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The Impact of the Termination of Aircraft Reconnaissance on Tropical Cyclone Warnings and Forecasts in the Western North Pacific

by

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Abstract

In August 1987, the reconnaissance mission into tropical cyclones over the western North Pacific was terminated. Since then, operational forecasting of these cyclones has been made without this piece of near-ground-truth information. This paper compares the warnings and forecasts made by two operational centres in this ocean basin prior to and after the termination of reconnaissance to determine its impact.

It is found that the initial position errors of both centres are larger in 1988 (when no reconnaissance information was available) than those in the period 1983-87 by about 30%, especially for weaker systems. Differences between warning positions issued by the two centres are also larger. Uncertainties in the warning positions have led to the 24-hour operational forecast errors for 1988 being larger than in previous years even after the 'forecast difficulty' of individual years has been taken into account. However, no impact is apparent for the 48- hour subjective forecasts although forecasts from a persistence-climatology type method are still affected. The effect of the lack of reconnaissance information is also apparently felt in the warning intensity as the warning intensity errors in 1988 are the highest within the entire data set for one of the centres.

1. Introduction

Since the late 1940s, the United States military had been responsible for sending reconnaissance planes into tropical cyclones over the western North Pacific (WNP). The main objective of such missions was to determine the location and intensity of these cyclones. However, the reconnaissance mission was terminated during August 1987. Since then, forecasters in the WNP region have been making tropical cyclone forecasts without this type of information. The consensus among operational forecasters is that the determination of the position and intensity of tropical cyclones has been more difficult without data from reconnaissance. If this is true, a larger variability in the initial position error[1] might result. Forecast errors of prediction methods which utilize persistence information might also be larger.

The first study to analyze the possible impact of the loss of aircraft reconnaissance was done by Martin (1988). He compared the initial position and forecast errors made by the Joint Typhoon Warning Center (JTWC) for cases with and without reconnaissance during the first 12 hours before warning time for the period 1980-1986. Results from his study suggest that reconnaissance information appeared to have helped the initial positioning

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[1]The initial position error is the magnitude of the vector difference between the warning and the best-track positions.

and intensity estimation. However, forecasts beyond 12 hours were, on the average, not significantly different between cases with and without reconnaissance except for recurving cyclones.

The present study represents an extension of that of Martin (1988) in the following respects. The analyses cover the period 1983-1988, the last year of which was completely devoid of reconnaissance information. This avoids the complication that reconnaissance data at some previous time might have influenced the forecasts (Martin (1988) combined cases with reconnaissance data more than 12 hours before warning time and those without any reconnaissance). In this study, only tropical cyclones within the Hong Kong Area of Responsibility (10-30°N, 105-125°E) are analyzed. Cyclones within this area are often affected by the terrain of Taiwan and the Philippines well before they make landfall (Brand and Blelloch, 1973, 1974; Chang, 1982; Bender *et al.*, 1987). Therefore, reconnaissance data may be more important in determining the short-term movement of the cyclone. On the other hand, ship and coastal radar reports are also more frequent in this region, which may reduce the forecaster's dependence on reconnaissance information. Comparisons are also made of the warning and forecast positions issued by the Royal Observatory (RO) and JTWC. Because each centre has a different set of objective techniques and prognostic products, how the forecasters assimilate the reconnaissance information into the overall forecast scheme may be different. This may result in a different impact when such information is not available.

This paper will present results of such a study with an overall objective of identifying the impact on the operational forecasts of tropical cyclone motion and intensity as a result of the termination of aircraft reconnaissance. Because such reconnaissance is not expected to be revived in the near future, how forecasters can make the best use of the currently-available information will also be discussed.

2. Data set

The warning and forecast positions consist of those issued by the RO and the JTWC (as received by the RO in real time) for tropical cyclones within the area bounded by (10°N, 105°E) and (30°N, 125°E) during 1983-88.

To compute the initial position and forecast errors, the best-track positions of the RO are used as the standard. To compare the errors made by the RO and the JTWC, a homogeneous data set is necessary. Therefore, unless otherwise stated, all comparisons are made using a data set which consists of warning or forecast positions issued by both centres.

