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Enhanced Accuracy of Typhoon Prediction of the Advanced Numerical Models at the Japan Meteorological Agency

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Abstract

The Japan Meteorological Agency (JMA) made major revisions on the numerical analysis and prediction models in March 1996. The revisions have lead to enhancement of accuracy of the typhoon track predictions of these models. The large northward drifting bias has been eliminated, while slow-speed bias has newly emerged in particular after recurvature of typhoons.

It is shown that the accuracy of typhoon track prediction of the global model has become nearly equal to those of other major numerical weather prediction centers. Besides that the limited-area typhoon model shows smaller errors in typhoon intensity prediction than the persistency method in predictions beyond T+24 h.

1. Introduction

On the occasion of the installation of the new Computer System for Meteorological Services (COSMETS), the Japan Meteorological Agency (JMA) started operations of advanced numerical analysis and prediction models in March 1996 to meet requirements for enhancement of meteorological services (JMA, 1997). On this system, typhoon prediction is performed four times a day with two numerical models, a global model and a re-locatable limited-area typhoon model, one after the other at 6-hour intervals. The Global Spectral Model (GSM) makes 84-hour and 192-hour predictions from 0000 and 1200UTC, respectively, and the spectral limited-area Typhoon Model (TYM) makes 78-hour predictions from 0600 and 1800 UTC.

Specifications of the models both of the old and new versions are shown in Table 1. In comparison of the new versions with old ones, GSM increased its horizontal resolution from T106 to T213 and the number of vertical layers from 21 to 30, while TYM did from 50 km to 40 km and from 8 to 15, respectively. Both models changed their cumulus parameterization schemes into a mass-flux-type (Arakawa-Schubert) scheme.

TYM is provided with predictions of GSM as its lateral boundary data and both models use the Global Analysis data (GANAL) as their initial fields. The global analysis is produced with a 6-hourly intermittent four-dimensional data assimilation cycle employing a statistical interpolation method, which was upgraded from a two-dimensional one on isobaric surfaces to a three-dimensional one on hybrid σ-p prediction model levels.

Both GSM and TYM employ so-called typhoon bogusing technique in making their initial fields. Note here that we call tropical cyclones with any intensity typhoons in this paper. At the stage of making global analysis (GANAL), axisymmetric synthetic typhoon structure is generated in geopotential and wind fields using two typhoon parameters given by a typhoon analyst; the central pressure and the radius of 15 m/s winds of a typhoon, and then merged with the asymmetric component derived from the 6-hour prediction by GSM. The bogus typhoon is implanted into the first guess field of the analysis. The resultant analysis (GANAL) is used as the initial field of GSM. Meanwhile, for TYM its own axisymmetric synthetic typhoon structure is generated with the same typhoon parameters as in the global analysis and then implanted into GANAL with an annular transition zone. Inside the annulus, the asymmetric bogus typhoon in GANAL had been replaced by the symmetric synthetic typhoon until 13 January 1997 when the asymmetric component started surviving the initialization process of TYM. A tuned asymmetric typhoon bogusing scheme utilizing the TYM prediction field was implemented into TYM on 12 November 1997 and it has been operationally employed since then.

The main purpose of this paper is to show the accuracy of typhoon predictions by GSM and TYM focusing on some notable features. In Section 2 position errors of both models are examined with their geographical dependence. Verification of the typhoon intensity prediction by TYM is described in Section 3.

2. Accuracy of typhoon track predictions

Typhoon track predictions are verified with the final analysis data, the RSMC Tropical Cyclone Best Track, made by the RSMC Tokyo – Typhoon Center. Note that typhoon tracks are traced with sea-level pressure minima in this study. The verifications are first made in position error which is defined as the distance along the great circle between the predicted position and the analyzed one of a typhoon at a validation time.

a. Mean position error

Figure 1 shows annual mean position errors of GSM and TYM for three years from 1994 to 1996. The errors of GSM decreased significantly in 1996 and so did TYM modestly in the same year. Sensitivity experiments between high and low resolutions and those between different types of physical parameterization have revealed that the enhancement of resolutions of the prediction models and the sophistication of physics, i.e., employment of the Arakawa–Schubert cumulus parameterization scheme, play major roles in the reductions of errors.

In Table 2(a) and Table 2(b), we stratify the verified cases in 1996 into three categories according to the stage of typhoon movement relative to recurvature. "Before recurvature" means that the direction of typhoon movement measured clockwise from the north is in 180° ~ 320°, "During recurvature" in 320° ~ 010°, and "After recurvature" in 010° – 180°, respectively.

Among verious predictions in forecasting times and stages, mean position errors are largest after recurvature after T+36h in both models. However, relative skill scores, such as improvement rates of accuracies of the numerical models with respect to their counterparts of the persistency method (see rows "improvement rate"), show a different nature of position errors. Improvement rates are largest after recurvature before T+60h in GSM and throughout the whole period in TYM and they are smallest during recurvature except for T+24h and T+36h in GSM and T+36h and T+72h in TYM. Therefore, as a whole, typhoon track prediction is most difficult during recurvature for the numerical models in terms of improvement rates while so is it after recurvature in terms of mean position errors in 1996.

Both numerical models have nearly the same accuracies for the whole cases in terms of relative scores, while mean position errors of TYM are slightly larger than those of GSM after T+36h. The most interesting fact found in this table is that after T+36h GSM performs better than TYM before recurvature while TYM does than GSM after recurvature in 1996 in terms of relative scores.

b. Systematic error (bias)

Figures 2(a), 2(b) and 2(c) show scatter diagrams of predicted positions of typhoons in 1996 relative to verifying analysis counterparts located at the origin of each panel. Almost no biases are seen before recurvature in either model, which is in notable contrast with the error characteristics of the old models showing significant northward drifting biases (see Figure 3). During recurvature, small biases to the southwest are seen in both GSM and TYM. Biases of the same kind are much larger after recurvature in both models, which means that a slow bias has newly developed in both models, especially after recurvature.

