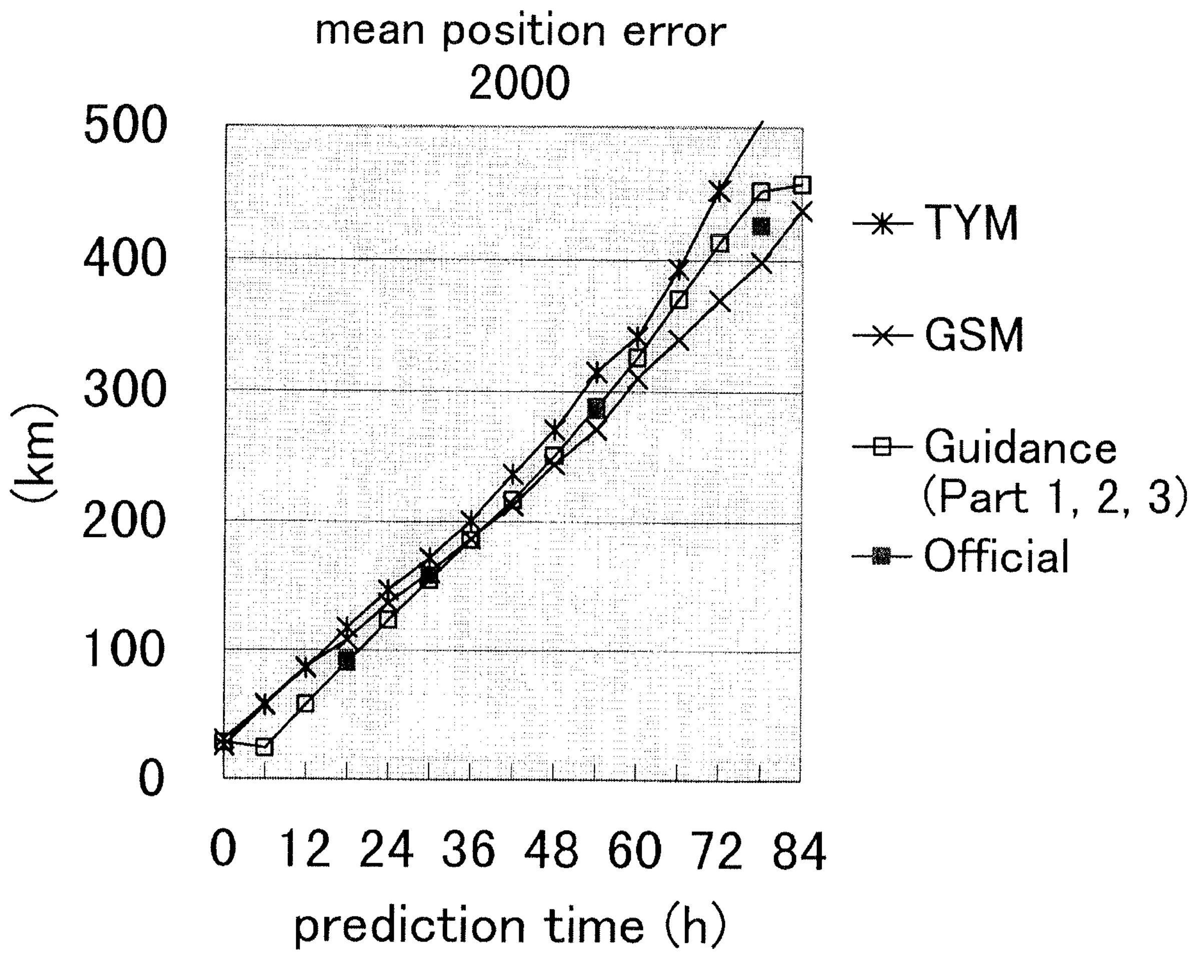

Fig. 4 Same as Fig. 1 but for the independent one-year period (2000).

