5. SUMMARY OR FORECAST VERIFICATION

5.1 ANNUAL FORECAST VERIFICATION

Verification of warning positions and intensities at initial, 12-, 24-, 48- and 72-hour forecast periods was made against the final best track. The (scalar) track forecast, along-track and cross-track errors (illustrated in Figure 5-1) were calculated for each verifying JTWC forecast. These data, in addition to a detailed summary for each tropical cyclone, are included as Chapter 6. This section summarizes verification data for 1997 and contrasts it with annual verification statistics from previous years.

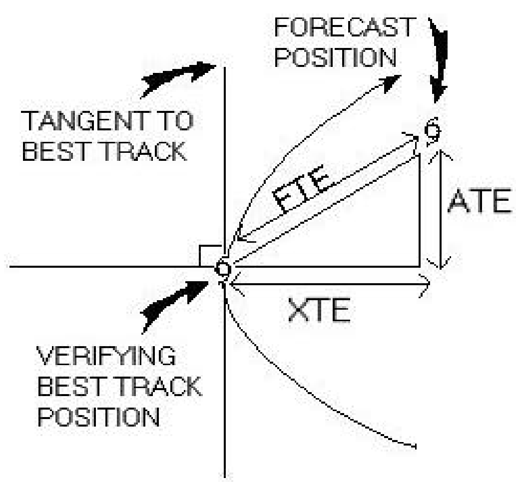

Figure 5-1 Definition of cross-track error (XTE), along-track error (ATE) and forecast track error (FTE). In this example, the forecast position is ahead of and to the right of the verifying best track position. Therefore, the XTE is positive (to the right of the best track) and the ATE is positive (ahead or faster than the best track). Adapted from Tsui and Miller, 1988.

5.1.1 NORTHWEST PACIFIC OCEAN The frequency distributions of errors for initial warning positions and 12-, 24-, 36-, 48- and 72-hour forecasts are presented in Figures 5-2a through 5-2f. Table 5-1 includes mean track, along-track and cross-track errors for 1983-1997. Figure 5-3 shows mean track errors and a 5-year running mean of track errors at 24-, 48- and 72-hours for the past 20 years. Table 5-2 lists annual mean track errors from 1959, when the JTWC was founded, until the present.

5.1.2 NORTH INDIAN OCEAN The frequency distributions of errors for warning positions and 12-, 24-, 36-, 48- and 72-hour forecasts are presented in Figures 5-4a through 5-4f, respectively. Table 5-3 includes mean track, along-track and cross-track errors for 1983-1997. Figure 5-5 shows mean track errors and a 5-year running mean of track errors at 24-, 48- and 72-hours for the past 20 years.

5.1.3 SOUTH PACIFIC AND SOUTH INDIAN OCEANS The frequency distributions of errors for warning positions and 12-, 24-, 36-, 48- and 72-hour forecasts are presented in Figures 5-6a through 5-6f, respectively. Table 5-4 includes mean track, along-track and cross-track errors for 1983-1997. Figure 5-7 shows mean track errors and a 5-year running mean of track errors at 24-, 48- and 72-hours for the 17 years that the JTWC has issued warnings in the region.

5.2 COMPARISON OF OBJECTIVE TECHNIQUES

JTWC uses a variety of objective techniques for guidance in the warning preparation process. Multiple techniques are required, because each technique has particular strengths and weaknesses which vary by basin, numerical model initialization, time of year, synoptic situation and forecast period. The accuracy of objective aid forecasts depends on both the specified position and the past motion of the tropical cyclone as determined by the working best track. JTWC initializes its objective techniques using an extrapolated working best track position so that the output of the techniques will start at the valid time of the next warning initial position.

Unless stated otherwise, all of the objective techniques discussed below run in all basins covered by JTWC's AOR and provide forecast positions at 12-, 24-, 36-, 48-, and 72-hours unless the technique aborts prematurely during computations. The techniques can be divided into six general categories: extrapolation, climatology and analogs, statistical, dynamic, hybrids, and empirical or analytical.

5.2.1 EXTRAPOLATION (XTRP) Past speed and direction are computed using the rhumb line distance between the current and 12 hour old positions of the tropical cyclone. Extrapolation from the current warning position is used to compute forecast positions.

5.2.2 CLIMATOLOGY and ANALOGS

5.2.2.1 CLIMATOLOGY (CLIM) Employs time and location windows relative to the current position of the tropical cyclone to determine which historical storms will be used to compute the forecast. The historical database is 1945-1981 for the Northwest Pacific, and 1900 to 1990 for the rest of JTWC's AOR. Objective intensity forecasts are available from these databases. Scatter diagrams of expected tropical cyclone motion at bifurcation points are also available from these databases.

5.2.2.2 ANALOG A revised Typhoon Analog 1993 (TYAN93) picks the top matches with the basin climatology of historical tropical cyclone best tracks. Matches are based upon the differences between the direction and speed of the superimposed historical best track positions and the past direction and speed of the cyclone. Specifically, the directions and speeds are calculated from the 12-hour old position to the current "fix" position and the 24-hr old position to the "fix" position. Separate comparisons are made for climatology cyclone tracks classified as "straight," "recurver" and "other". There is also a "total" group, that includes the top matches without regard to classification of tracks.

TYAN93 works in the same manner for all basins. The time-window is +/- 35 days from the "fix." The space-window is +/- 2.5 degrees latitude and +/- 5 degrees longitude from the "fix" position on the first pass of each forecast. The maximum-wind-speed window is as follows (for basins with climatology wind speeds): a. If "fix" wind speed is < 25 kt, (13 m/s) climatology cyclone wind speed must be < 30 kt. (15 m/s) b. If "fix" wind speed is 30 kt, (15 m/s) climatology cyclone wind speed must be in range from 25 to 35 kt. (13 to 17 m/s) c. If "fix" wind speed is > 35 kt (17 m/s), climatology cyclone wind speed must be at least 35 kt. (17 m/s). Matching is based upon weighted direction and speed errors. Forecasting is based upon "straight" and "recurver" type climatology tropical cyclones, where the 12-hour and 24-hour best "straight" ("recurver") matches are combined into one set of best matches for "straight" ("recurver").

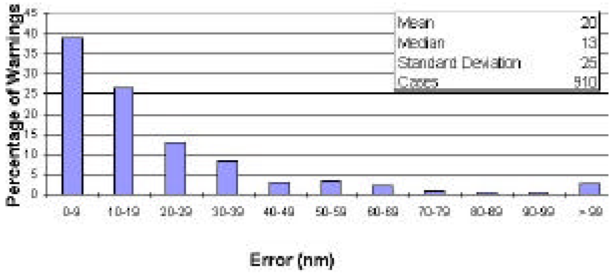

Figure 5-2a Frequency distribution of initial warning position errors (10-nm increments) for western North Pacific Ocean tropical cyclones in 1997. The largest error, 168 nm, occurred on Super Typhoon Keith (29W).

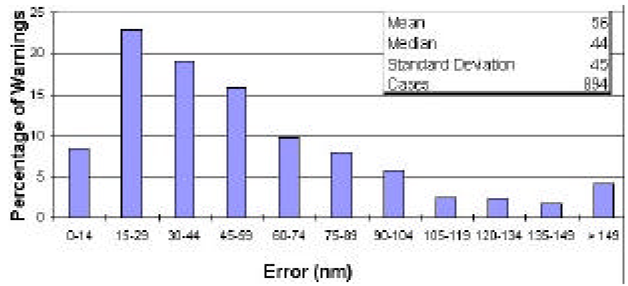

Figure 5-2b Frequency distribution of 12-hour track forecast errors (15-nm increments) for western North Pacific Ocean tropical cyclones in 1997. The largest error, 334 nm, occurred on Super Typhoon Keith (29W).