The old models which had been operated at JMA until March 1996 had large northward drifting biases, especially the global model, as seen in Figure 3 showing the year-to-year variation of northward bias error of the old GSM (before 1996) and of the new GSM (in 1996) of JMA. The bias has disappeared after the major revision of the model in March 1996.

c. Comparison of typhoon track predictions among global models of major numerical weather prediction centers

Global models at some major numerical weather prediction centers are now capable of predicting tracks of tropical cyclones fairly well. Figure 4 compares mean position errors of typhoon tracks over the western North Pacific in 1996 predicted by such global models. The figure shows that the accuracies of typhoon track predictions of the three global models of JMA, the European Center for Medium-Range Weather Forecasts (ECMWF), and the United Kingdom Meteorological Office (UKMO) are almost the same over the western North Pacific only with slight superiority of ECMWF to the other two between T+72h and T+96h.

d. Geographic areal dependence of systematic error (bias)

The verifications of track predictions above have been made without considering geographical dependence. In this subsection, area-to-area variability of systematic track prediction error for typhoons in 1996 is examined by calculating mean positional error vectors on each latitude-longitude grid point with 2° intervals. In this calculation, error vectors are defined from predicted positions to analyzed ones of typhoons opposite to the conventional definition and are averaged at each grid point for cases where the predicted positions are within a circle of radius of 10° around the grid point. Resultant diagrams for T+48h are shown in Figure 5. Those for T+72h have similar distributions of error vectors but with larger amplitudes.

The diagrams show that error vectors are relatively large in mid latitudes (north of 30°N), in the eastern part of the analyzed domain (east of 140°E), around the Philippines and in the South China Sea. Meanwhile they are small in the East China Sea, near and southeast of the Nansei Islands of Japan, near Taiwan and in southern China. The error characteristics are almost the same between GSM and TYM.

Northeastward error vectors indicating southwestward biases of track predictions are prevailing in mid latitudes (north of 30°N) and in the eastern part of the analyzed domain (east of 140°E). Most of them in the former region must be corresponding with the slow speed bias after recurvature which has already been addressed. Around the Philippines and in the South China Sea, northward error vectors indicating southward biases are dominant.

This kind of diagram serves to provide an expected prediction error to forecasters when they are given a track prediction by the models. It should be noted, however, relatively small-scale features can vary from case to case due to character of each typhoon and features of environmental conditions and also from year to year due to natural variability of the global climate system.

3. Intensity prediction by TYM

Until recently, it had been considered that intensity prediction of a typhoon by numerical models is extremely difficult in comparison with track prediction, partly because resolutions of prediction models are too coarse and partly because typhoon intensity is affected by many factors, such as large-scale atmospheric fields, evolutions of mesoscale inner features and air-sea interactions, which are not always simulated well in numerical models. On the occasion of the major revisions of JMA's numerical prediction models we examined current capability of the numerical models in predicting typhoon intensity.

Figure 6 shows bias and root-mean-square errors of central pressure of typhoons predicted by TYM in 1996. They are compared with those by the persistency method in which the central pressure of a typhoon is assumed not to change with time from its initial value. The results show that TYM has 5-8 hPa positive biases throughout the prediction hours and that it has 10 hPa (T+0h) to 20 hPa (T+72h) root-mean-square errors (RMSEs). The root-mean-square errors are smaller than those of the persistency method after T+24h while the biases are larger than those of the persistency method during the prediction period. This implies that TYM carries useful information of typhoon intensity after T+24h, although the error is still large. This is confirmed by looking at the histogram of errors of maximum wind speeds of typhoons predicted by TYM in 1996 (Figure 7). The figure shows that the errors of maximum wind speeds have nearly normal distributions except for a few cases at very large errors and that even at T+48h and T+72h one third of the whole cases fall into an error range of ±3.75 m/s and two thirds of them into an error range of ±8.75 m/s.

4. Summary

Verifications were made for typhoon predictions by JMA's advanced numerical prediction models, the Global Spectral Model (GSM) and the Typhoon Model (TYM), against RSMC Tropical Cyclone Best Track data. The results have shown enhancement of accuracy of the typhoon track predictions of these models. The large northward drifting bias has been eliminated while a slow-speed bias has newly emerged in both models. It is also shown that the accuracy of typhoon track prediction of the global model at JMA has become equivalent with those at other major numerical weather prediction centers.

Area-to-area variabilities of systematic errors of tracks predicted by GSM and TYM are examined. It is found that large region-to-region variabilities exist and that the distribution of systematic errors is very similar between GSM and TYM.

Besides that TYM shows smaller root-mean-square errors in typhoon intensity prediction than the persistency method after T+24h, which means TYM carries useful information of typhoon intensity after T+24h, although the error is still large.

Reference

Japan Meteorological Agency, 1997: Outline of the operational numerical weather prediction at the Japan Meteorological Agency. Appendix to PROGRESS REPORT ON NUMERICAL WEATHER PREDICTION. Numerical Prediction Division, Japan Meteorological Agency, March 1997.

Table 1 Specifications of the numerical prediction models for typhoon forecast

Model	GSM		TYM	
Version	new (T213L30)	old (T106L21)	new (40kmL15)	old (50kmL8)
Domain	global		limited-area, re-locatable	
Number of transform grids	640×320	320×160	163×163	109×109
Resolution				
horizontal	T213, ~55km	T106, ~110km	40km	50km
number of vertical layers	30	21	15	8
Physics				
cumulus parameterization	Arakawa-Schubert	Kuo	Arakawa-Schubert	moist convective adjustment
Operation				
prediction length (initial time)	84h, 192h (0000, 1200UTC)	72h, 192h (0000, 1200UTC)	78h (0600, 1800UTC)	60h (0000, 1200UTC)
Initial fields	Global Analysis (3-D statistical interpolation on hybrid σ-p model surfaces) (T213L30)	Global Analysis (2-D statistical interpolation on isobaric surfaces) (1.875°)	Global Analysis (3-D statistical interpolation on hybrid σ-p model surfaces) (0.5625°)	Global Analysis (2-D statistical interpolation on isobaric surfaces) (1.875°)
Lateral boundary	N/A		6 hourly predictions of GSM	
Bogusing				
symmetric	synthetic structure based on Pc and R_{15}*		synthetic structure based on Pc and R_{15}*	
asymmetric	none (before 23 August 1994) derived from GSM (after 23 August 1994)		none (before 13 January 1997) derived from GSM (after 13 January 1997) derived from TYM (after 12 November 1997)	

* Pc : central pressure of typhoon
R_{15} : radius of 15m/s wind speed

Table 2(a) Mean position errors (unit: km) of GSM vs persistence (PER) method for typhoons in 1996 with respect to stage of motion. Number of cases is given in parentheses. Improvement rates are defined as (PER−GSM)/PER.