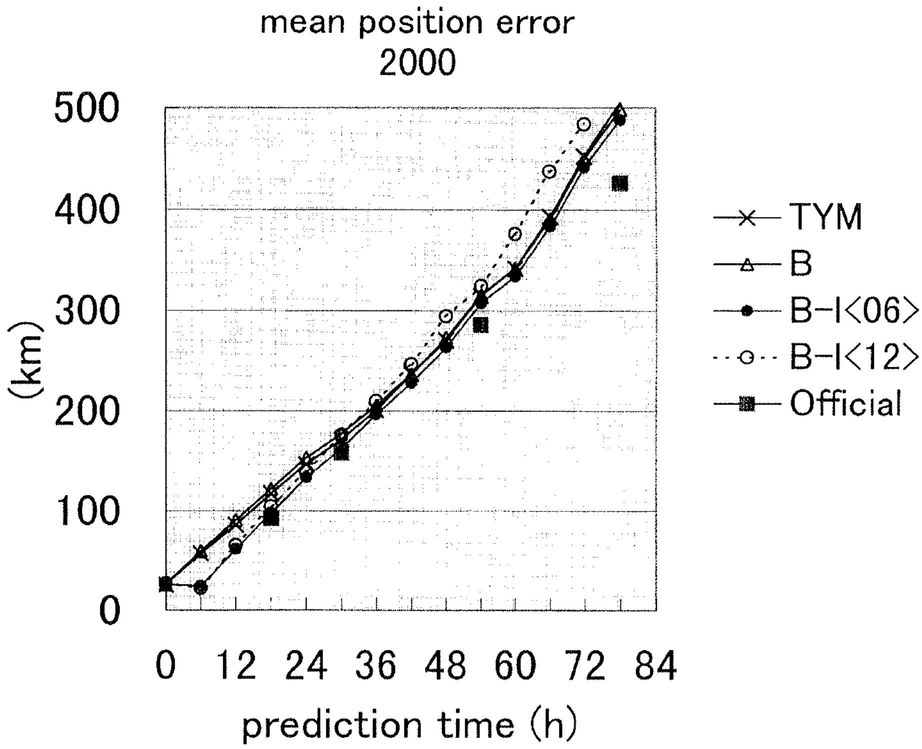

Fig. 5 Same as Fig. 2 but for the independent one-year period (2000).

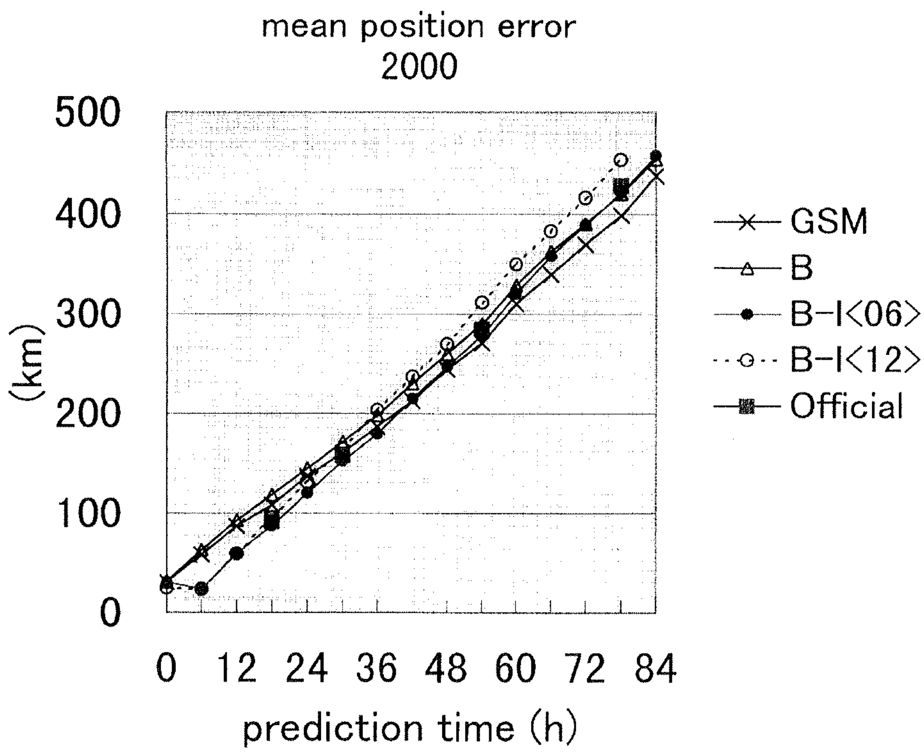

Fig. 6 Same as Fig. 3 but for the independent one-year period (2000).