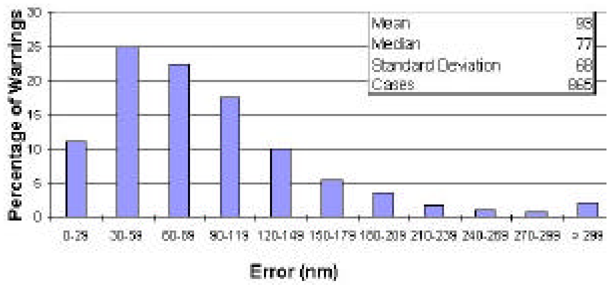

Figure 5-2c Frequency distribution of 24-hour track forecast errors for western North Pacific Ocean tropical cyclones in 1997. The largest error, 499 nm, occurred on Tropical Storm Levi (05W).

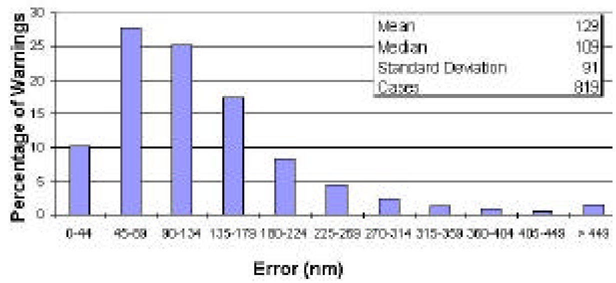

Figure 5-2d Frequency distribution of 36-hour track forecast errors for western North Pacific Ocean tropical cyclones in 1997. The largest error, 706 nm, occurred on Typhoon Linda (30W).

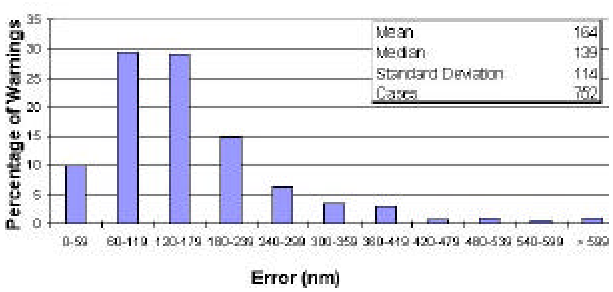

Figure 5-2e Frequency distribution of 48-hour track errors for western North Pacific Ocean tropical cyclones in 1997. The largest error, 891 nm, occurred on Tropical Storm Levi (05W).

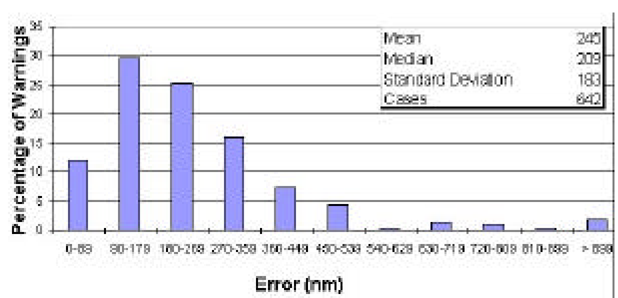

Figure 5-2f Frequency distribution of 72-hour track forecast errors for western North Pacific Ocean tropical cyclones in 1997. The largest error, 1382 nm, occurred on Super Typhoon Oliwa (02C).

5.2.3 STATISTICAL

5.2.3.1 CLIMATOLOGY AND PERSISTENCE (CLIPER or CLIP) A statistical regression technique that is based on climatology, current position and 12-hour and 24-hour past movement. This technique is used as a crude baseline against which to measure the forecast skill of other, more sophisticated techniques. CLIP in the western North Pacific uses third-order regression equations, and is based on the work of Xu and Neumann (1985). CLIPER has been available outside this basin since mid-1990, with regression coefficients recently recomputed by FNMOC based on the updated 1900-1989 database.

5.2.3.2 COLORADO STATE UNIVERSITY MODEL (CSUM) A statistical-dynamical technique based on the work of Matsumoto (1984). Predictor parameters include the current and 24-hr old position of the storm, heights from the current and 24-hr old NOGAPS 500-mb analyses, and heights from the 24-hr and 48-hr NOGAPS 500-mb prognoses. Height values from 200-mb fields are substituted for storms that have an intensity exceeding 90 kt (45 m/s) and are located north of the subtropical ridge. Three distinct sets of regression equations are used depending on whether the storm's direction of motion falls into "below," "on" or "above" the subtropical ridge categories. During the development of the regression equation coefficients for CSUM, the so-called "perfect prog" approach was used, in which verifying analyses were substituted for the numerical prognoses that are used when CSUM is run operationally. Thus, CSUM was not "tuned" to any particular version of NOGAPS, and in fact, the performance of CSUM should presumably improve as new versions of NOGAPS improve. CSUM runs only in the western North Pacific, South China Sea, and North Indian Ocean basins.

5.2.3.3 JTWC92 or JT92 JTWC92 is a statistical-dynamical model for the western North Pacific Ocean basin which forecasts tropical cyclone positions at 12-hour intervals to 72 hours. The model uses the deep-layer mean height field derived from the NOGAPS forecast fields. These deep-layer mean height fields are spectrally truncated to wave numbers 0 through 18 prior to use in JTWC92. Separate forecasts are made for each position. That is, the forecast 24-hour position is not a 12-hour forecast from the forecasted 12-hour position.

JTWC92 uses five internal sub-models which are blended and iterated to produce the final forecasts. The first sub-model is a statistical blend of climatology and persistence, known as CLIPER. The second sub-model is an analysis mode predictor, which only uses the "analysis" field. The third sub-model is the forecast mode predictor, which uses only the forecast fields. The fourth sub-model is a combination of 1 and 2 to produce a "first guess" of the 12-hourly forecast positions. The fifth sub-model uses the output of the "first guess" combined with 1, 2, and 3 to produce the forecasts. The iteration is accomplished by using the output of sub-model 5 as though it were the output from sub-model 4. The optimum number of iterations has been determined to be three.

When JTWC92 is used in the operational mode, all the NOGAPS fields are forecast fields. The 00Z and 12Z tropical forecasts are based upon the previous 12-hour old synoptic time NOGAPS forecasts. The 06Z and 18Z tropical forecasts are based on the previous 00Z and 12Z NOGAPS forecasts, respectively. Therefore, operationally, the second sub-model uses forecast fields and not analysis fields.

5.2.4 DYNAMIC

5.2.4.1 NOGAPS VORTEX TRACKING ROUTINE (NGPS/X) Tropical cyclone vortices are tracked at FNMOC by converting the 1000-mb u and v wind component fields into isogons. The intersection of isogons are either the center of a cyclonic or anticyclonic circulation, or a col. The tracking program starts at the last known location of the cyclone - a warning position. Based on this position and the last known speed and direction of movement, the program hunts for the next cyclonic center representing the tropical cyclone. Confidence factors are generated within the program and are modified, as required, by a quality control program that formats the data for transmission.

5.2.4.2 GEOPHYSICAL FLUID DYNAMICS MODEL - NAVY (GFDN) This model uses a triple nested movable mesh with 18 sigma levels. The outer mesh domain covers a 75°x75° area with a horizontal resolution of 1° and is fixed for the duration of the model run based on the initial location and movement of the tropical cyclone (TC). The 10°x10° middle and a 5°x5° inner (resolution 1/6°) nested meshes move with the cyclone. Based on the global analysis and an initialization message, the TC is removed from the global analysis, and replaced by a synthetic vortex which has an asymmetric (beta-advection) component added. Boundary conditions are updated periodically from forecast fields generated by a global forecast model. In addition to standard output fields, the model outputs TC track forecasts and maximum isotach swaths indicating the location of maximum winds in relation to the TC track.

