Influence of Synoptic Track Aircraft Reconnaissance on JTWC Tropical Cyclone Track Forecast Errors

DANIEL N. SHOEMAKER, WILLIAM M. GRAY, AND JOHN D. SHEAFFER

Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado

(Manuscript received 27 September 1989, in final form 22 May 1990)

ABSTRACT

This report examines the impact of synoptic reconnaissance by United States Air Force aircraft on the accuracy of tropical cyclone motion forecasts. Synoptic reconnaissance missions were requested for the purpose of collecting data on atmospheric conditions in proximity to developed cyclones at levels and locations which were assumed to govern the future motion of each storm. The results presented here suggest that synoptic reconnaissance data contributed to improved JTWC motion forecasts. Data include results for cyclone-motion forecasts aided by 63 synoptic missions in the western North Pacific during the 1983–86 seasons. Position errors were analyzed for approximately 200 motion forecasts for 24-, 48-, and 72-h movements following the synoptic missions as well as for forecast errors for predictions without synoptic reconnaissance data. Inspection of the storm tracks for which synoptic missions were flown indicated that the reconnaissance-assisted forecasts were for forecasting situations which were typically as difficult as those which occurred for the average forecast.

1. Introduction

Although aircraft reconnaissance of tropical cyclones by the US Air Force (USAF) has now been phased out in the Northwest Pacific Region, the value of reconnaissance flights for improved warnings and forecasts in other cyclone basins still needs to be addressed. Prior to termination of the northwest Pacific program, three types of reconnaissance had been supported including:

1) investigative flights into tropical disturbances with characteristics indicative of likely development into tropical storms;
2) position (fix) missions into developed storms to obtain detailed meteorological data and precise measurements of storm positions; and
3) synoptic missions to gather data on mid-tropospheric conditions along tracks spanning the principal regional synoptic features likely to influence the movements of developed storms.

Data from these reconnaissance missions have been used extensively in research on the development and motion of tropical cyclones (see Weatherford and Gray 1988a, 1988b). Results presented by Martin (1988) indicated that longer range (72-h) forecast errors in the West Pacific were only slightly improved with data from position-fix aircraft reconnaissance. However, until now there has been no quantitative assessment of the effects of data gathered in synoptic reconnaissance missions on the accuracy of typhoon motion forecasts by the Joint Typhoon Warning Center (JTWC).

2. Data

Synoptic reconnaissance missions were usually requested whenever forecasters at JTWC believed an ambiguous or otherwise difficult forecast situation was developing. During the more active portions of the typhoon season one or more synoptic missions might occur daily, contingent on conditions and the availability of aircraft and personnel. For the purposes of this study, flight time data for the initiation and completion of reconnaissance missions were taken directly from the standard forms used in flight by the aerial reconnaissance weather officers. Verification of forecast errors was made using data tabulated in the Annual Tropical Cyclone Reports, published by JTWC. The present study encompasses the years 1983–86 (the last four years of the program) for which 63 synoptic missions were available.

Synoptic flights were flown near the subtropical ridge, typically 5°–10° north of the storm center, as shown in Fig. 1. These missions were generally oriented in an east-west direction at the 400-mb level and might occasionally include a leg directed southwestward, ahead of the anticipated storm track. Observations were taken at flight level every 111 km [60 nautical miles (nm)] including air temperature, dew point, winds, height of standard pressure surface, clouds and weather and atmospheric phenomena near the aircraft. Drop-

Corresponding author address: William M. Gray, Department of Atmospheric Science, Colorado State University, Fort Collins, CO 80523.