GSM 1996

TIME	MODEL	Before	During	After	All
T=12	GSM	117.6 (147)	123.7 (55)	97.6 (110)	111.6 (312)
	PER	114.0 (147)	114.5 (55)	114.0 (110)	114.1 (312)
	improvement rate	-3.2%	-8.0%	14.4%	2.2%
T=24	GSM	175.4 (128)	176.0 (50)	158.5 (106)	169.2 (284)
	PER	200.9 (128)	218.3 (50)	254.2 (106)	223.9 (284)
	improvement rate	12.7%	19.4%	37.6%	24.4%
T=36	GSM	218.5 (107)	230.3 (45)	217.7 (101)	220.3 (253)
	PER	290.9 (107)	335.9 (45)	419.1 (101)	350.0 (253)
	improvement rate	24.9%	31.4%	48.1%	37.1%
T=48	GSM	239.2 (87)	290.7 (41)	298.4 (98)	274.2 (226)
	PER	434.1 (87)	407.4 (41)	589.1 (98)	496.4 (226)
	improvement rate	44.9%	28.6%	49.3%	44.8%
T=60	GSM	289.1 (70)	327.2 (37)	400.9 (95)	348.7 (202)
	PER	553.1 (70)	505.8 (37)	782.3 (95)	652.2 (202)
	improvement rate	47.7%	35.3%	48.8%	46.5%
T=72	GSM	324.1 (59)	366.0 (29)	494.4 (86)	415.2 (174)
	PER	663.2 (59)	724.9 (29)	941.0 (86)	810.8 (174)
	improvement rate	51.1%	49.5%	47.5%	48.8%
T=84	GSM	350.2 (47)	397.0 (21)	590.7 (82)	488.2 (150)
	PER	794.3 (47)	700.3 (21)	1160.5 (82)	981.3 (150)
	improvement rate	55.9%	43.3%	49.1%	50.2%

Table 2(b) Mean position errors (unit: km) of TYM vs persistence (PER) method for typhoons in 1996 with respect to stage of motion. Number of cases is given in parentheses. Improvement rates are defined as (PER−TYM)/PER.

TYM 1996

TIME	MODEL	Before	During	After	All
T=12	TYM	114.2 (143)	110.1 (51)	96.1 (106)	107.1 (300)
	PER	112.0 (143)	104.6 (51)	123.4 (106)	114.8 (300)
	improvement rate	-2.0%	-5.3%	22.1%	6.7%
T=24	TYM	168.8 (122)	178.6 (47)	151.6 (104)	163.9 (273)
	PER	202.1 (122)	183.4 (47)	269.1 (104)	224.4 (273)
	improvement rate	16.5%	2.6%	43.7%	27.0%
T=36	TYM	225.2 (101)	211.9 (45)	229.2 (101)	224.4 (247)
	PER	295.5 (101)	294.2 (45)	445.2 (101)	356.5 (247)
	improvement rate	23.8%	30.2%	48.5%	43.6%
T=48	TYM	281.1 (84)	269.1 (42)	309.8 (98)	291.4 (224)
	PER	420.8 (84)	385.5 (42)	656.0 (98)	517.1 (224)
	improvement rate	33.2%	30.2%	52.8%	43.6%
T=60	TYM	346.7 (67)	330.7 (38)	409.2 (94)	373.2 (199)
	PER	580.0 (67)	485.6 (38)	851.0 (94)	690.0 (199)
	improvement rate	40.2%	31.9%	51.9%	45.9%
T=72	TYM	401.1 (55)	406.9 (31)	498.7 (89)	451.8 (175)
	PER	668.5 (55)	768.3 (31)	1036.0 (89)	873.1 (175)
	improvement rate	40.0%	47.0%	51.9%	48.3%
T=78	TYM	414.8 (50)	396.2 (22)	527.8 (89)	474.7 (161)
	PER	777.2 (50)	677.1 (22)	1168.6 (89)	979.9 (161)
	improvement rate	46.6%	41.5%	54.8%	51.6%