5.2.4.3 ONE-WAY (INTERACTIVE) TROPICAL CYCLONE MODEL (OTCM) This technique is a coarse resolution (205-km grid), three layer, primitive equation model with a horizontal domain of 6400 x 4700 km. OTCM is initialized using 6-hour or 12-hour prognostic fields from the latest NOGAPS run, and the initial fields are smoothed and adjusted in the vicinity of the storm to induce a persistence bias into OTCM's forecast. A symmetric bogus vortex is then inserted, and the boundaries updated every 12 hours by NOGAPS fields as the integration proceeds. The bogus vortex is maintained against frictional dissipation by an analytical heating function. The forecast positions are based on the movement of the vortex in the lowest layer of the model (effectively 850-mb).

5.2.4.4 FNMOC BETA AND ADVECTION MODEL (FBAM) This model is an adaptation of the Beta and Advection model used by the National Center for Environmental Prediction (NCEP). The forecast motion results from a calculation of environmental steering and an empirical correction for the observed vector difference between that steering and the 12-hour old storm motion. The steering is computed from the NOGAPS Deep Layer Mean (DLM) wind fields which are a weighted average of the wind fields computed for the 1000-mb to 100-mb levels. The difference between past storm motion and the DLM steering is treated as if the storm were a Rossby wave with an "effective radius" propagating in response to the horizontal gradient of the coriolis parameter, beta. The forecast proceeds in one-hour steps, recomputing the effective radius as beta changes with storm latitude, and blending in a persistence bias for the first 12 hours.

5.2.5 HYBRIDS

5.2.5.1 HALF PERSISTENCE AND CLIM-ATOLOGY (HPAC) Forecast positions generated by equally weighting the forecasts given by XTRP and CLIM.

5.2.5.2 BLENDED (BLND) A simple average of JTWC's six primary forecast aids: OTCM, CSUM, FBAM, JT92, CLIP, and HPAC.

5.2.5.3 WEIGHTED (WGTD) A weighted average of the forecast guidance used to compute BLND: OTCM (29%), CSUM (22%), FBAM (14%), JT92 (14%), HPAC (14%), and CLIP (7%).

5.2.5.4 DYNAMIC AVERAGE (DAVE) A simple average of all dynamic forecast aids: NOGAPS (NGPS), Bracknell (EGRR), Japanese Typhoon Model (JTYM), JT92, FBAM, OTCM, and CSUM.

5.2.6 EMPIRICAL OR ANALYTICAL

5.2.6.1 DVORAK An estimation of a tropical cyclone's current and 24-hour forecast intensity is made from the interpretation of satellite imagery (Dvorak, 1984). These intensity estimates are used with other intensity related data and trends to forecast short-term tropical cyclone intensity.

5.2.6.2 MARTIN/HOLLAND The technique adapts an earlier work (Holland, 1980) and specifically addresses the need for realistic 35-, 50- and 100-kt (18-, 26- and 51-m/sec) wind radii around tropical cyclones. It solves equations for basic gradient wind relations within the tropical cyclone area, using input parameters obtained from enhanced infrared satellite imagery. The diagnosis also includes an asymmetric area of winds caused by tropical cyclone movement. Satellite-derived size and intensity parameters are also used to diagnose internal steering components of tropical cyclone motion known collectively as "beta-drift."

5.2.6.3 TYPHOON ACCELERATION PREDICTION TECHNIQUE (TAPT) — This technique (Weir, 1982) utilizes upper-tropospheric and surface wind fields to estimate acceleration associated with the tropical cyclone's interaction with the mid-latitude westerlies. It includes guidelines for the duration of acceleration, upper limits and probable path of the cyclone.

5.3 TESTING AND RESULTS

A comparison of selected techniques is included in Table 5-5 for all western North Pacific tropical cyclones, Table 5-6 for all North Indian Ocean tropical cyclones and Table 5-7 for the Southern Hemisphere. For example, in Table 5-5 for the 12-hour mean forecast error, 734 cases available for a homogeneous comparison, the average forecast error at 12 hours was 72 nm (133 km) for NGPS and 53 nm (98 km) for JTWC. The difference of 19 nm (35 km) is shown in the lower right. Differences are not always exact, due to computational round-off which occurs for each of the cases available for comparison.

Table 5-1 INITIAL POSITION AND FORECAST ERRORS (NM) FOR THE WESTERN NORTH PACIFIC FOR 1983-1997

	Initial Position		24-Hour				48-Hour				72-Hour			
	Num	Error	Num	Track	Along	Cross	Num	Track	Along	Cross	Num	Track	Along	Cross
1983	445	16	342	117	76	73	253	260	169	164	184	407	259	263
1984	611	22	492	117	84	64	378	232	163	131	286	363	238	216
1985	592	18	477	117	80	68	336	231	153	138	241	367	230	227
1986	743	21	645	126	85	70	535	261	183	151	412	394	276	227
1987	657	18	563	107	71	64	465	204	134	127	389	303	198	186
1988	465	23	373	114	85	58	262	216	170	103	183	315	244	159
1989	710	20	625	120	83	69	481	231	162	127	363	350	265	177
1990	794	21	658	103	72	60	525	203	148	110	432	310	225	168
1991	835	22	733	96	69	53	599	185	137	97	484	287	229	146
1992	941	25	841	107	77	59	687	205	143	116	568	305	210	172
1993	853	26	725	112	79	63	570	212	151	117	437	321	226	173
1994	1058	24	938	105	76	56	776	186	131	105	631	258	176	152
1995	599	29	539	123	89	67	421	215	159	117	319	325	240	167
1996	922	25	880	105	76	56	711	178	134	89	607	272	203	137
1997	910	20	865	93	76	55	752	164	134	87	642	245	202	120
15-Year Average 1983-1997	742	22	646	111	79	62	517	212	151	119	412	321	228	179