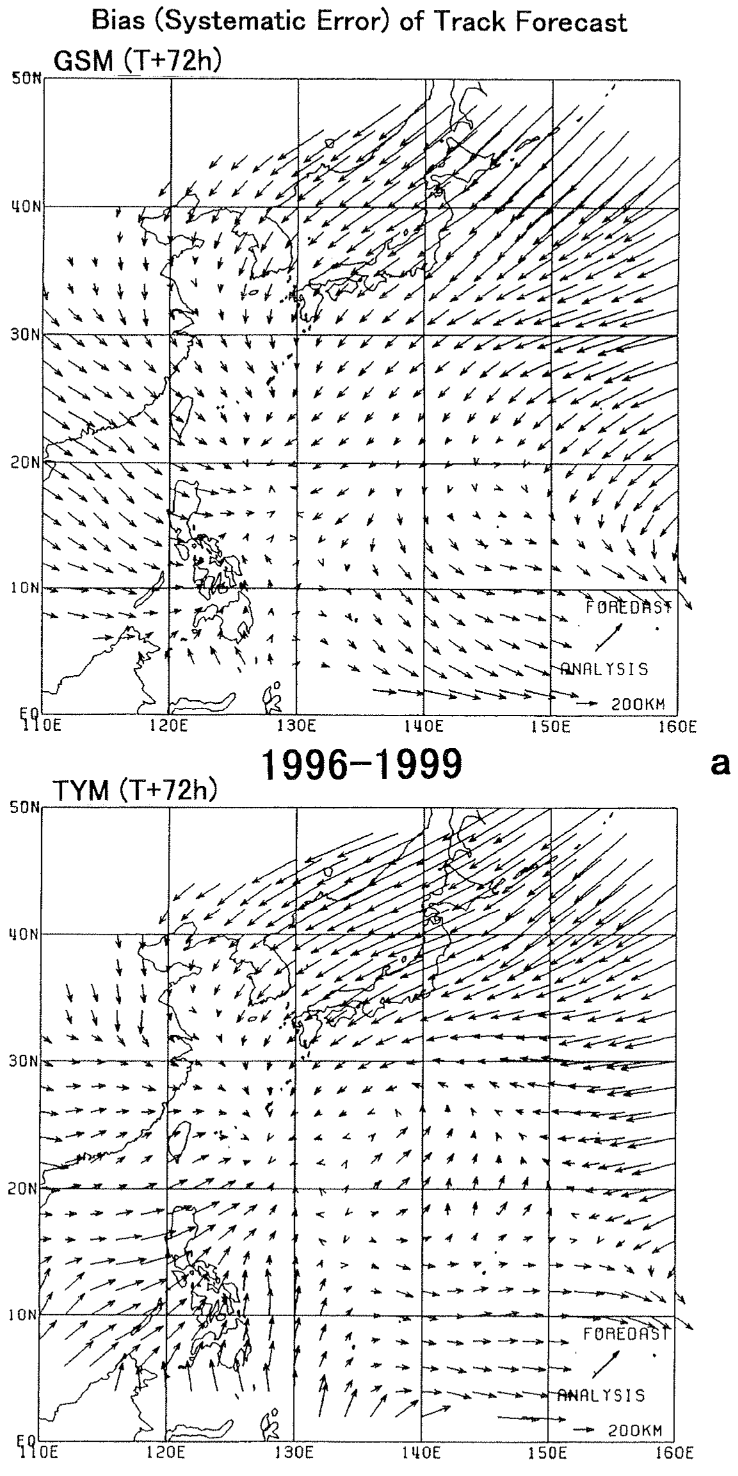

Fig. 7 Regional distribution of systematic track error vectors (Forecast - Analysis) at T+72h of prediction. Top panel for GSM and bottom one for TYM. Scale of vectors is shown in the down right corner in each panel. (a) the four-year period (1996-1999) and (b) the one-year period (2000). The large systematic 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.