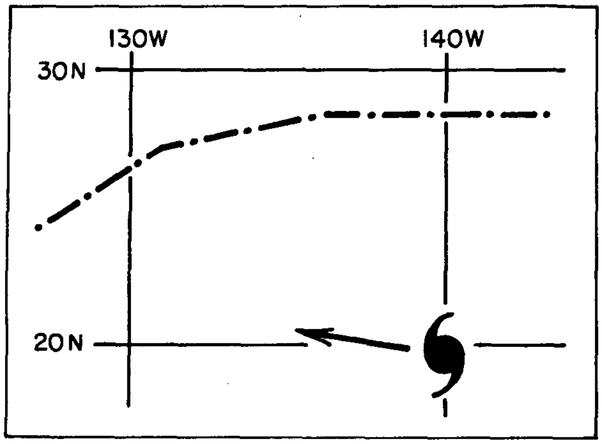


FIG. 1. Illustration of typical reconnaissance mission (dot-dash line) in relation to current storm position (spiral arms) in the western North Pacific. Flights were at 400 mb and observations were made every 111 km.

sonde profiles of temperature, moisture, and sea-level pressure were taken every 741 km (400 nm).

In-flight measurements of wind and pressure height provided an indication of the strength of the subtropical ridge and of the penetration of midlatitude troughs into the subtropics. Weakening of the ridge or the approach of a trough were possible signs of impending recurvature and forecasts would be adjusted accordingly. Aircraft observations of wind and thickness were immediately transmitted to JTWC where they were analyzed in conjunction with other synoptic and storm data. These data were also relayed to the global weather networks for inclusion in modeling and analyses.

A typical illustration of how data from synoptic missions were employed to improve forecasting is provided in the discussion of Tropical Storm Ellis (JTWC 1986). JTWC prepares forecasts based on several factors including the most recent official forecasts, observed motions, current analyses and new forecasts generated by a variety of forecasting aids (see JTWC 1984). Usually, an obvious consensus is derived from these sources and the official JTWC forecast is issued. However, inconsistent features in the objective analysis of mid-tropospheric wind fields near Ellis provided by the Fleet Numerical Oceanographic Center suggested possible misanalysis. The objective analysis indicated weak ridging northeast of Ellis and, consequently, continued west-northwest motion under the ridge had been forecast. A synoptic reconnaissance mission was requested because of the uncertainty regarding the analysis. Observations from the synoptic mission revealed rather strong northerly flow at the 400-mb level in the region northwest of Ellis. Shortly thereafter the storm turned toward the south-southwest (as forecast) and began to weaken in response to this northerly flow. Regional numerical analyses issued the following day were revised considerably, reflecting the northerly flow conditions observed by the synoptic mission. Without the observations from the synoptic flight, continued west-northwest (rather than southwest) storm motion would have been forecast.

The following analysis is intended to assess to what extent forecasts of tropical cyclone movements over 24, 48, and 72 hours were improved when observations from synoptic missions were available. To do so, all JTWC track forecast errors for all forecasts which were made within 6, 12, 18 and 24 hours following a synoptic mission were analyzed. These errors were then compared with the average errors for all tropical cyclone motion forecasts, made both with and without the benefit of data from a recent (within the prior 24 hours) synoptic mission.

3. Results

Comparative error values for JTWC cyclone track forecasts during the period 1983–86, including forecasts made both with and without synoptic reconnaissance data, are summarized in Table 1. Values are given for average and standard errors for all JTWC 24-, 48-, and 72-h forecasts which were subsequently verified (i.e. cyclone did not dissipate prior to forecast validation time) during this period. An average 24-h forecast error of 222 km is observed for the forecasts made without synoptic reconnaissance. This value decreased to 200 km for the cases wherein synoptic missions had been flown (i.e. observations completed) within 24 hours prior to the time that the forecast was issued, hence a 10% smaller mean 24-h forecast error for the 245 verified forecasts made with synoptic reconnaissance data. The average errors for reconnaissance aided forecasts for 48- and 72-h motions are smaller than for the no-reconnaissance by factors of 17% and 20%, respectively.

TABLE 1. Comparisons of average and standard errors (in km) for cyclone track forecasts made with and without synoptic aircraft reconnaissance data. The ratio of mean and standard errors (with/without) are also shown. (Number of forecasts verified for each case is shown in parenthesis).