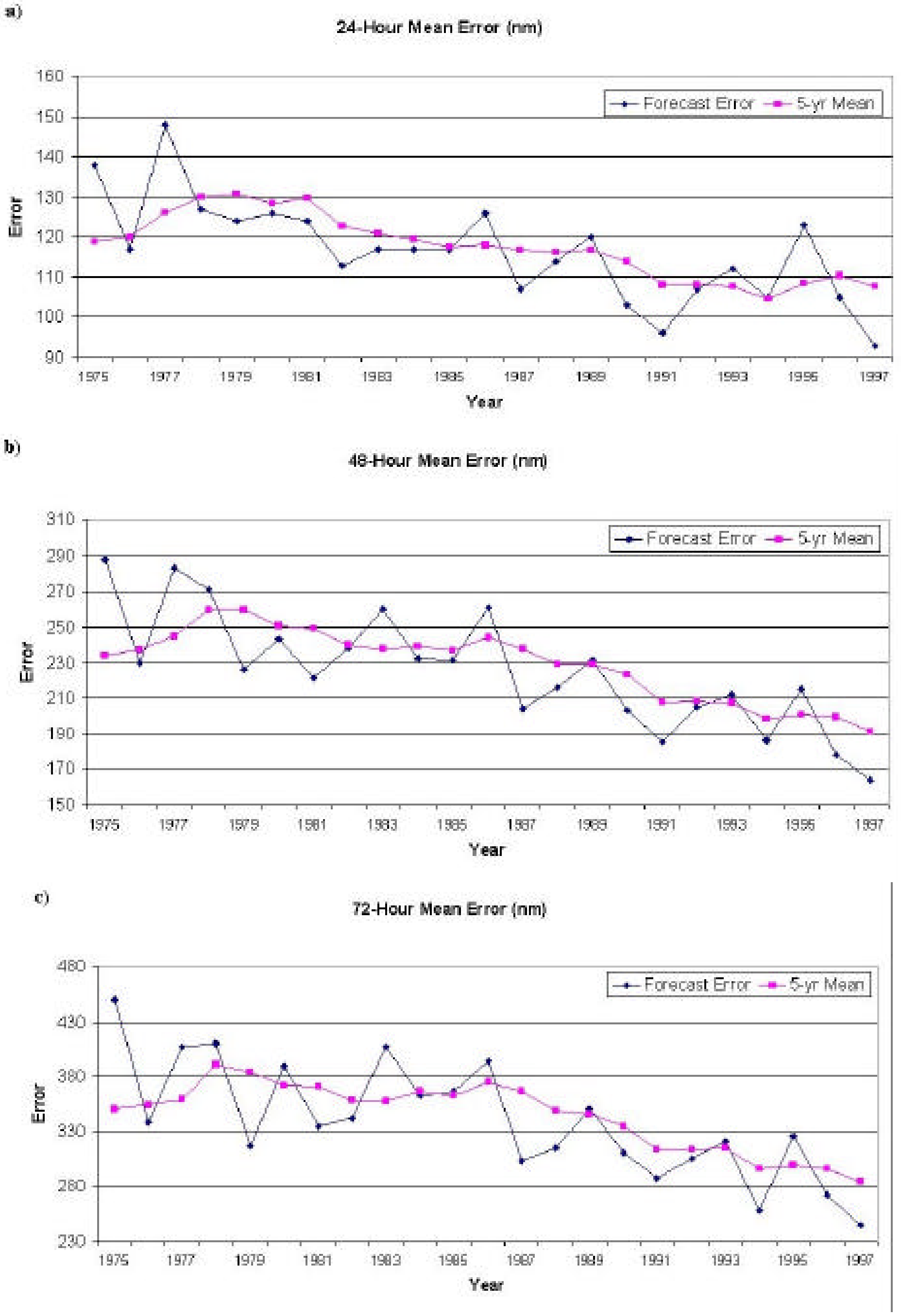

Figure 5-3 Mean track forecast error (nm) and 5-year running mean for a) 24 hours b) 48 hours and c) 72 hours for the western North Pacific Ocean tropical cyclones for the period 1975 to 1997.

Table 5-2 MEAN FORECAST TRACK ERRORS (NM) FOR WESTERN NORTH PACIFIC TROPICAL CYCLONES FOR 1959-1997

	24-HOUR				48-HOUR				72-HOUR			
YEAR	TY (1)	TC	CROSS TRACK (2)	ALONG TRACK (2)	TY (1)	TC	CROSS TRACK (2)	ALONG TRACK (2)	TY (1)	TC	CROSS TRACK (2)	ALONG TRACK (2)
1959	117*				267*							
1960	177*				354*							
1961	136				274							
1962	144				287				476			
1963	127				246				374			
1964	133				284				429			
1965	151				303				418			
1966	136				280				432			
1967	125				276				414			
1968	105				229				337			
1969	111				237				349			
1970	98	104			181	190			272	279		
1971	99	111	64		203	212	118		308	317	177	
1972	116	117	72		245	245	146		382	381	210	
1973	102	108	74		193	197	134		245	253	162	
1974	114	120	78		218	226	157		357	348	245	
1975	129	138	84		279	288	181		442	450	290	
1976	117	117	71		232	230	132		336	338	202	
1977	140	148	83		266	283	157		390	407	228	
1978	120	127	71	87	241	271	151	194	459	410	218	296
1979	113	124	76	81	219	226	138	146	319	316	182	214
1980	116	126	76	86	221	243	147	165	362	389	230	266
1981	117	124	77	80	215	221	131	146	342	334	219	206
1982	114	113	70	74	229	238	142	162	337	342	211	223
1983	110	117	73	76	247	260	164	169	384	407	263	259
1984	110	117	64	84	228	232	131	163	361	363	216	238
1985	112	117	68	80	228	231	138	153	355	367	227	230
1986	117	126	70	85	261	261	151	183	403	394	227	276
1987	101	107	64	71	211	204	127	134	318	303	186	198
1988	107	114	58	85	222	216	103	170	327	315	159	244
1989	107	120	69	83	214	231	127	162	325	350	177	265
1990	98	103	60	72	191	203	110	148	299	310	168	225
1991	93	96	53	69	187	185	97	137	298	287	146	229
1992	97	107	59	77	194	205	116	143	295	305	172	210
1993	102	112	63	79	205	212	117	151	320	321	173	226
1994**	96	105	56	76	172	186	105	131	244	258	152	176
1995	105	123	67	89	200	215	117	159	311	325	167	240
1996	85	105	56	76	157	178	89	134	252	272	137	203
1997	86	93	55	76	159	164	87	134	251	245	120	202

1. Forecasts were verified for typhoons when intensities were at least 35kt (18 m/sec).

2. Cross-track and along-track errors were adopted by the JTWC in 1986. Right angle errors (used prior to 1986) were recomputed as cross-track errors after-the fact to extend thedata base. See Figure 5-1 for the definitions of cross-track and along-track.

*Forecast positions north of 35 degrees north latitude were not verified.

**Statistics were recalculated to resolve earlier ALONG- and CROSS-Track discrepancies.

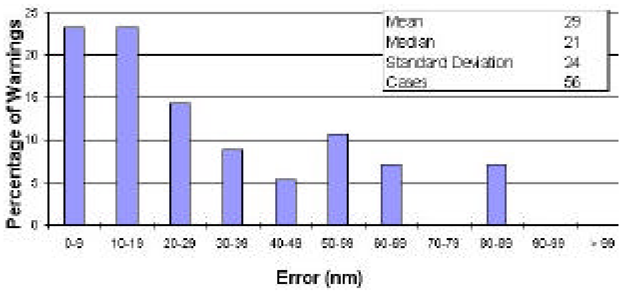

Figure 5-4a Frequency distribution of initial warning position errors (10-nm increments) for North Indian Ocean tropical cyclones in 1997. The largest error, 87 nm, occurred on Tropical Cyclone 02B.

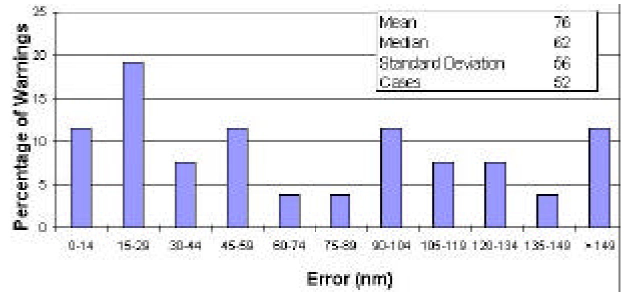

Figure 5-4b Frequency distribution of 12-hour track forecast errors (15-nm increments) for North Indian Ocean tropical cyclones in 1997. The largest error, 232 nm, occurred on Tropical Cyclone 01B.

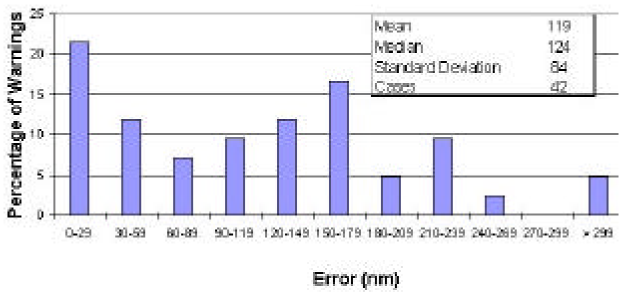

Figure 5-4c Frequency distribution of 24-hour track forecast errors for North Indian Ocean tropical cyclones in 1997. The largest error, 316 nm, occurred on Tropical Cyclone 01B.