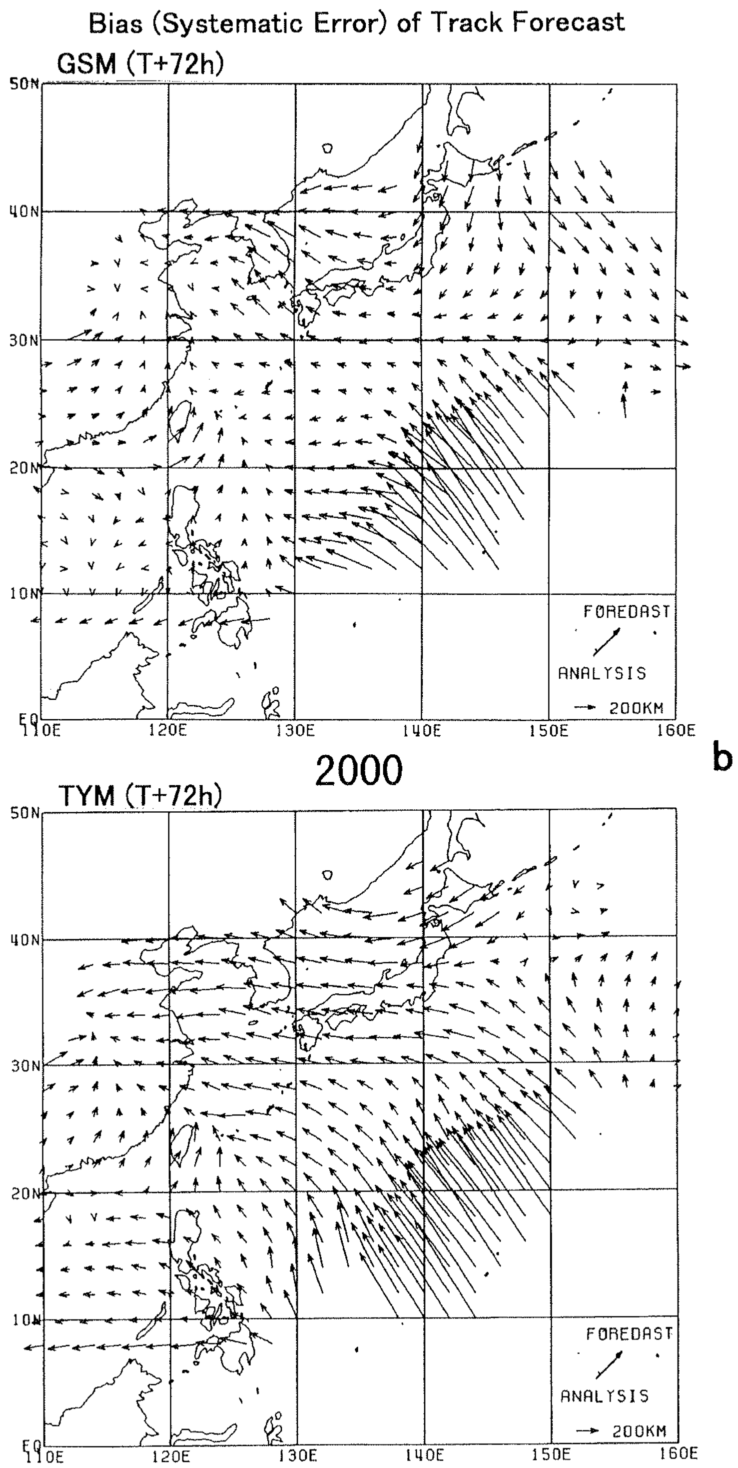
Bias (Systematic Error) of Track Forecast
GSM (T+72h)
50N
40N
30N
20N
10N
EQ
110E
120E
130E
140E
150E
160E
FORECAST
ANALYSIS
200KM
2000
b
TYM (T+72h)
50N
40N
30N
20N
10N
EQ
110E
120E
130E
140E
150E
160E
FORECAST
ANALYSIS
200KM