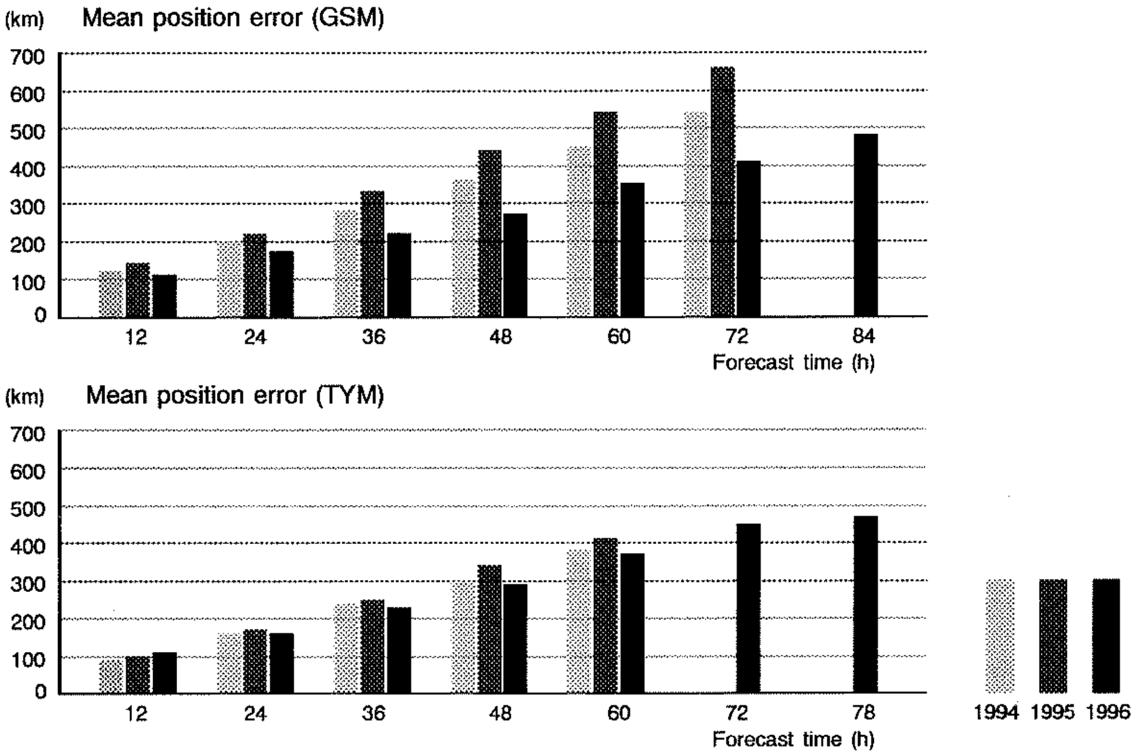


Figure 1 Annual mean position errors of GSM and TYM for three years from 1994 to 1996.

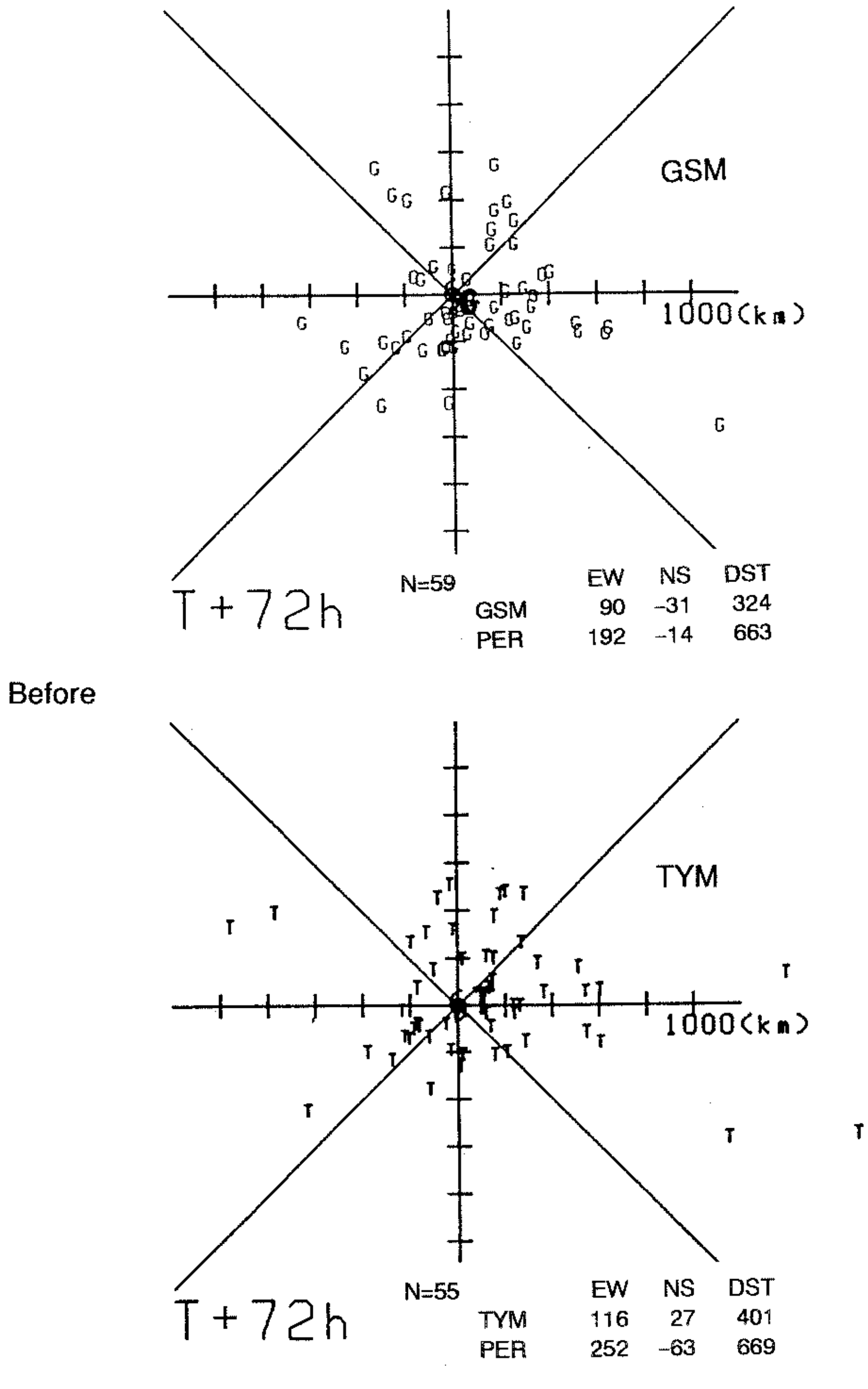
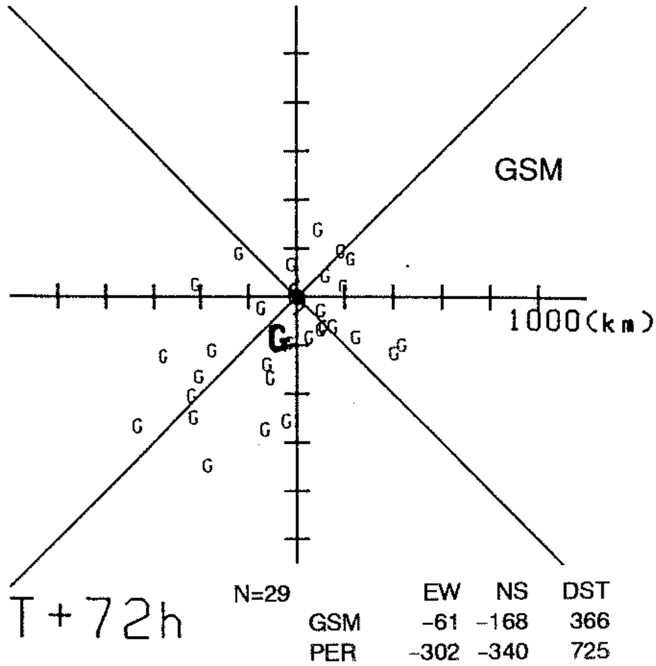


Figure 2(a) Scattering diagrams of center position errors of GSM (upper) and TYM (lower) at T+72h for typhoons in 1996 according to the stage "Before recurvature". Predicted typhoon centers are plotted with respect to corresponding analyzed ones at the origin. Deviations upward (downward, leftward, rightward) from the origin mean that the predicted typhoon center is located north (south, west, east) of the analyzed one. Large symbols show the mean (systematic) errors, which are specified in figures (unit: km) at the lower right of each panel. 'EW' denotes the mean error in the "Zonal" direction, 'NS' that in the "Meridional" direction, while 'DST' the mean distance error.