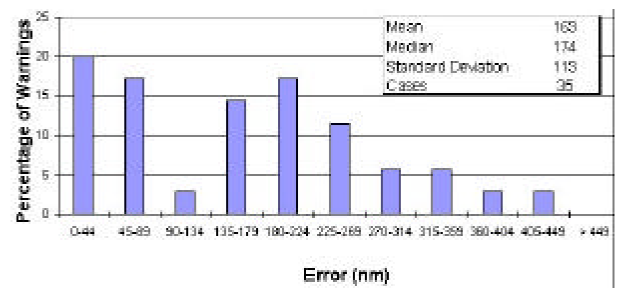

Figure 5-4d Frequency distribution of 36-hour track forecast errors for North Indian Ocean tropical cyclones in 1997. The largest error, 406 nm, occurred on Tropical Cyclone 02B.

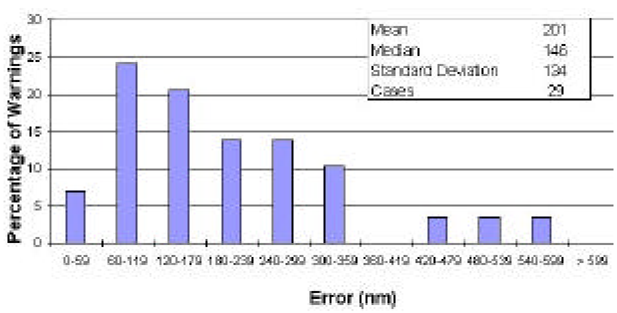

Figure 5-4e Frequency distribution of 48-hour track errors for North Indian Ocean tropical cyclones in 1997. The largest error, 541 nm, occurred on Typhoon Cyclone 02B.

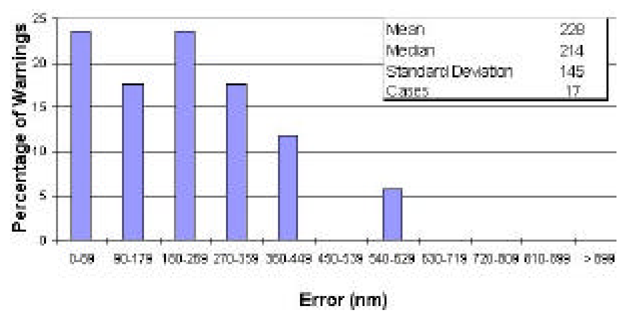

Figure 5-4f Frequency distribution of 72-hour track forecast errors for North Indian Ocean tropical cyclones in 1997. The largest error, 545 nm, occurred on Tropical Cyclone 02B.

Table 5-3 INITIAL POSITION AND FORECAST POSITION ERRORS (NM) FOR THE NORTH INDIAN OCEAN FOR 1983 - 1997

	Initial Position		24-Hour				48-Hour				72-Hour			
	Num	Error	Num	Track	Along	Cross	Num	Track	Along	Cross	Num	Track	Along	Cross
1983	18	38	7	117	90	50	18	153	137	53	0			
1984	67	33	42	154	124	67	20	274	217	139	16	338	339	121
1985	53	31	30	122	102	53	8	242	119	194	0			
1986	28	52	16	134	118	53	7	168	131	80	5	269	189	180
1987	83	42	54	144	97	100	25	205	125	140	21	305	219	188
1988	44	34	30	120	89	63	18	219	112	176	12	409	227	303
1989	44	19	33	88	62	50	17	146	94	86	12	216	164	111
1990	46	31	36	101	85	43	24	146	117	67	17	185	130	104
1991	56	38	43	129	107	54	27	235	200	89	14	450	356	178
1992	191	35	149	128	73	86	100	244	141	166	62	398	276	218
1993	36	27	28	125	87	79	20	198	171	74	12	231	176	116
1994	60	25	44	97	80	44	28	153	124	63	13	213	177	92
1995	54	30	47	138	119	58	32	262	247	77	20	342	304	109
1996	135	33	123	134	94	80	85	238	181	127	58	311	172	237
1997	56	29	42	119	87	49	29	201	168	92	17	228	195	110
15-YEAR AVERAGE														
1983-1997	65	33	48	123	94	62	31	206	152	108	19	300	225	159

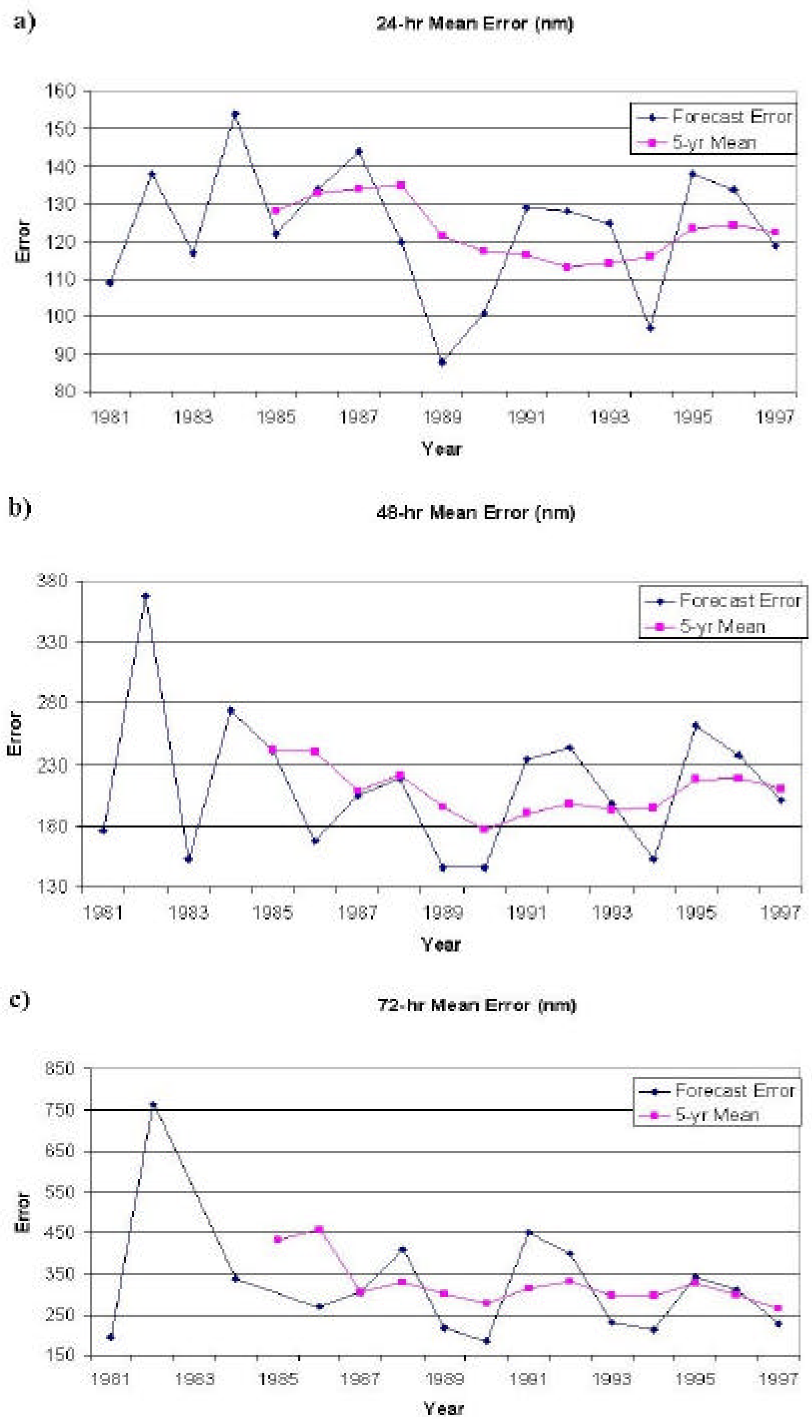

Figure 5-5 Mean track forecast error (nm) and 5-year running mean for a) 24 hours b) 48 hours and c) 72 hours for the western North Indian Ocean tropical cyclones for the period 1981 to 1997.

