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.

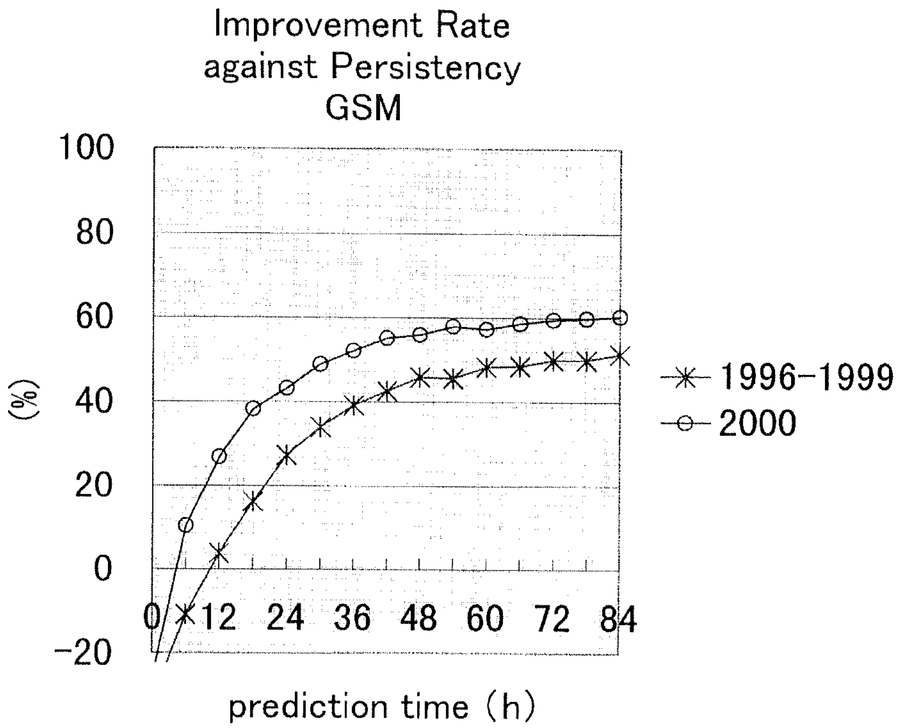
Besides, they presumably influenced the global analyses through the "forecast-analysis" cycle. In Fig. 1b are shown improvement rates of track predictions by the Typhoon Model (TYM) from the persistency forecasts. Those for the year 2000 are slightly better than those for the previous four-year period (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.

a



b

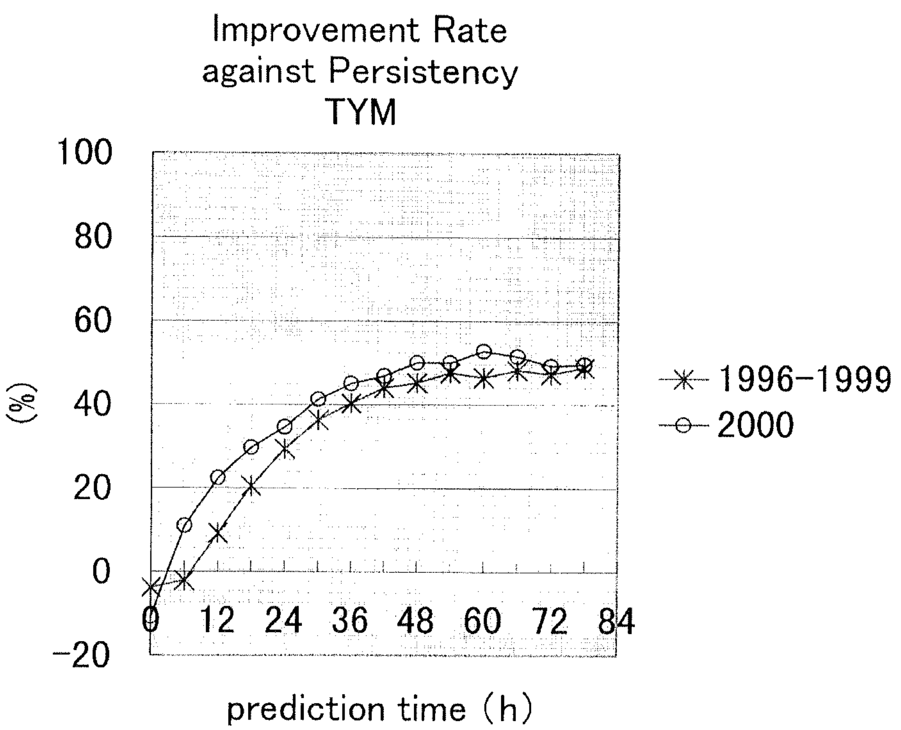


Fig. 1 Improvement rates of track predictions by the models from those by the persistency method for the 4-year period 1996-1999 (line with asterisks) and for the year 2000 (line with open circles). Improvement rates are defined as (PER-MDL)/PER*100 (%), where PER and MDL denote mean position errors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