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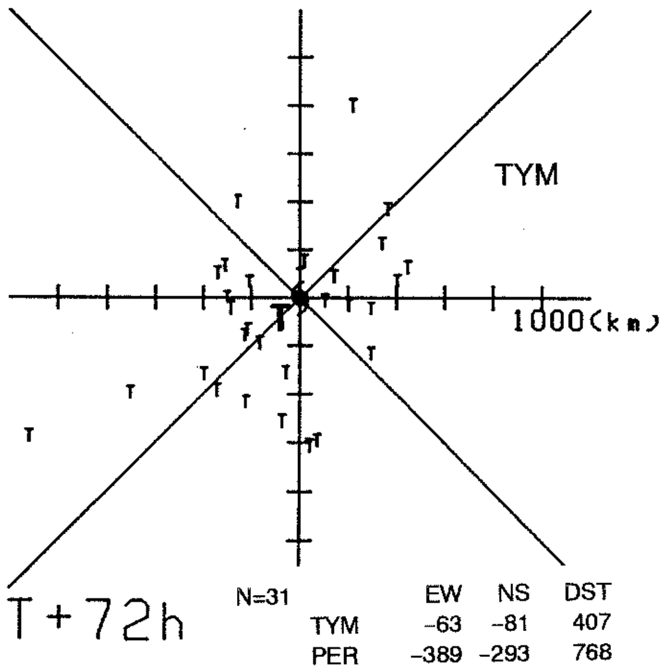
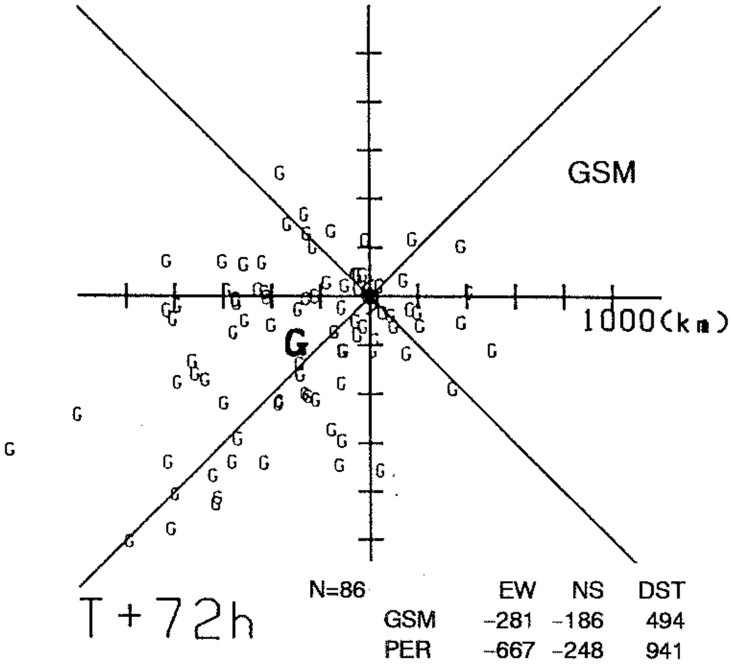


Figure 2(b) Same as in Figure 2(a) except for the stage "During recurvature".



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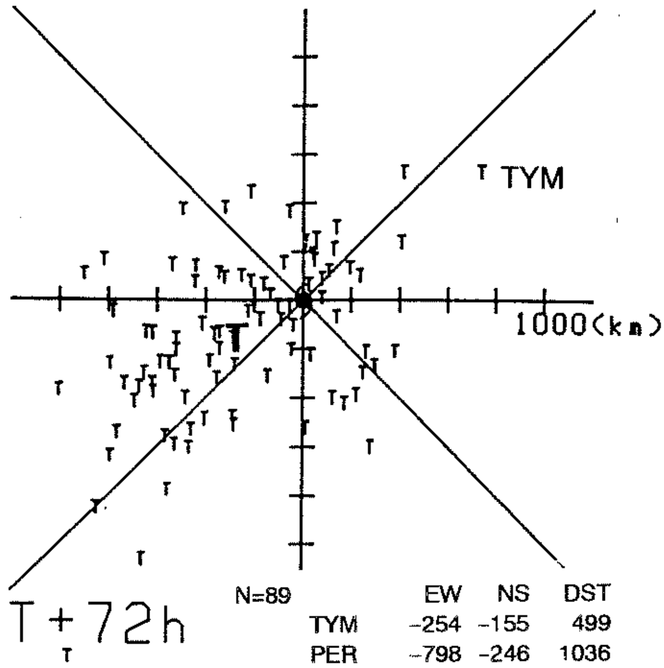


Figure 2(c) Same as in Figure 2(a) except for the stage "After recurvature".