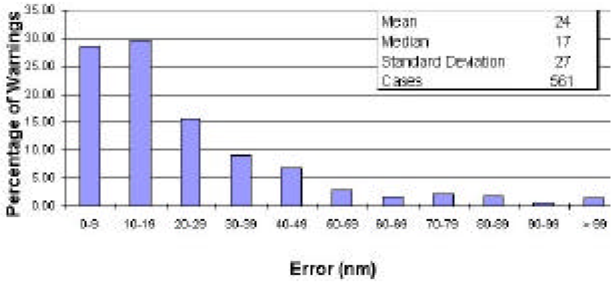

Figure 5-6a Frequency distribution of initial warning position errors for South Pacific and South Indian Ocean tropical cyclones in 1997. The largest error, 251 nm, occurred on Tropical Cyclone 21S (Iletta).

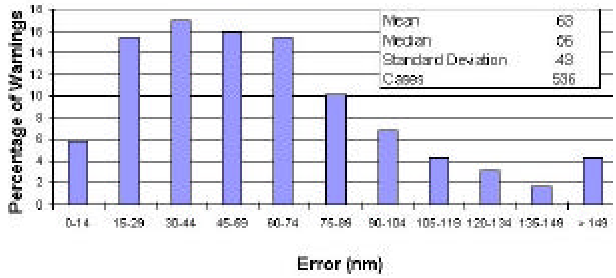

Figure 5-6b Frequency distribution of 12-hour track forecast errors for South Pacific and South Indian Ocean tropical cyclones in 1997. The largest error , 373 nm, occurred on Tropical Cyclone 25S (Karlette).

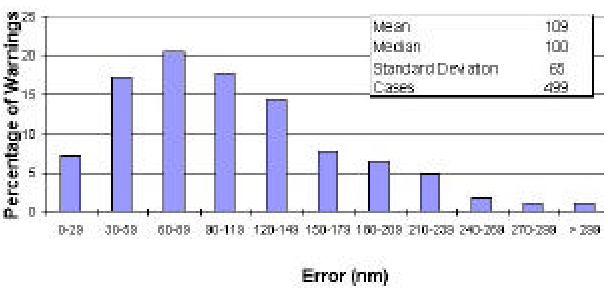

Figure 5-6c Frequency distribution of 24-hour track forecast errors for South Pacific and South Indian Ocean tropical cyclones in 1997. The largest error, 412 nm, occurred on Tropical Cyclone 25S (Karlette)

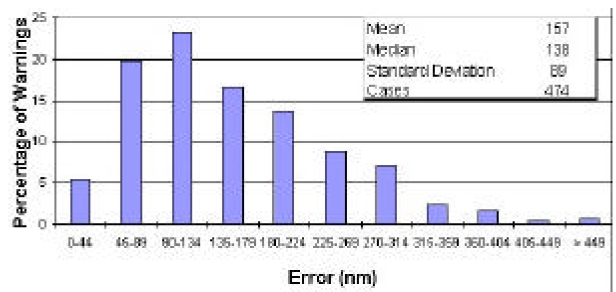

Figure 5-6d Frequency distribution of 36-hour track forecast errors for South Pacific and South Indian Ocean tropical cyclones in 1997. The largest error, 545 nm, occurred on Tropical Cyclone 05S (Melanie).

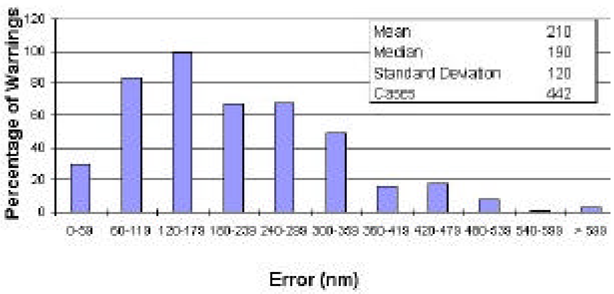

Figure 5-6e Frequency distribution of 48-hour track forecast errors for South Pacific and South Indian Ocean tropical cyclones in 1997. The largest error, 732 nm, occurred on Tropical Cyclone 05S (Melanie).

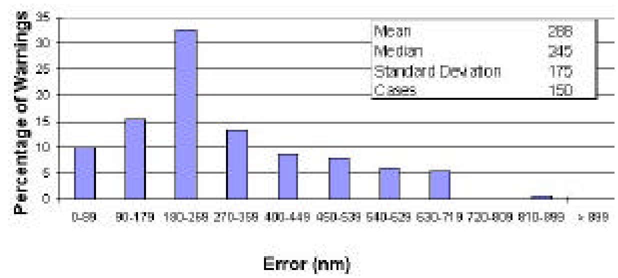

Figure 5-6f Frequency distribution of 72-hour track forecast errors for South Pacific and South Indian Ocean tropical cyclones in 1997. The largest error, 854 nm, occurred on Tropical Cyclone 26S (Harold).

TABLE 5-4 INITIAL POSITION AND FORECAST POSITION ERRORS (NM) FOR THE SOUTHERN HEMISPHERE FOR 1983-1997														
	Initial Position		24-Hour				48-Hour				72-Hour			
	Warnings	Error	Num	Track	Along	Cross	Num	Track	Along	Cross	Num	Track	Along	Cross
1983	191	35	163	130	88	77	126	241	158	145				
1984	301	36	252	133	90	79	191	231	159	134				
1985	306	36	257	134	92	79	193	236	169	132				
1986	279	40	227	129	86	77	171	262	169	164				
1987	189	46	138	145	94	90	101	280	153	138				
1988	204	34	99	146	98	83	48	290	246	144				
1989	287	31	242	124	84	73	186	240	166	136				
1990	272	27	228	143	105	74	177	263	178	152				
1991	264	24	231	115	75	69	185	220	152	129				
1992	267	28	230	124	91	64	208	240	177	129				
1993	257	21	225	102	74	57	176	199	142	114				
1994	386	28	345	115	77	68	282	224	147	134				
1995	245	24	222	108	82	55	175	198	144	108	53	291	169	190
1996	343	24	298	125	90	67	237	240	174	129	46	277	221	133
1997	561	24	499	109	82	72	442	210	163	135	150	288	248	175
15-YEAR AVERAGE														
1983-1997	290	31	244	125	87	72	193	87	166	135	83	285	213	166

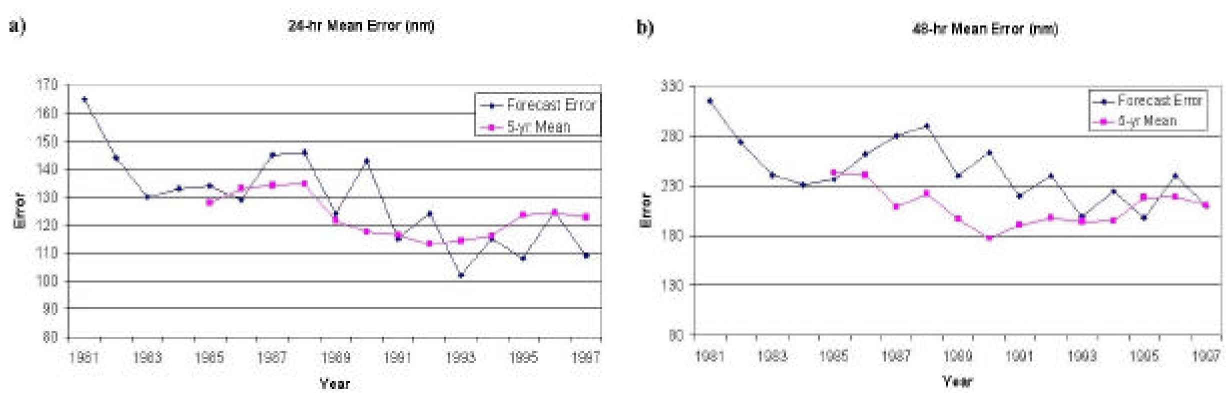

Figure 5-5 Mean track forecast error (nm) and 5-year running mean for a) 24 hours b) 48 hours for the South Indian Ocean tropical cyclones for the period 1981 to 1997.