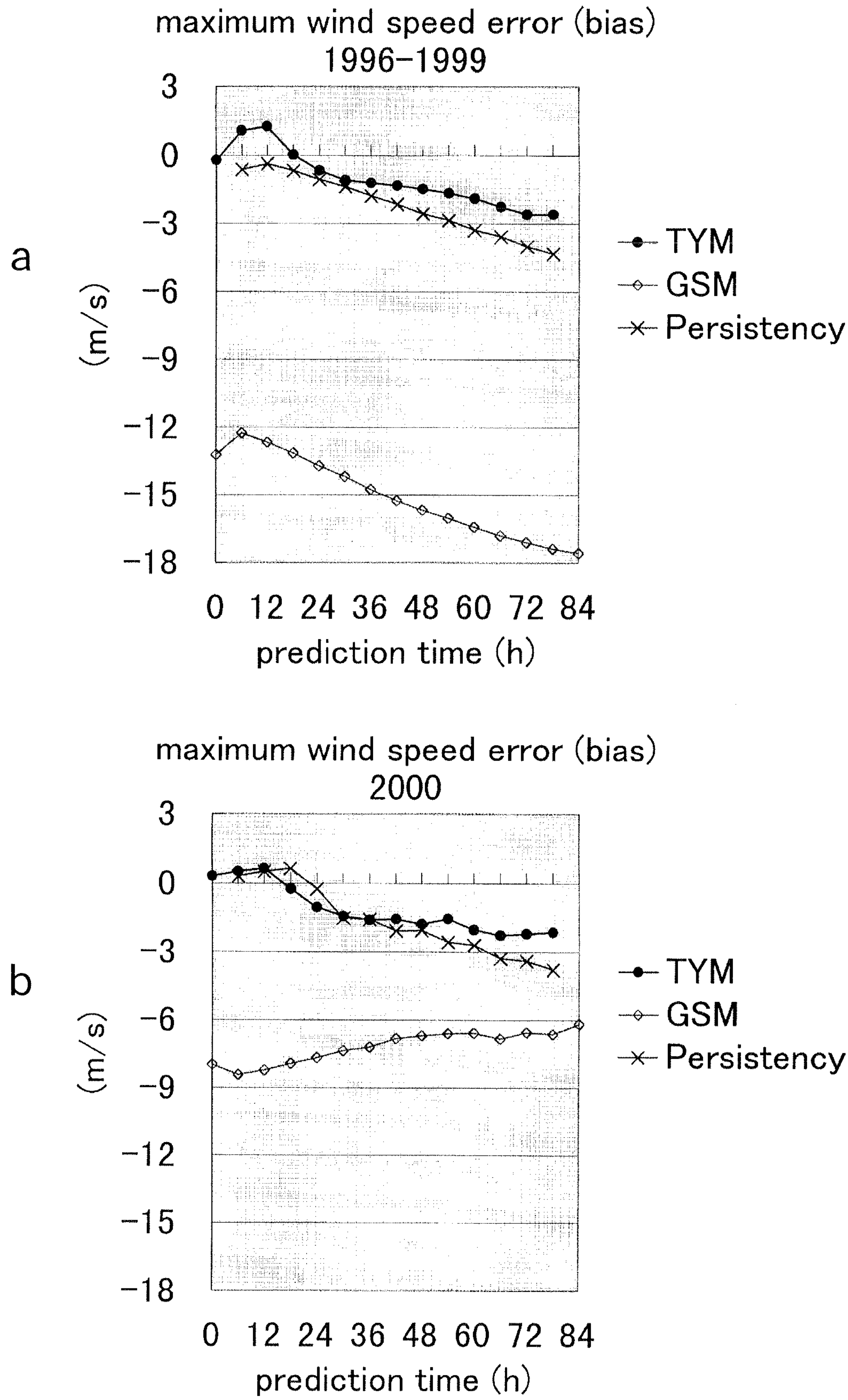
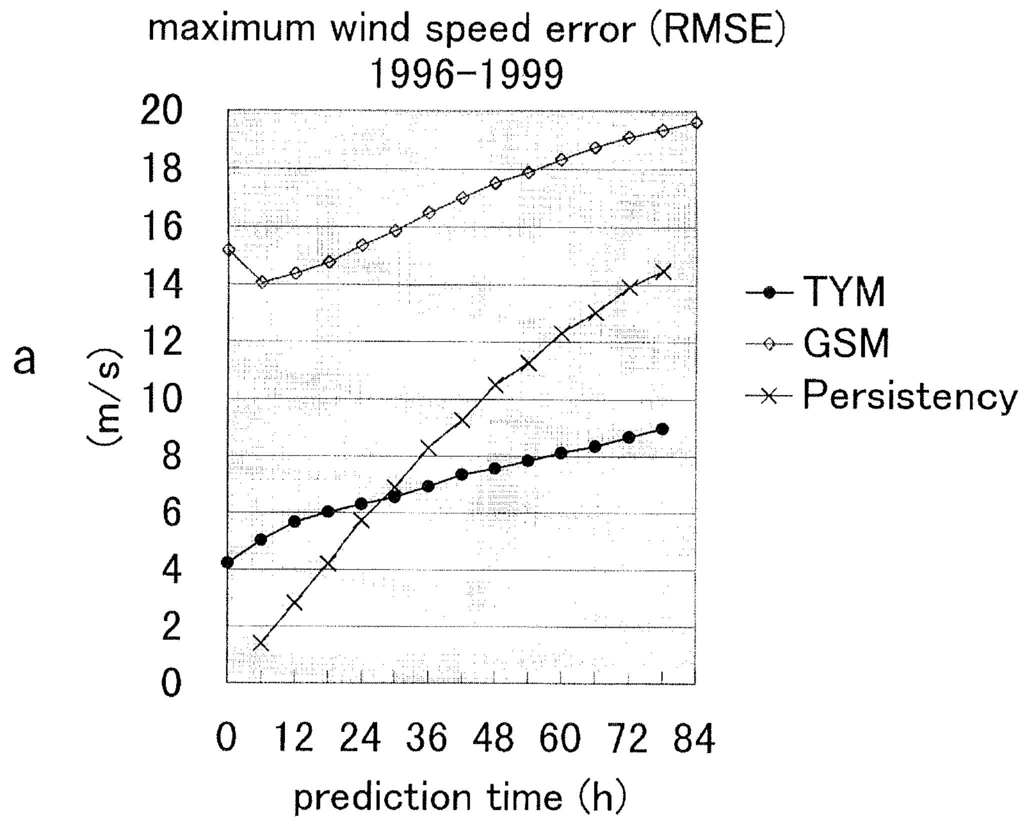