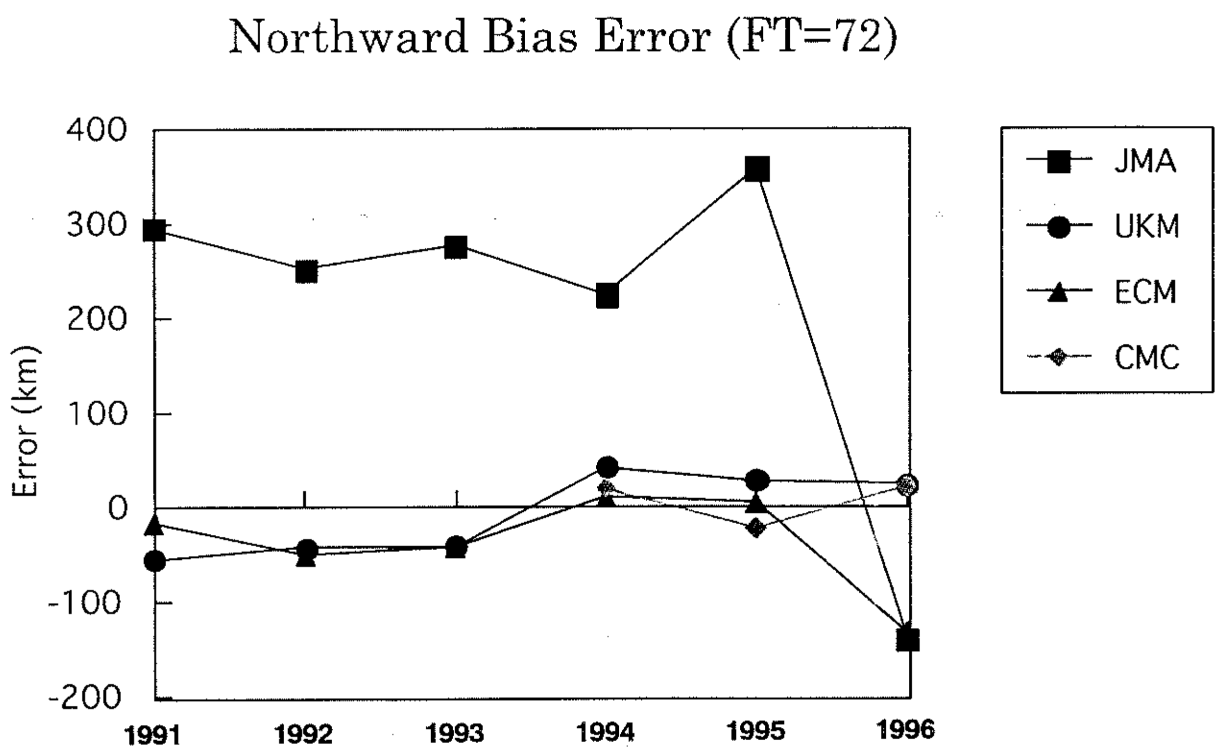


Figure 3 Year–to–year variation of northward drifting bias error of typhoon tracks at T+72h for GSM of JMA in comparison with those for global models at some major numerical weather prediction centers. Names of these centers are represented in abbreviatied forms in the figure; UKM: the United Kingdom Meteorological Office, ECM: the European Center for Medium–Range Weather Forecasts and CMC: the Canadian Meteorological Center.

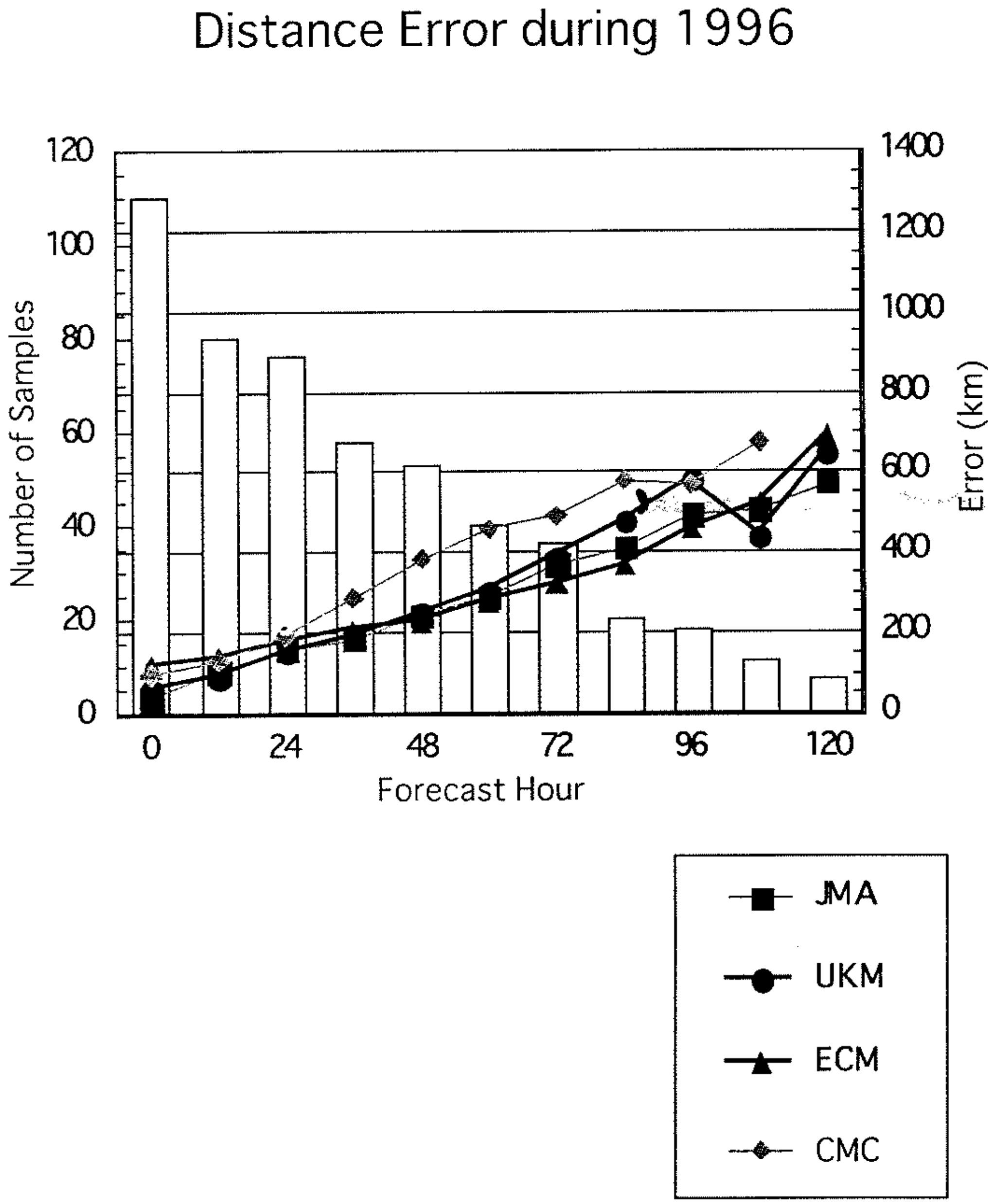


Figure 4 Mean position errors of typhoon tracks (scale on the right) for GSM of JMA and those for global models at some major numerical weather prediction centers. Numbers of homogeneous samples are also shown with shaded bars (scale on the left).