Table 5-5 1997 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES THE NORTHWEST PACIFIC
(1 JAN 1997 - 31 DEC 1997)

KEY FOR ERROR STATISTICS TABLES

Number of Cases	X-Axis Technique Error
Y-Axis Technique Error	Error Difference (Y-X)

12-HOUR MEAN FORECAST ERROR(NM)

	JTWC		NGPS		GFDN		FBAM		CSUM		JGSM		JTYM		CLIP		DAVE	
JTWC	849	55																
	55	0																
NGPS	734	53	758	73														
	72	19	73	0														
GFDN	700	51	647	70	712	67												
	67	16	65	-5	67	0												
FBAM	814	55	717	72	677	66	868	60										
	56	1	55	-17	51	-15	60	0										
CSUM	743	55	652	72	618	66	787	59	793	63								
	59	4	57	-15	54	-12	63	4	63	0								
JGSM	315	47	312	60	262	64	310	49	291	51	321	53						
	53	6	52	-8	52	-12	53	4	53	2	53	0						
JTYM	313	47	267	72	299	55	302	47	282	51	6	92	319	56				
	56	9	56	-16	55	0	55	8	55	4	83	-9	56	0				
CLIP	840	55	739	72	698	66	865	60	792	63	319	53	310	56	897	64		
	61	6	59	-13	56	-10	64	4	64	1	52	-1	52	-4	64	0		
DAVE	757	56	673	73	640	67	770	59	723	62	284	54	276	57	792	63	793	58
	56	0	54	-19	51	-16	57	-2	57	-5	47	-7	49	-8	58	-5	58	0

24- HOUR MEAN FORECAST ERROR (NM)

	JTWC		NGPS		GFDN		FBAM		CSUM		EGRR		JGSM		JTYM		CLIP		DAVE	
JTWC	816	92																		
	92	0																		
NGPS	718	90	739	112																
	111	21	112	0																
GFDN	678	87	635	109	686	99														
	98	11	99	-10	99	0														
FBAM	786	93	703	111	658	98	841	104												
	99	6	99	-12	91	-7	104	0												
CSUM	716	93	639	111	601	98	762	102	767	114										
	110	17	108	-3	105	7	114	12	114	0										
EGRR	336	87	329	102	269	99	340	100	317	107	376	105								
	99	12	97	-5	97	-2	100	0	97	-10	105	0								
JGSM	312	81	312	97	262	98	307	93	288	100	279	89	319	81						
	81	0	81	-16	82	-16	82	-11	82	-18	79	-10	81	0						
JTYM	306	81	265	110	295	87	296	84	276	100	6	129	6	133	312	89				
	88	7	88	-22	87	0	88	4	88	-12	134	5	109	-24	89	0				
CLIP	809	93	723	111	677	98	838	104	766	114	352	100	317	81	304	88	867	116		
	112	19	110	-1	106	8	115	11	116	2	113	13	100	19	100	12	116	0		
DAVE	728	93	657	111	619	97	744	101	698	113	316	95	282	82	271	89	763	114	764	91
	88	-5	87	-24	83	-14	90	-11	90	-23	84	-11	80	-2	80	-9	91	-23	91	0

Table 5-5 (Continued) 36-HOUR MEAN FORECAST ERROR(NM)

	JTWC		NGPS		GFDN		FBAM		CSUM		JGSM		JTYM		CLIP		DAVE	
JTWC	770	129																
	129	0																
NGPS	666	125	682	149														
	148	23	149	0														
GFDN	643	124	590	146	648	135												
	135	11	131	-15	135	0												
FBAM	742	129	654	150	625	135	801	159										
	153	24	148	-2	145	10	159	0										
CSUM	674	129	595	150	570	135	724	156	729	170								
	165	36	162	12	159	24	170	14	170	0								
JGSM	293	117	288	135	249	134	289	149	270	152	300	109						
	110	-7	109	-26	109	-25	110	-39	111	-41	109	0						
JTYM	293	116	249	147	283	124	284	132	264	155	6	179	299	116				
	111	-5	109	-38	110	-14	114	-18	114	-41	142	-37	116	0				
CLIP	763	129	671	149	643	135	798	159	728	170	298	110	292	115	825	176		
	170	41	167	18	164	29	175	16	176	6	158	48	161	46	176	0		
DAVE	684	129	610	148	585	131	708	157	664	168	265	112	259	116	724	174	725	128
	123	-6	121	-27	117	-14	128	-29	127	-41	118	6	115	-1	128	-46	128	0

48-HOUR MEAN FORECAST ERROR(NM)

	JTWC		NGPS		GFDN		FBAM		CSUM		EGRR		JGSM		JTYM		CLIP		DAVE	
JTWC	707	163																		
	163	0																		
NGPS	596	159	615	189																
	189	30	189	0																
GFDN	594	159	529	186	602	176														
	176	17	173	-13	176	0														
FBAM	682	164	591	190	582	177	756	220												
	211	47	208	18	203	26	220	0												
CSUM	617	161	538	193	528	175	683	215	686	227										
	219	58	216	23	211	36	227	12	227	0										
EGRR	296	157	274	175	238	177	304	214	281	218	334	168								
	163	6	153	-22	155	-22	162	-52	153	-65	168	0								
JGSM	283	157	269	178	238	183	278	211	259	215	252	156	288	139						
	139	-18	139	-39	135	-48	138	-73	139	-76	133	-23	139	0						
JTYM	276	155	231	197	269	170	271	196	251	213	6	188	6	212	284	151				
	146	-9	141	-56	143	-27	148	-48	150	-63	158	-30	176	-36	151	0				
CLIP	701	163	607	188	598	176	755	220	685	227	314	163	287	139	278	149	779	244		
	231	68	228	40	224	48	242	22	242	15	241	78	228	89	229	80	244	0		
DAVE	625	164	551	189	543	170	664	217	623	225	277	156	254	141	246	151	681	241	681	166
	159	-5	157	-32	154	-16	166	-51	166	-59	158	2	161	20	158	7	166	-75	166	0

Table 5-5 (Continued) 72-HOUR MEAN FORECAST ERROR(NM)

	JTWC		NGPS		GFDN		FBAM		CSUM		EGRR		JGSM		JTYM		CLIP		DAVE	
JTWC	598	245																		
	245	0																		
NGPS	491	229	515	279																
	284	55	279	0																
GFDN	484	232	431	278	500	284														
	282	50	270	-8	284	0														
FBAM	578	245	497	282	485	285	662	351												
	328	83	332	50	320	35	351	0												
CSUM	523	243	448	285	440	283	594	341	597	338										
	319	76	311	26	310	27	337	-4	338	0										
EGRR	239	239	222	264	189	284	255	339	232	336	280	233								
	232	-7	216	-48	218	-66	227	-112	213	-123	233	0								
JGSM	239	240	225	277	197	296	241	341	222	336	210	223	249	214						
	215	-25	211	-66	197	-99	213	-128	215	-121	204	-19	214	0						
JTYM	232	240	194	297	222	277	232	322	211	329	3	155	5	277	242	238				
	232	-8	211	-86	219	-58	235	-87	239	-90	248	93	200	-77	238	0				
CLIP	592	245	508	280	496	284	661	351	596	338	261	227	248	213	236	236	680	389		
	354	109	353	73	344	60	387	36	382	44	396	169	378	165	367	131	389	0		
DAVE	525	246	460	280	447	274	579	351	542	342	229	216	218	213	206	236	591	385	591	264
	251	5	248	-32	249	-25	263	-88	262	-80	259	43	276	63	259	23	264	-121	264	0