3. Initial position errors

The initial position (IP) errors made by the two centres are shown in Fig. 1 with the values listed in Table 1. The most obvious result is that the IP errors in 1988 for both centres are larger than those in all the previous years in the data set.[2] In some cases, the differences are very large. For example, the IP errors made by both centres in 1988 are about twice those in 1987. For the period 1983-86 (during which reconnaissance data were available), the weighted mean IP errors of RO and JTWC are 33.6

[2]Note that the reason for the JTWC errors to be usually larger than those of the RO is probably that the IP errors are determined based on the RO best-track.

and 45.8 km respectively, which are only about two- thirds of those in 1988. These results appear to confirm the feeling among operational forecasters that the determination of the warning position has been more difficult without reconnaissance information.

Because some of the warning positions between 1983 and 1987 were also issued without any reconnaissance information, it may be more meaningful to compare the IP errors in 1988 with only those cases in these other years in which reconnaissance data were available. To do this, a method similar to that used by Martin (1988) was adopted. That is, the warning positions between 1983 and 1987 are divided into three groups: (a) those in which reconnaissance data were available within 6 hours before the warning time (D < 6), (b) those in which these data were available within 6 to 12 hours (D < 12) and (c) the rest of the data sample. Comparisons are then made between the IP errors among groups (a), (b) and the average for all cases in 1983-87 with those in 1988 for different intensity categories (Table 2).

The most notable result in the comparison is that the IP errors in 1988 of both centres for all intensity categories (except for the STS category of RO) are larger than those in previous years in which reconnaissance data were available within 12 hours of warning time. The difference is the largest for tropical depressions (TD) and tropical storms (TS). This result therefore suggests that without reconnaissance data, the operational estimate of the position is much more difficult especially for weaker systems.

Another observation from Table 2 is that when reconnaissance was available, the IP errors of both centres decrease with the intensity of the cyclone (except for tropical depressions). However, this decrease only occurs in 1988 between the TS and severe tropical storm (STS) categories. A possible reason why the IP errors for tropical depressions are smaller is that estimates of the best-track positions at this stage are often based on the warning positions as not much other information is usually available even during post-analysis.

It is also interesting to note that when reconnaissance information was available within 6 hours before warning time, the IP errors of both centres are comparable (other than the TD category). However, these errors differ more when reconnaissance data were only available within 6 to 12 hours. In 1988 when no reconnaissance information was available, differences in the IP errors between the two centres are quite large even for the two most intense categories of cyclones (STS and T). This suggests that by relying almost entirely on satellite or synoptic information, forecasters from different centres can have very different ideas on where the cyclone might be.

4. Forecast errors

Because the RO does not issue 72-hour forecasts, only the 24- and 48-hour forecasts of the two centres are compared. In addition, a climatology-persistence forecast computed by the RO is also included for comparison. This method averages the predictions made using the persistence and climatology methods and is therefore known as (P+C)/2. Neumann (1981) suggested that forecasts from this type of technique can be used as a baseline to evaluate the performance of other forecast methods and as an indication of the difficulty of the forecasts in a particular year. Because this technique depends on persistence, the presence or absence of reconnaissance data may also affect the performance of this technique.

a. 24-hour forecast errors

The 24-hour forecast errors of the two centres and the (P+C)/2 method are shown in Table 3. Notice that the errors of (P+C)/2 appear to go through a two-year cycle. Applying the concept of forecast difficulty of Neumann (1981), 1988 could be considered as a more difficult year. Though the error of 232 km in 1988 is higher by about 10% than the average for the period 1983-86 (216 km) during which reconnaissance information was available, it is comparable with those of the other two "difficult" years of 1984 and 1986. If this two-year cycle is genuine, it appears that the lack of reconnaissance data in 1988 did not have an adverse effect on the performance of the (P+C)/2 method in its 24-hour forecasts. This may partly be due to the compensatory effect of the climatology forecasts in the (P+C)/2 method.