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

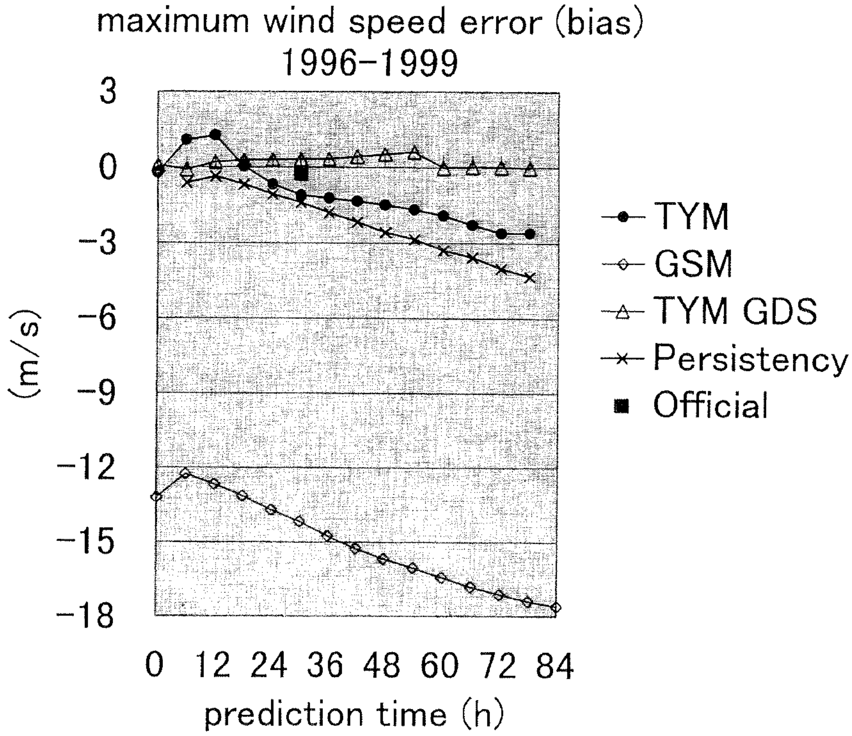

Fig. 8a Mean intensity errors (biases of maximum wind speed) of predictions by TYM, GSM, the guidance based only on TYM with bias correction and initial adjustment (TYM GDS), and the persistency method assuming no intensity change, for the dependent four-year period (1996-1999). Those of JMA's official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

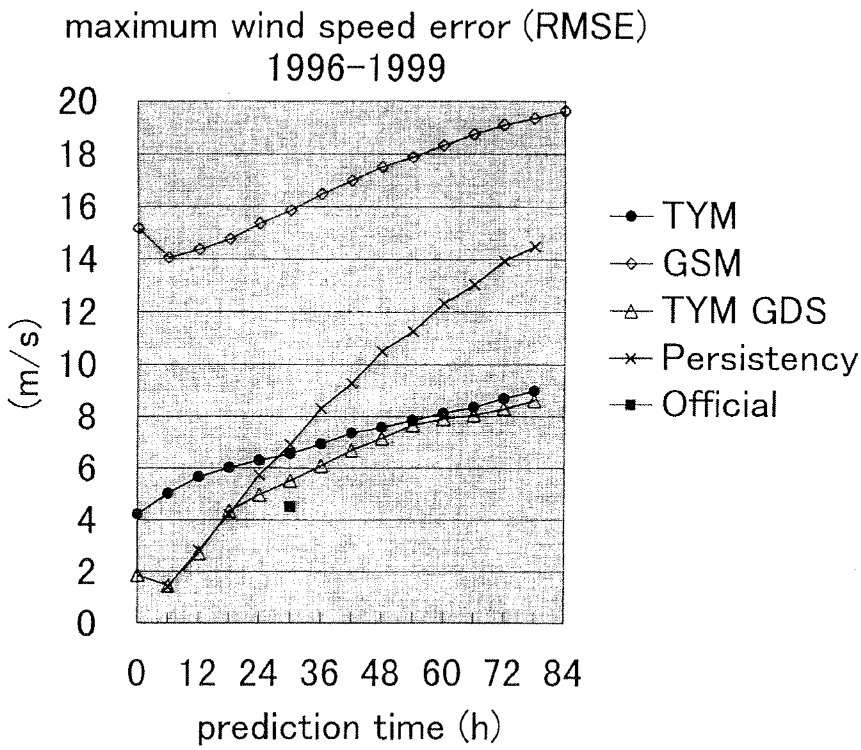

Fig. 8b Same as Fig. 8a but for root-mean-square errors (RMSEs) of maximum wind speed.