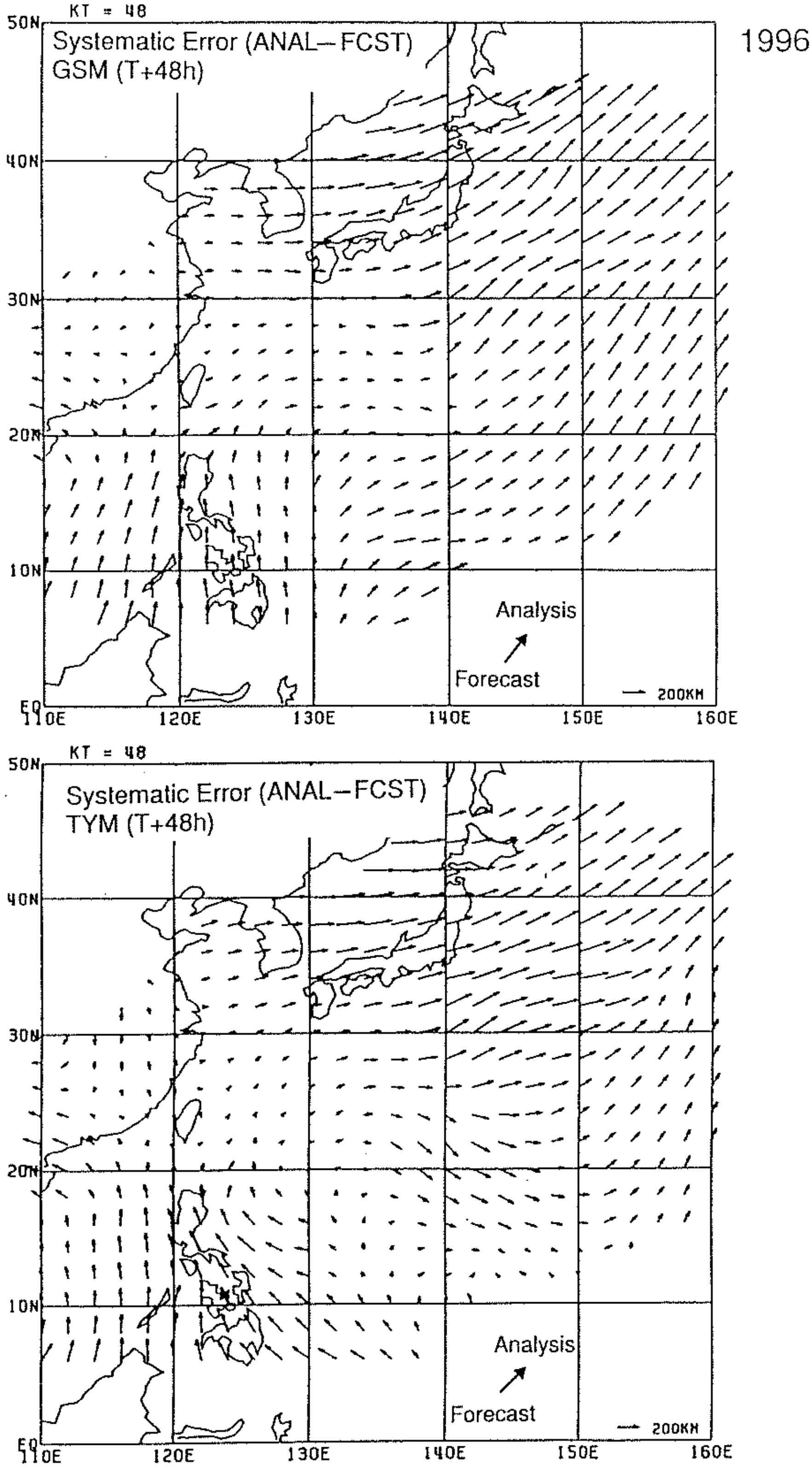
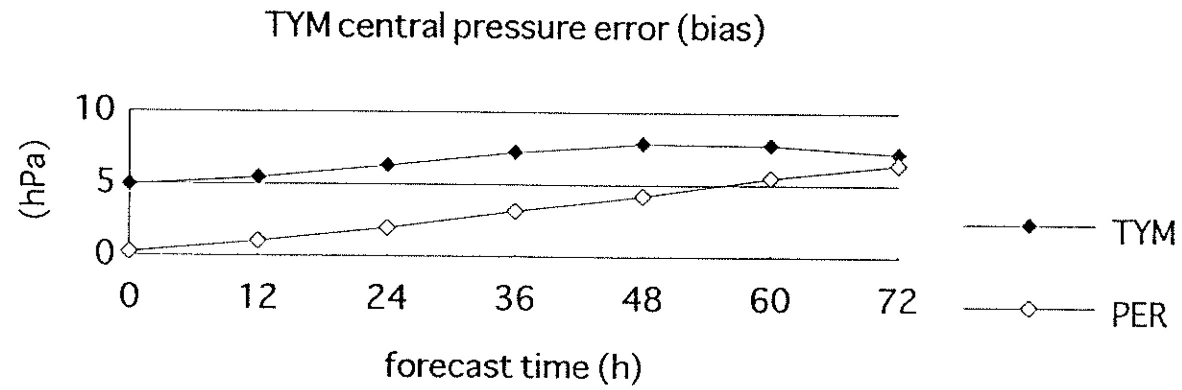


Figure 5 Distribution of systematic track error vectors (Analysis − Prediction) at T+48h for typhoons in 1996. Top panel for GSM and bottom one for TYM. Scale for vectors is shown in the down right corner in each panel. Systematic error (bias) vectors are calculated on a latitude−longitude grid with two−degree intervals.