The mean 24-hour forecast errors in 1988 for both centres are also the highest within the data set, with that of JTWC having the largest value. If these errors are plotted relative to those of (P+C)/2 (Fig. 2), it can be seen that the JTWC performance is the worst in 1988, suggesting that the lack of reconnaissance information had a significant impact on the 24-hour forecasts of the JTWC. On the other hand, the RO forecasts in this year is comparable to those of (P+C)/2. Although 1988 can be considered as a difficult year, the RO forecasts in the past two "difficult years" (1984 and 1986) were both lower than those of (P+C)/2. Therefore, the relatively poor RO performance cannot be attributed to forecast difficulty alone. Rather, the uncertainty in the warning positions due to the lack of reconnaissance information must have had a contribution.

As in the last section, comparisons between the two centres can also be made for different intensity categories and using only cases in which reconnaissance information was available. The results in Table 4 show that, on the average, for all tropical cyclones during 1983-87 for which reconnaissance data were available within 12 hours, the 24- hour forecasts of the two centres and the (P+C)/2 method are lower than the corresponding forecasts for 1988. A similar observation can be made for tropical cyclones in different intensity categories with the exception of a few. Further, for severe tropical storms and typhoons, the subjective forecasts in 1988 are only comparable or worse than the (P+C)/2 forecasts but those in previous years are better especially for cyclones in the D < 6 category.

Differences in the 24-hour forecast errors between the two centres are also much smaller when reconnaissance data were available. In fact, even for typhoons, this difference in 1988 is 38 km compared with ~ 10 km for previous years with reconnaissance data.

These results are consistent with those for the IP errors in that uncertainty in the warning positions has led to erroneous estimate of the persistence component and thus the 24-hour forecasts. This is true even for the most intense systems.

b. 48-hour forecast errors

A similar two-year oscillation also occurs in the 48- hour (P+C)/2 forecast errors, with that in 1988 being the highest (Table 5). The error of 550 km is about 100 km greater than the mean of the errors during 1983-1986 (448 km). This is at least partly related to the uncertainty in the persistence component due to the lack of reconnaissance information. However, because of the small number of cases in 1988, such a conclusion should be considered only as preliminary.

The 48-hour forecast errors of the RO is again the highest in 1988 while that of the JTWC is the second highest within the data set. However,

relative to (P+C)/2, they actually decrease compared with 1987 with the JTWC having the lowest relative error within the data set (Fig. 3). Two possible reasons may account for this result. Because the (P+C)/2 forecast errors in 1988 are higher, any increase in the absolute errors of the two centres will be reduced when compared with this method. It is also possible that persistence does not play a very significant role in the subjective forecasts at 48 hours so that uncertainties in the warning positions do not have a large impact on these forecasts, at least on the average. More data are necessary to determine which of these two reasons is correct.

If the forecasts are categorized by the intensity and availability of reconnaissance data, the number of cases in each category for 1988 is very small (between 1 and 14) which makes the sample not representative. Therefore, these results will not be shown.

In any case, it appears that the termination of reconnaissance has an impact on the (P+C)/2 forecasts even at 48 hours. However, forecasters in both centres seem to be utilizing other information such as synoptic data and prognoses in making predictions for this time period so that persistence may not play as an important role as the 24-hour forecast.

5. Warning intensity errors

Besides the determination of the centre of a tropical cyclone, the reconnaissance mission would also provide an estimate of the intensity of the cyclone. Without this information, such an estimate will be based almost exclusively on satellite analysis using, for example, the Dvorak (1975, 1984) technique. Martin (1988) has shown that satellite analysts analyzing the same picture could come up with very different estimates of the intensity. Therefore, the warning intensity could differ from the best-track estimate by a significant amount.

To study this, the absolute differences between the warning intensities issued by the two centres and the best- track estimate of intensity made by the RO are computed. It can be seen from Fig. 4 (values listed in Table 6) that, for the RO, these differences (warning intensity (WI) errors) in 1988 are higher than those in almost all the previous years, though not by a very large amount. However, the WI errors of the JTWC in 1988 are smaller than those in two previous years (1985 and 1987).