1983–1986	24-h error (no. cases)	48-h error (no. cases)	72-h error (no. cases)
With reconnaissance			
Mean error	200 (245)	387 (229)	588 (196)
Standard error	130	267	453
Without reconnaissance			
Mean error	222 (1716)	468 (1291)	731 (924)
Standard error	151	307	455
All forecasts			
Mean error	218 (1961)	455 (1520)	705 (1120)
Standard error	148	301	454
Error ratios (with/without)			
Mean errors	0.90	0.83	0.80
Standard errors	0.86	0.87	1.00

Although the relative accuracy of the reconnaissance aided forecasts, expressed as an average error, improves in relation to the no-reconnaissance forecasts at 48 and 72 hours, the difference in the standard errors becomes smaller at the longer forecast times. In fact, for 72-hour forecasts, the standard errors are essentially identical. These diverging trends in the relative size of mean versus standard errors with increasing forecast lead time have two implications: First, for 24- and 48-h forecasts, the synoptic reconnaissance observations may have contributed to error reductions, both for the relatively small errors which occur for well behaved storms as well as for the occasional very large errors which mostly affect the standard error values. Second, whereas the incidence of large forecast errors at 72 hours is unaffected by synoptic reconnaissance data, the average 72-h track forecast for the majority of the storms (which tend to be reasonably well behaved) is improved.

In view of this apparent success, it is important to examine the comparative level of difficulty for the two sets of forecasts to determine if the difference in these forecast errors might in fact be attributable to some element of systematic selectivity. Considerations include the possibility that synoptic missions may tend to occur for storms at lower latitudes where simple persistence of motion is very common or at more westerly longitudes where known climatological tracks tend to be good forecasts. Because of these considerations, forecast errors are known to be smaller in both areas. Jarrell et al. (1978) examined Northwest Pacific forecast-error data from 1966 to 1975 and determined average forecast cyclone track errors as a function of latitude and longitude. Unfortunately, Jarrell et al. did not simultaneously stratify by both longitude and latitude, a consideration which would have allowed the creation of a grid of expected forecast errors by storm position. Nevertheless, Jarrell's spatial stratifications were used to independently assess the latitudinal and longitudinal dependence of forecast difficulty. To determine if the result of Jarrell et al. might still be valid, their average error data for 1966–75 were compared to average forecast errors for the 1976–87 period and also, to errors for the 1983–86 period, examined in this study. These results, presented in Table 2, show no evidence of a large change in forecast accuracy over this time interval and imply that Jarrell's findings are probably applicable to the problem at hand.

TABLE 2. Average JTWC cyclone track forecast errors (in km) for three recent time periods.

	Forecast errors		
Years	24-h	48-h	72-h
1966–75	233	457	683
1976–87	224	446	674
1983–86	218	455	705

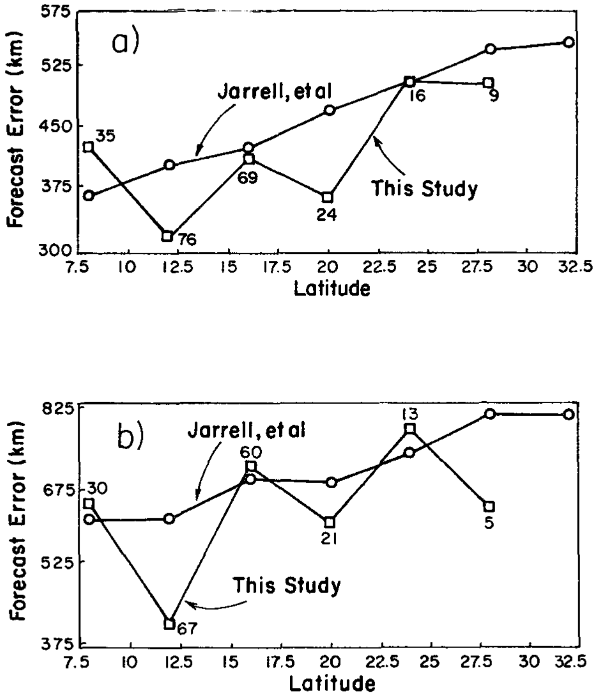
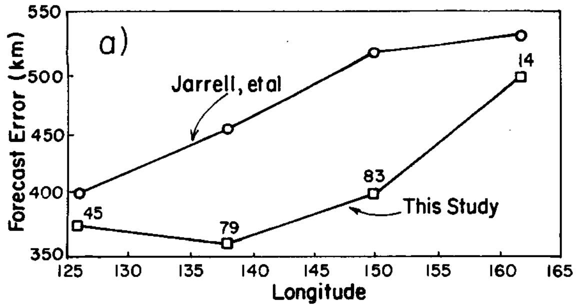