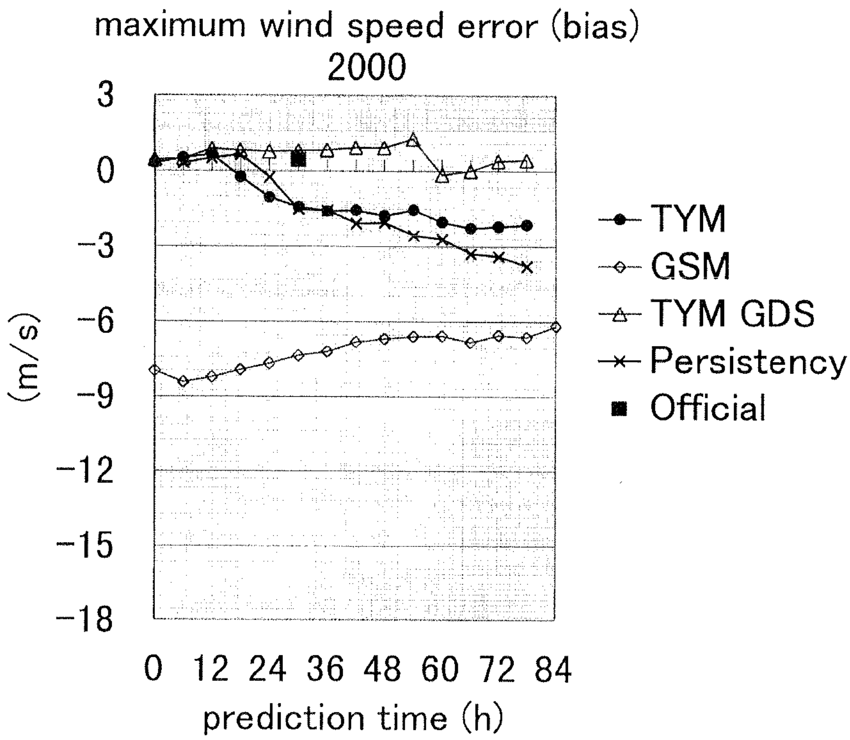

Fig. 9a Same as Fig. 8a but for the independent one-year period (2000).

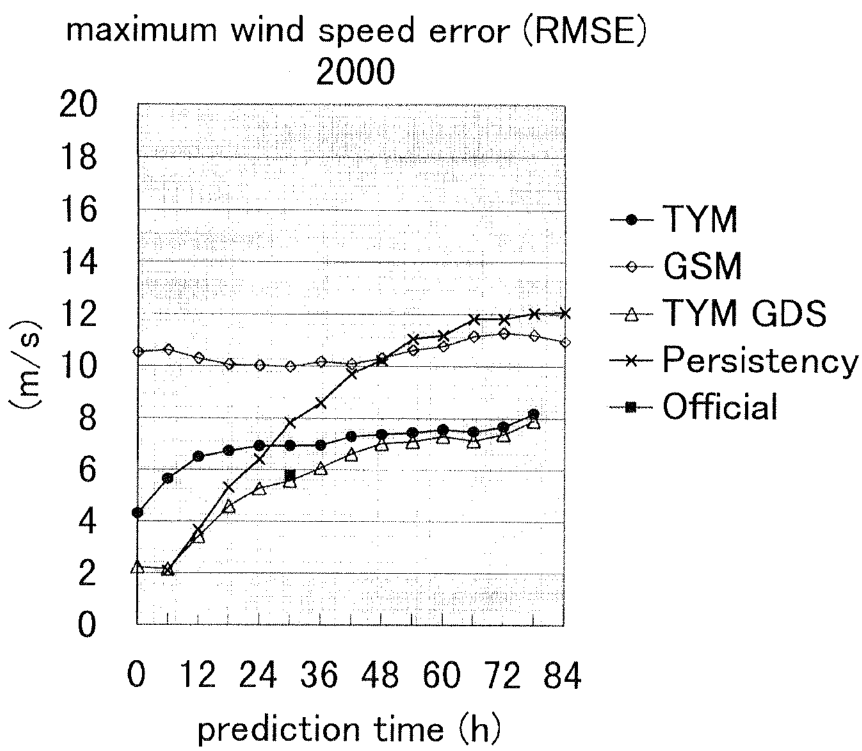

Fig. 9b Same as Fig. 8b but for the independent one-year period (2000).

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.

References

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