A further analysis of the WI errors can be made by categorizing the sample according to the best-track intensity. Because the WI given by JTWC is a one-minute average while that of RO is a ten-minute average, this analysis is only done using the RO data. The results (Table 7) suggest that the WI errors are the largest in 1988 for all classes of tropical cyclones except typhoons. This means that because of the lack of reconnaissance information, estimates of the intensity of weaker cyclones have become less accurate. For more intense systems, the convective features are usually better defined on satellite imageries and hence the reconnaissance reports of the intensity are less critical.

6. Summary and discussion

Because of the termination of reconnaissance missions, forecasters in the western North Pacific had to rely mostly on satellite analyses in issuing warnings and forecasts of tropical cyclones in 1988. Comparisons of the warning and forecast errors during this year and those of previous years show a definite impact of the termination of the reconnaissance mission. Specifically, the uncertainty of the warning positions increased by > 30 %

compared with previous years. Such an increase in uncertainty occurs regardless of the intensity of the tropical cyclone, and especially so for tropical depressions and tropical storms. With no reconnaissance as "ground truth", differences between warning positions issued by the Royal Observatory and those by the Joint Typhoon Warning Center are larger in 1988 compared with those differences in previous years. Because of the increase in the uncertainty in determining the warning positions, the 24-hour forecast errors have also increased for both subjective and objective methods. The *impact on the forecast errors extends to the persistence-climatology type* technique but apparently not as much to the subjective forecasts.

Without reconnaissance information, estimates of the intensity of tropical cyclones in 1988 had to rely almost exclusively on the analysis of satellite imageries. This large subjectivity led to a decrease in the accuracy of the warning intensities compared with previous years.

While these results are only valid for a small area of the western North Pacific, they do highlight the impact of the lack of reconnaissance information and substantiate the findings of Martin (1988). Other types of information available within the area of the present study such as synoptic and radar observations and ship reports do not appear to be able to take the place of reconnaissance data. To substantiate these results further, the warnings and forecasts for the entire ocean basin should be analyzed. Such an analysis can even be considered as a routine in future years to determine if forecasters have adapted to this new situation of operating without reconnaissance data.

As the reconnaissance mission is not expected to be revived in the near future, these results suggest that operational centres should now devote more attention to the development of techniques to improve the estimate of the warning position of tropical cyclones as well as their intensities. With no reason to expect an increase in land- based observations or ship reports, these techniques will almost have to be based exclusively on satellite analyses. As Chan and Holland (1989) have suggested, researchers in satellite applications for tropical cyclone forecasting should also concentrate their effort in this area in order to help the forecasting community. Only through the cooperation between these two groups can an improvement in tropical cyclone warning and forecasting result.

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Table 1. Initial position errors (km) of the RO and the JTWC. σ = standard deviation.

	YEAR					
	1983	1984	1985	1986	1987	1988
No. of cases	124	174	159	218	149	121
RO						
error	30.4	39.7	23.9	37.6	23.3	45.0
σ	28.5	43.5	28.7	44.0	22.6	42.9
JTWC						
error	36.2	61.9	41.4	41.7	34.3	62.2
σ	31.4	66.4	54.0	44.8	33.4	54.0

Table 2. Average initial position errors (km) made by RO and JTWC during 1988 and 1983-87 categorized by availability of reconnaissance data and best-track intensity.
D < 6 = data available within 6 hours before warning time, D < 12 = data available within 6 to 12 hours before warning time. The group '1983-87 Average' includes all the available data for these years.
TD = tropical depression, TS = tropical storm, STS = severe tropical storm, T = typhoon; N = number of cases, σ = standard deviation.