Table 5-6 1997 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE NORTH INDIAN OCEAN
(1 JAN 1997 - 31 DEC 1997)

12 HOUR MEAN FORECAST ERRORS(NM)

	JTWC		NGPS		OTCM		GFDN		CLIP		HPAC	
JTWC	52	76										
	76	0										
NGPS	47	72	48	75								
	74	2	75	0								
OTCM	40	77	38	70	40	96						
	96	19	92	22	96	0						
GFDN	43	79	41	78	35	98	44	110				
	108	29	105	27	106	8	110	0				
CLIP	50	78	47	71	40	96	42	106	56	83		
	86	8	79	8	83	-13	89	-17	83	0		
HPAC	51	77	47	71	40	96	42	106	56	83	57	86
	86	9	80	9	84	-12	90	-16	87	4	86	0

24 HOUR MEAN FORECAST ERRORS(NM)

	JTWC		NGPS		OTCM		GFDN		CLIP		HPAC	
JTWC	42	119										
	119	0										
NGPS	39	122	43	112								
	113	-9	112	0								
OTCM	25	111	27	94	27	123						
	123	12	123	29	123	0						
GFDN	33	128	36	121	23	125	36	209				
	216	88	209	88	205	80	209	0				
CLIP	41	121	43	112	27	123	36	209	50	133		
	135	14	139	27	134	11	144	-65	133	0		
HPAC	42	119	43	112	27	123	36	209	50	133	51	138
	135	16	141	29	122	-1	148	-61	140	7	138	0

Table 5-6 (Continued) 36 HOUR MEAN FORECAST ERRORS(NM)

	JTWC		NGPS		OTCM		GFDN		CLIP		HPAC	
JTWC	35	164										
	164	0										
NGPS	32	167	35	136								
	133	-34	136	0								
OTCM	15	159	17	120	17	167						
	176	17	167	47	167	0						
GFDN	27	172	27	145	13	178	27	314				
	314	142	314	169	281	103	314	0				
CLIP	34	168	35	136	17	167	27	314	42	195		
	198	30	206	70	217	50	208	-106	195	0		
HPAC	35	164	35	136	17	167	27	314	42	195	43	200
	195	31	205	69	196	29	209	-105	203	8	200	0

48 HOUR MEAN FORECAST ERRORS(NM)

	JTWC		NGPS		OTCM		GFDN		CLIP		HPAC	
JTWC	29	201										
	201	0										
NGPS	26	200	27	157								
	154	-46	157	0								
OTCM	8	231	8	171	8	224						
	224	-7	224	53	224	0						
GFDN	21	206	21	170	8	224	21	352				
	352	146	352	182	375	151	352	0				
CLIP	28	206	27	157	8	224	21	352	34	248		
	258	52	260	103	326	102	264	-88	248	0		
HPAC	29	201	27	157	8	224	21	352	34	248	35	243
	239	38	240	83	292	68	245	-107	247	-1	243	0

72 HOUR MEAN FORECAST ERRORS(NM)

	JTWC		NGPS		OTCM		GFDN		CLIP		HPAC	
JTWC	17	228										
	228	0										
NGPS	13	203	13	125								
	125	-78	125	0								
OTCM	2	108	1	136	2	413						
	413	305	464	328	413	0						
GFDN	11	200	9	149	2	413	11	441				
	441	241	376	227	538	125	441	0				
CLIP	17	228	13	125	2	413	11	441	22	343		
	358	130	289	164	420	7	382	-59	343	0		
HPAC	17	228	13	125	2	413	11	441	22	343	22	300
	285	57	226	101	172	-241	261	-180	300	-43		

Table 5-7 1997 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE SOUTHERN HEMISPHERE
(1 JUL 1996 - 30 JUN 1997)

12-HOUR MEAN FORECAST ERROR (NM)

	JTWC		NGPS		OTCM		GFDN		CLIP		HPAC	
JTWC	540	64										
	64	0										
NGPS	434	60	721	85								
	83	23	85	0								
OTCM	416	60	636	83	700	110						
	108	48	109	26	110	0						
GFDN	209	58	284	76	274	111	314	84				
	83	25	82	6	84	-27	84	0				
CLIP	536	64	505	84	488	109	242	83	704	124		
	108	44	104	20	100	-9	123	40	124	0		
HPAC	529	63	499	83	485	109	238	82	693	122	696	76
	70	7	70	-13	69	-40	66	-16	76	-46	76	0

24-HOUR MEAN FORECAST ERROR (NM)

	JTWC		NGPS		OTCM		GFDN		EGRR		CLIP		HPAC	
JTWC	503	110												
	110	0												
NGPS	412	107	705	127										
	125	18	127	0										
OTCM	385	104	606	123	662	171								
	171	67	170	47	171	0								
GFDN	196	99	275	121	258	184	299	122						
	117	18	119	-2	120	-64	122	0						
EGRR	186	101	276	116	235	163	104	123	342	134				
	111	10	114	-2	112	-51	116	-7	134	0				
CLIP	501	109	497	127	463	171	231	118	225	115	684	178		
	158	49	156	29	149	-22	182	64	164	49	178	0		
HPAC	496	109	492	126	461	171	228	118	223	115	675	175	678	132
	122	13	124	-2	123	-48	116	-2	124	9	132	-43	132	0

36-HOUR MEAN FORECAST ERROR (NM)

	JTWC		NGPS		OTCM		GFDN		CLIP		HPAC	
JTWC	478	158										
	158	0										
NGPS	393	156	667	174								
	165	9	174	0								
OTCM	358	150	564	171	615	235						
	230	80	234	63	235	0						
GFDN	188	143	263	167	237	255	283	165				
	156	13	160	-7	158	-97	165	0				
CLIP	476	157	473	168	431	235	222	160	656	237		
	213	56	215	47	205	-30	239	79	237	0		
HPAC	466	156	459	163	428	235	214	158	638	231	641	188
	175	19	179	16	179	-56	169	11	187	-44	188	0

Table 5-7 (continued) 48-HOUR MEAN FORECAST ERROR (NM)

	JTWC		NGPS		OTCM		GFDN		EGRR		CLIP		HPAC	
JTWC	446	211												
	211	0												
NGPS	367	210	630	211										
	212	2	211	0										
OTCM	318	201	518	203	563	302								
	300	99	301	98	302	0								
GFDN	175	192	248	216	219	319	271	221						
	213	21	217	1	209	-110	221	0						
EGRR	156	200	234	192	194	286	89	229	298	190				
	191	-9	183	-9	177	-109	186	-43	190	0				
CLIP	444	210	449	212	399	306	214	216	194	187	627	301		
	277	67	277	65	269	-37	300	84	292	105	301	0		
HPAC	433	208	436	207	397	306	206	212	189	183	609	296	611	247
	231	23	241	34	238	-68	226	14	241	58	248	-48	247	0

72-HOUR MEAN FORECAST ERROR (NM)

	JTWC		NGPS		OTCM		GFDN		EGRR		CLIP		HPAC	
JTWC	147	295												
	295	0												
NGPS	137	303	541	286										
	319	16	286	0										
OTCM	114	297	415	274	461	426								
	435	138	419	145	426	0								
GFDN	90	265	213	313	184	438	238	343						
	329	64	332	19	331	-107	343	0						
EGRR	54	280	190	255	153	406	72	370	244	258				
	273	-7	246	-9	247	-159	263	-107	258	0				
CLIP	146	295	390	295	328	428	194	351	156	265	551	417		
	387	92	399	104	394	-34	406	55	409	144	417	0		
HPAC	147	295	379	290	325	426	188	342	151	259	536	411	538	635
	299	4	348	58	343	-83	352	10	347	88	366	-45	365	0