FIG. 2. a) Variation of 48-h cyclone track forecast errors as a function of lat. Observations are centered on 2.5°-lat. intervals beginning at 7.5°N. Open circles represent values obtained by Jarrell et al. (1978) and squares represent JTWC forecasts made using synoptic reconnaissance data. The numbers adjacent to the squares indicate the number of forecasts represented by each square. b) As in 2a except for 72-h forecasts.

Spatially stratified data for cyclone track forecasts which were made with synoptic reconnaissance data, shown in comparison with Jarrell et al.'s results in Figs. 2 and 3, indicate that the synoptic missions may have contributed to an overall reduction in forecast errors for almost all latitude or longitude stratifications. Storm tracks for the 30 cyclones on which the 63 synoptic missions were flown included 8 straight runners, and 16 recurvers. Six other storms classified as miscellaneous included two pairs of cyclones which were undergoing binary interaction with each other. This set of storm tracks appears to be fairly representative of Northwest Pacific storm tracks in general and is not biased toward simple forecasts.

A comparison of track forecast errors made using two operational forecast aids provides additional evidence of the level of forecast difficulty for the synoptic mission storms. The specific forecast aids used for this test are termed CLIPER (Neumann and Pelissier 1981), for climatology and persistence (but which also includes current intensity and past movement) and HPAC (JTWC 1984) for half persistence and (half) climatology. Because of their simplicity, CLIPER and HPAC are routinely included in formulating storm track forecasts and provide an assessment of both skill and forecast difficulty. These two aids typically incur



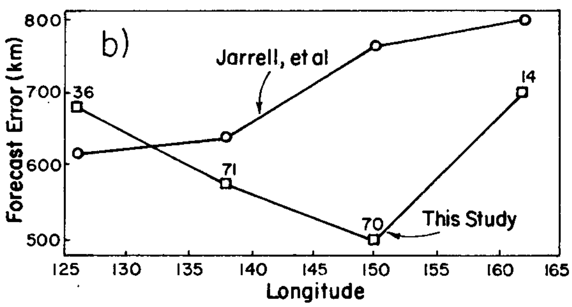


FIG. 3. a,b) As in Fig. 2a,b but where forecasts are stratified by longitude. Observations are centered on 12° long. intervals spanning 126°–162°E.

relatively small errors when past storm motion persists or follows climatological tracks. However, when storm motions deviate significantly from simple climatology or persistence, these aids do poorly and the storm track may be considered a more difficult forecast situation.

Because neither CLIPER or HPAC can use the types of data obtained by synoptic missions, the comparative accuracy of their forecasts provides an objective and independent comparison of the relative difficulty of the forecast situations for which synoptic mission data were collected. Results in Tables 3 and 4 summarize comparative forecast errors obtained for the with and without synoptic reconnaissance cases using these two aids. Note in Table 4 that, for five of the six comparative error values, the storm track errors for CLIPER and HPAC were larger for storms where synoptic missions were flown, indicating that the reconnaissance cases tended to be more difficult forecast situations.

TABLE 4. Percentage increase (positive values) of forecast errors by CLIPER and HPAC for forecast situations wherein synoptic reconnaissance missions were flow. Because CLIPER and HPAC do not use synoptic reconnaissance data in making cyclone motion forecasts, the increased error values by these aids for the synoptic mission storms suggests that, as a group, these forecast situations were at least as difficult to forecast as the average motion forecast situation.