Legend:

No. of cases (N)	
RO error	JTWC error
RO σ	JTWC σ

Data Group	INTENSITY CATEGORY TD		TS		STS		T		Total	
D < 6	N=9		N=47		N=51		N=89		N=196	
	48.5	59.4	53.2	48.6	28.6	27.2	19.3	17.1	31.2	29.2
	43.4	70.5	60.9	40.6	21.9	22.5	14.6	9.0	37.3	31.5
D < 12	N=9		N=24		N=27		N=47		N=107	
	46.2	52.7	50.0	65.8	29.2	36.9	23.6	27.2	32.8	40.4
	40.1	27.2	35.6	34.8	24.1	19.6	15.6	18.9	28.2	28.7
1983-87 Average	N=106		N=224		N=189		N=305		N=824	
	41.1	77.3	48.8	62.0	27.5	35.2	18.6	22.5	31.7	43.2
	40.8	70.1	51.7	57.1	26.3	25.3	14.4	15.8	36.5	46.6
1988	N=18		N=31		N=35		N=37		N=121	
	64.5	110.1	66.5	68.9	25.8	47.3	35.7	47.4	45.0	62.2
	39.4	72.7	47.3	42.3	23.3	31.3	43.3	54.5	42.9	54.0

Table 3. 24-hour forecast errors (km) of the (P+C)/2 method, the RO and the JTWC. σ = standard deviation.

	YEAR					
	1983	1984	1985	1986	1987	1988
No. of cases	87	128	116	174	116	71
(P+C)/2						
error	171	238	189	239	192	232
σ	135	145	92	154	132	143
RO						
error	199	213	170	213	200	231
σ	123	116	83	148	110	133
JTWC						
error	159	211	194	209	197	254
σ	96	127	109	152	93	138

Table 4. 24-hour forecast errors (km) made by the (P+C)/2 method, the RO and the JTWC during 1988 and 1983-87 categorized by availability of reconnaissance data and best-track intensity.
D < 6 = data available within 6 hours before warning time, D < 12 = data available within 6 to 12 hours before warning time. The group '1983-87 Average' includes all the available data for these years.
TD = tropical depression, TS = tropical storm, STS = severe tropical storm, T = typhoon; N = number of cases, σ = standard deviation.

Legend:

No. of cases (N)	
RO error	RO σ
JTWC error	JTWC σ
(P+C)/2 error	(P+C)/2 σ

	INTENSITY CATEGORY									
Data Group	TD		TS		STS		T		Total	
D < 6	N=7		N=34		N=47		N=74		N=162	
	318	151	248	115	199	91	185	98	208	108
	289	123	212	135	179	88	174	99	188	109
	395	189	234	109	229	132	206	102	227	124
D < 12	N=8		N=15		N=23		N=39		N=85	
	209	82	283	144	196	156	179	152	205	151
	312	110	302	204	175	118	191	156	217	162
	251	135	289	183	215	140	194	127	222	147
1983-87 Average	N=67		N=139		N=154		N=261		N=621	
	226	111	237	132	189	121	182	113	201	122
	251	129	221	149	184	112	179	106	197	124
	232	165	233	141	219	145	190	121	211	138
1988	N=10		N=11		N=21		N=29		N=71	
	278	142	301	168	147	108	250	97	231	133
	310	152	354	120	232	122	212	125	254	134
	287	147	243	144	185	137	243	135	232	143

Table 5. 48-hour forecast errors (km) of all the four operational centres and the (P+C)/2 method. σ = standard deviation, r = range of the largest 10% of the errors in units of σ.

	YEAR					
	1983	1984	1985	1986	1987	1988
No. of cases	38	77	62	129	73	25
(P+C)/2						
error	308	477	400	495	306	550
σ	282	285	176	324	170	321
RO						
error	418	421	329	449	354	501
σ	234	260	168	314	204	236
JTWC						
error	366	392	335	496	342	446
σ	220	271	241	394	153	337

Table 6. Warning intensity errors (kt) of the RO and the JTWC. σ = standard deviation.