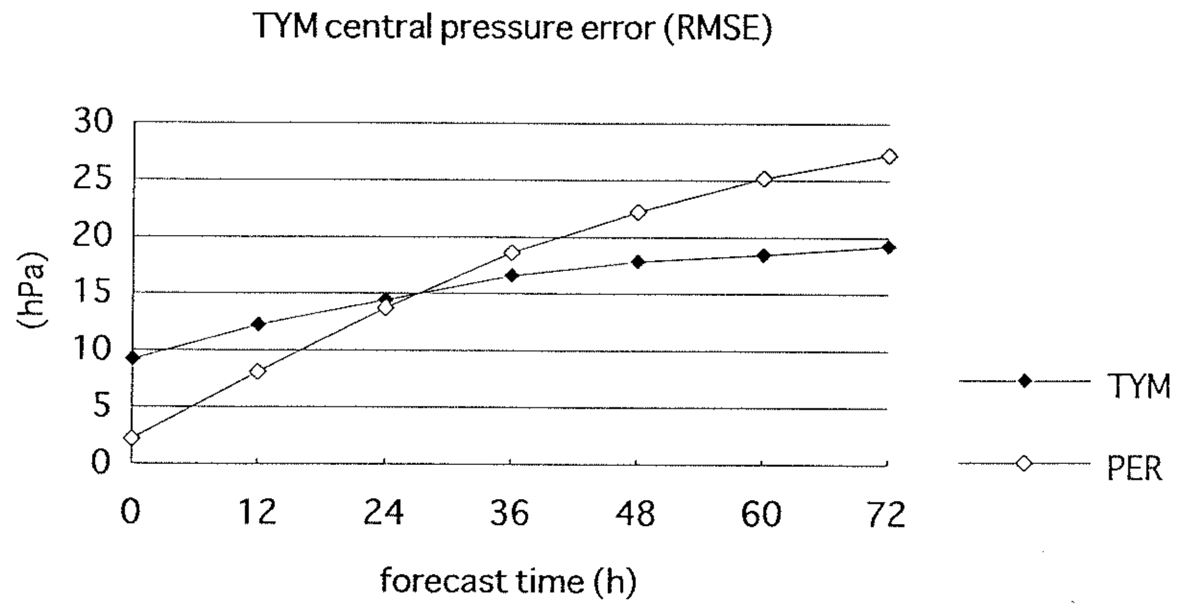


Figure 6 Central pressure errors of typhoons predicted by TYM in 1996. Top: bias error (hPa), bottom: root-mean-square error (hPa). Those by the persistency method are also shown.

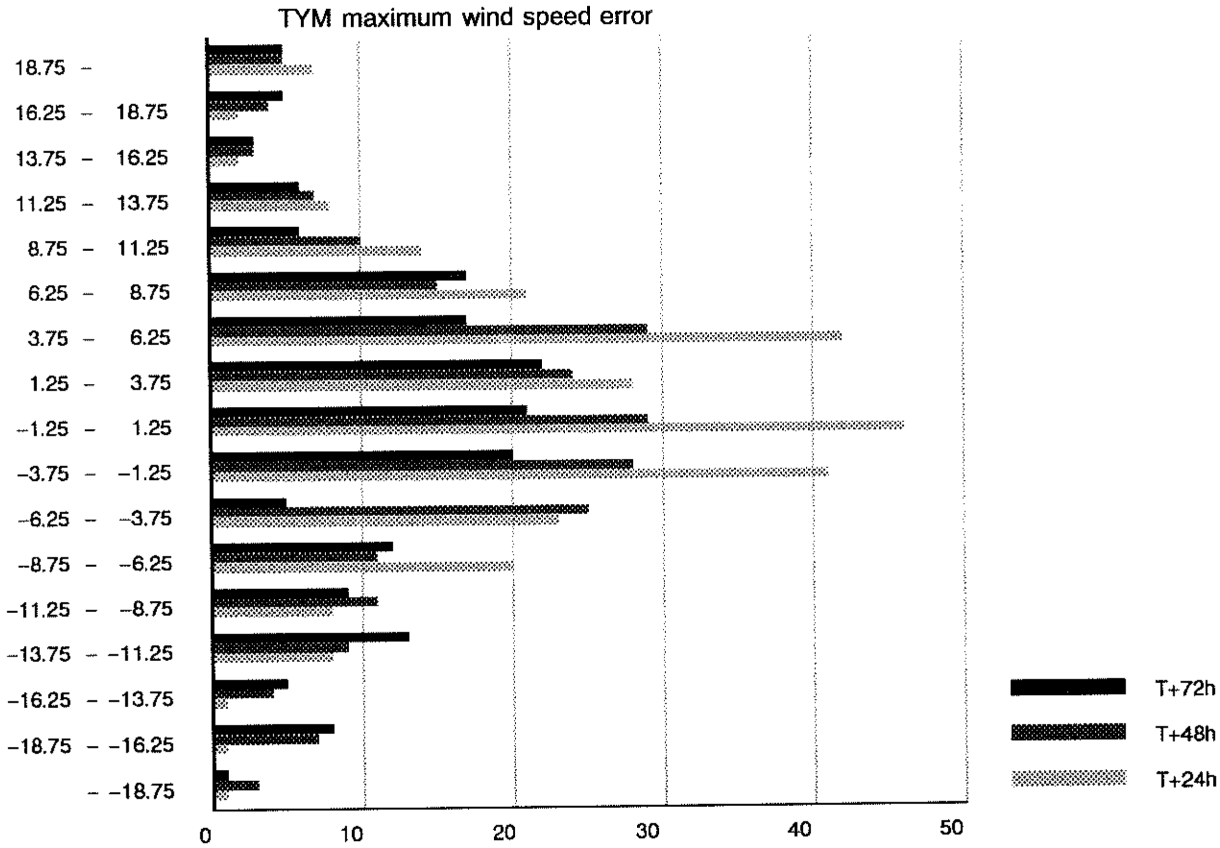


Figure 7 Histogram of errors of maximum wind speeds (m/s) of typhoons predicted by TYM in 1996 with 2.5 m/s windows.