	Increase of forecast errors (%)		
	24 h	48 h	72 h
CLIPER	4	13	9
HPAC	−3	9	8

Another illustration of the possible contribution of synoptic reconnaissance to more accurate forecasts can be observed in the relative accuracy of reconnaissance-assisted JTWC forecasts over routine CLIPER and HPAC forecasts. As shown in Table 5, the accuracy of the official JTWC forecasts in relation to these two aids was appreciably better, especially for the 48- and 72-h forecasts, when a synoptic mission was flown within 24 hours prior to the forecasts. Although the values given in Table 5 cannot be regarded as definitive measures of enhanced skill, they show that JTWC forecast errors were consistently small relative to errors for these two aids when synoptic reconnaissance data were available.

4. Summary

Large average forecast errors still occur at JTWC, especially for 48- and 72-h forecasts. Unfortunately, the apparent benefits of the now discontinued synoptic missions, though encouraging, are not likely to be realized. When synoptic reconnaissance data were available, average track forecast errors for 24- to 72-h time periods were found to be approximately 10%–20% smaller, respectively, relative to forecasts for which reconnaissance data were not available. In addition, the incidence of large forecast errors was smaller for 24- and 48-h reconnaissance aided forecasts. The results also suggest that the synoptic reconnaissance aided forecasts were made for forecast situations which were at least as complex as those for which reconnaissance

TABLE 3. Average track forecast errors (km) for CLIPER and HPAC for all forecasts and for forecast situations when synoptic reconnaissance missions were flown. The number of forecasts for each group is shown in parentheses.

	Mean errors for all forecasts, 1983–86			Mean forecast errors for synoptic track situations		
	24 h (1961)	48 h (1520)	72 h (1120)	24 h (245)	48 h (229)	72 h (196)
CLIPER	229	477	724	238	538	788
HPAC	227	453	648	220	494	700

TABLE 5. Comparative accuracy (percent) of JTWC forecasts in relation to forecasts by CLIPER and HPAC, for forecasts made both with and without synoptic reconnaissance data. Positive values occur for situations wherein the mean JTWC official forecast errors were smaller than the mean errors for the forecast aids.

	Comparative accuracy (%)					
	Without synoptic track 1983–86			With synoptic track		
	24 h	48 h	72 h	24 h	48 h	72 h
CLIPER	3	0	−3	19	39	34
HPAC	3	−5	−13	10	28	19

missions were not flown. Because average motion forecast errors for reconnaissance aided forecasts were consistently smaller, it is our opinion that the loss of aircraft reconnaissance in the Western Pacific has diminished the potential for improved long-range cyclone motion forecasts in the immediate future.

Acknowledgments. The authors are most grateful to Dr. Ted Tsui of the Naval Environmental Prediction Research Facility, who provided statistical data on forecast aid performance. Financial support for this research was received from the USAF Geophysical Laboratory, Cambridge, Massachusetts and the Marine Meteorology Section of the Office of Naval Research. Three anonymous reviewers provided useful comments for clarifying both text and figures.

REFERENCES

Jarrell, J. D., S. Brand and D. S. Nicklin, 1978: An analysis of western north Pacific tropical cyclone forecast errors. *Mon. Wea. Rev.*, **106**, 925–937.

Joint Typhoon Warning Center, 1970–1987: Annual tropical cyclone reports 1970–1986. US Naval Oceanography Command Center, Joint Typhoon Warning Center, COMNAVMARIANAS Box 17, FPO San Francisco, California.

Martin, J. D., 1988: Tropical cyclone observation and forecasting with and without aircraft reconnaissance. Dept. of Atmos. Sci. Paper No. 428, Colo. State Univ., Fort Collins, Colorado.

Neumann, C. J., and J. M. Pelissier, 1981: Models for prediction of tropical cyclone motion over the North Atlantic: an operational evaluation. *Mon. Wea. Rev.*, **109**, 522–538.

Weatherford, C., and W. M. Gray, 1988a: Typhoon structure as revealed by aircraft reconnaissance: Part I: Data analysis and climatology. *Mon. Wea. Rev.*, **116**, 1032–1043.

——, and ——, 1988b: Typhoon structure as revealed by aircraft reconnaissance: Part II: Structural variability. *Mon. Wea. Rev.*, **116**, 1044–1056.