	YEAR					
	1983	1984	1985	1986	1987	1988
No. of cases	124	174	159	218	149	121
RO						
error	4.8	3.9	4.5	3.3	4.3	5.2
σ	7.4	5.3	6.2	4.2	4.6	5.0
JTWC						
error	7.2	5.7	8.0	5.9	8.5	7.5
σ	6.9	5.7	7.0	4.9	8.4	8.1

Table 7. Warning intensity errors (kt) of RO for individual years categorized by best-track intensity.
TD = tropical depression, TS = tropical storm, STS = severe tropical storm, T = typhoon; N = number of cases, σ = standard deviation.

	INTENSITY CATEGORY				
Year	TD	TS	STS	T	Total
1983	N=18	N=34	N=35	N=37	N=124
error	1.8	3.6	4.9	7.3	4.8
σ	2.3	4.0	6.2	10.6	7.4
1984	N=27	N=53	N=62	N=32	N=174
error	1.4	3.1	3.1	8.8	3.9
σ	2.2	3.9	4.9	6.8	5.3
1985	N=30	N=31	N=36	N=62	N=159
error	0.8	5.2	4.2	6.0	4.5
σ	1.9	4.5	4.5	8.1	6.2
1986	N=13	N=85	N=31	N=89	N=218
error	1.6	2.3	5.1	3.8	3.3
σ	2.0	3.4	4.8	4.4	4.2
1987	N=18	N=21	N=25	N=85	N=149
error	1.5	4.2	4.2	5.0	4.3
σ	2.5	2.8	3.7	5.2	4.6
1988	N=18	N=31	N=35	N=37	N=121
error	3.5	6.5	5.9	4.7	5.2
σ	3.4	5.2	4.3	5.7	5.0

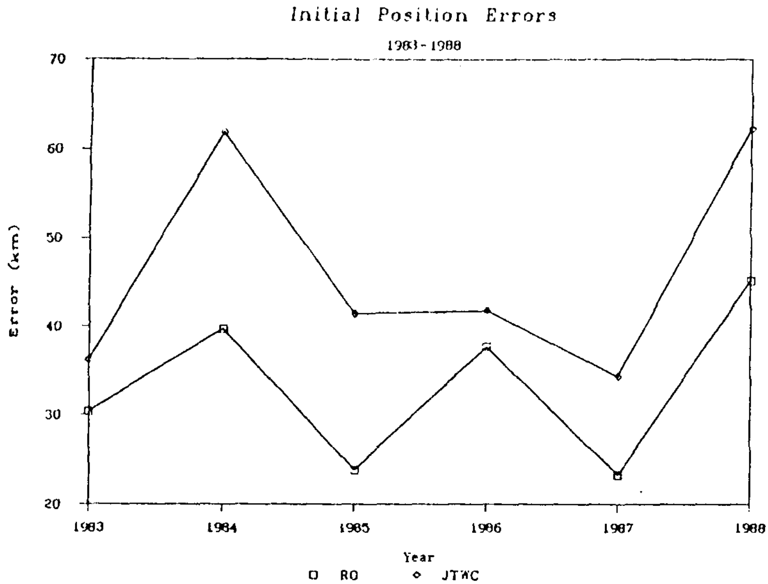

Fig. 1. Initial position errors of the RO and the JTWC for the years 1983-88.