Fig. 2 Biases of maximum wind speed of tropical cyclones in the western North Pacific for TYM and GSM against the persistency method. (a): 1996-1999, (b): 2000.



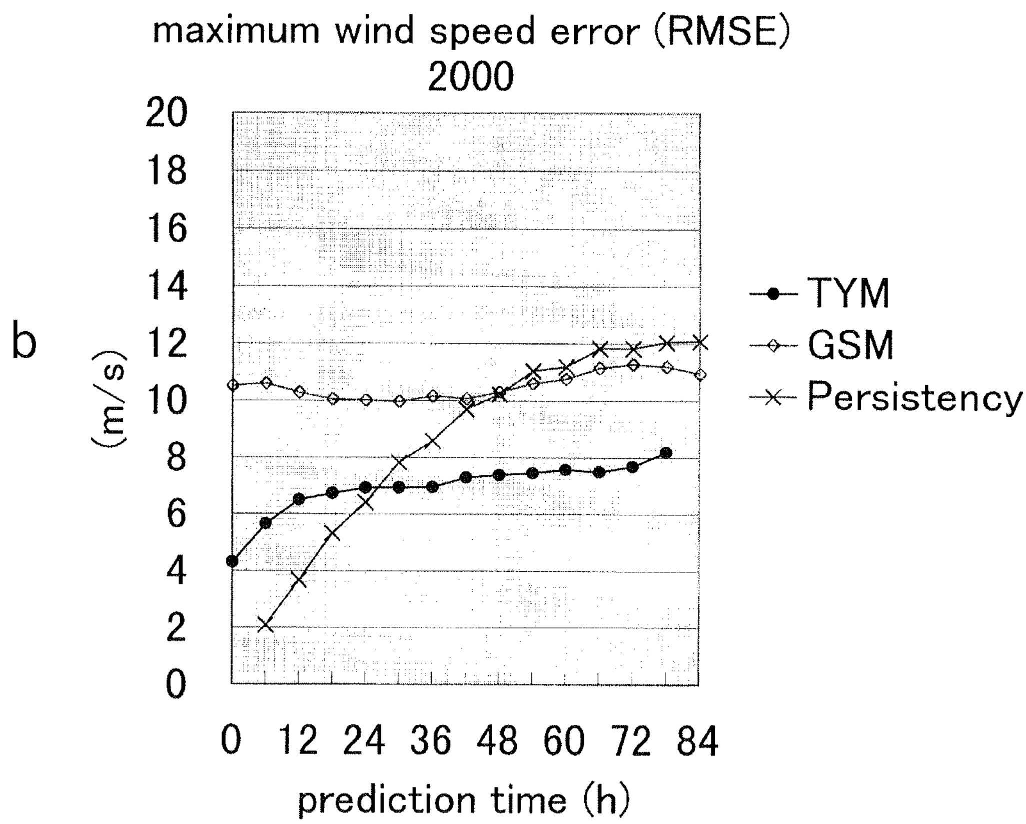


Fig. 3 Same as Fig. 2 but for root-mean-square errors (RMSEs).

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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