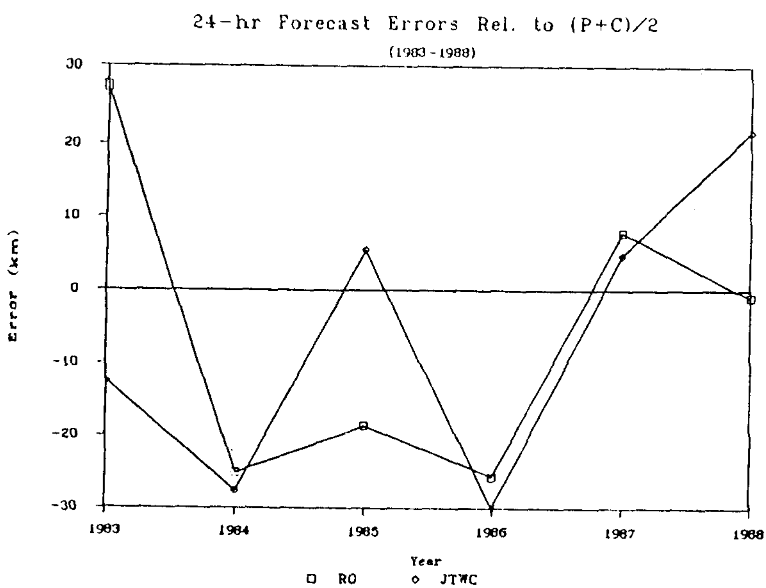

Fig. 2. 24-hour forecast errors of the RO and the JTWC relative to those of the (P+C)/2 method for the years 1983-88. A positive (negative) value means that the forecast is worse (better) than that of the (P+C)/2 method.

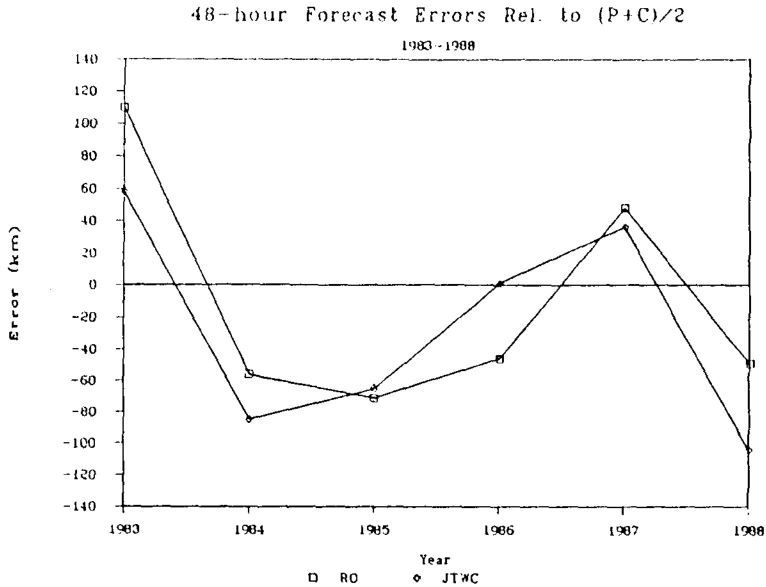

Fig. 3. 48-hour forecast errors of the RO and the JTWC relative to those of the (P+C)/2 method for the years 1983-88. A positive (negative) value means that the forecast is worse (better) than that of the (P+C)/2 method.

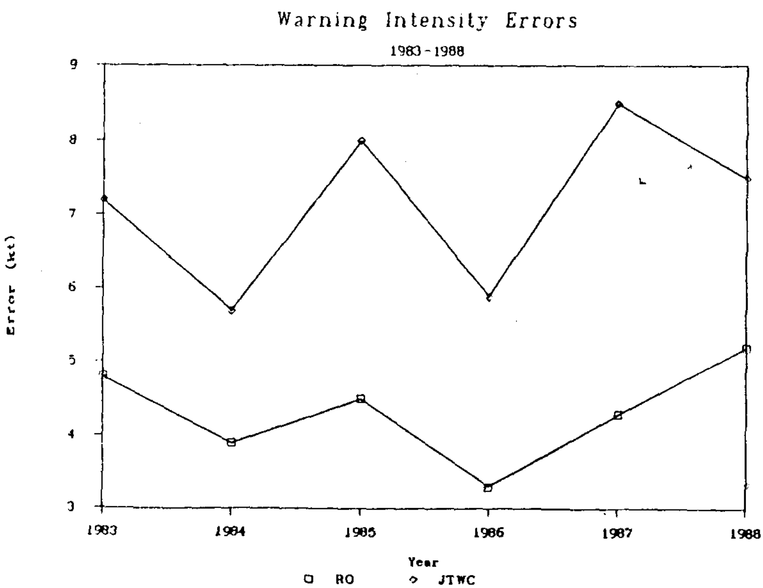

Fig. 4. Warning intensity errors of the RO and JTWC for the years 1983-88.