# 5. SUMMARY OF FORECAST VERIFICATION

## 5.1 ANNUAL FORECAST VERIFICATION

Verification of warning positions and intensities at initial, 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 1994 and contrasts it with annual verification statistics from previous years.

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, respectively. Table 5-1 includes mean track, along-track and cross-track errors for 1978-1994. 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. Figure 5-4 illustrates JTWC intensity forecast errors at 24-, 48- and 72-hours for the past 20 years.

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 5-5a through 5-5f, respectively. Table 5-3 includes mean track, along-track and cross-track errors for 1978-1994. Figure 5-6 shows mean track errors and a 5-year running mean of track errors at 24-, 48- and 72-hours for the 20 years that the JTWC has issued warnings in the region.

5.1.3 SOUTH PACIFIC AND SOUTH INDIAN OCEANS — The frequency distributions of errors for warning positions and 12-, 24-, 36-, and 48-hour forecasts are presented in Figures 5-7a through 5-7e, respectively. Table 5-4 includes mean track, along-track and cross-track errors for 1981-1994. Figure 5-8 shows mean track errors and a 5-year running mean of track errors at 24- and 48-hours for the 13 years that the JTWC has issued warnings in the region.

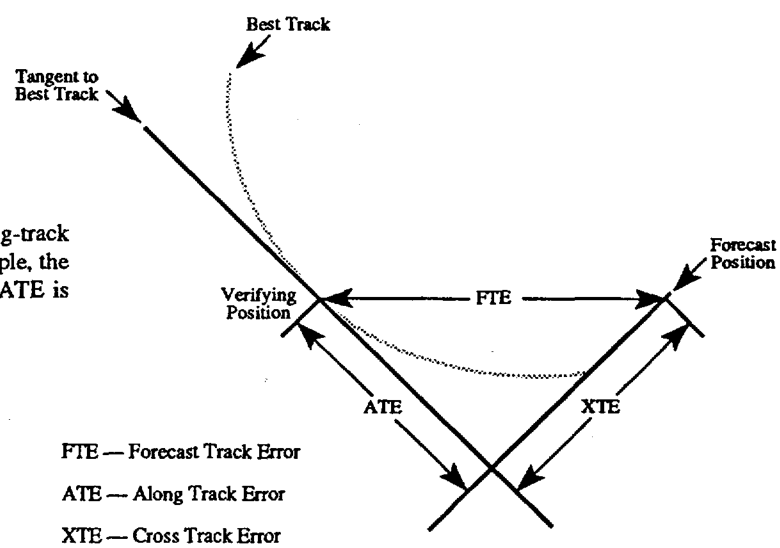


**Figure 5-1** Definition of cross-track error (XTE), along-track error (ATE) and forecast track error (FTE). In this example, the XTE is positive (to the right of the best track) and the ATE is negative (behind or slower than the best track).

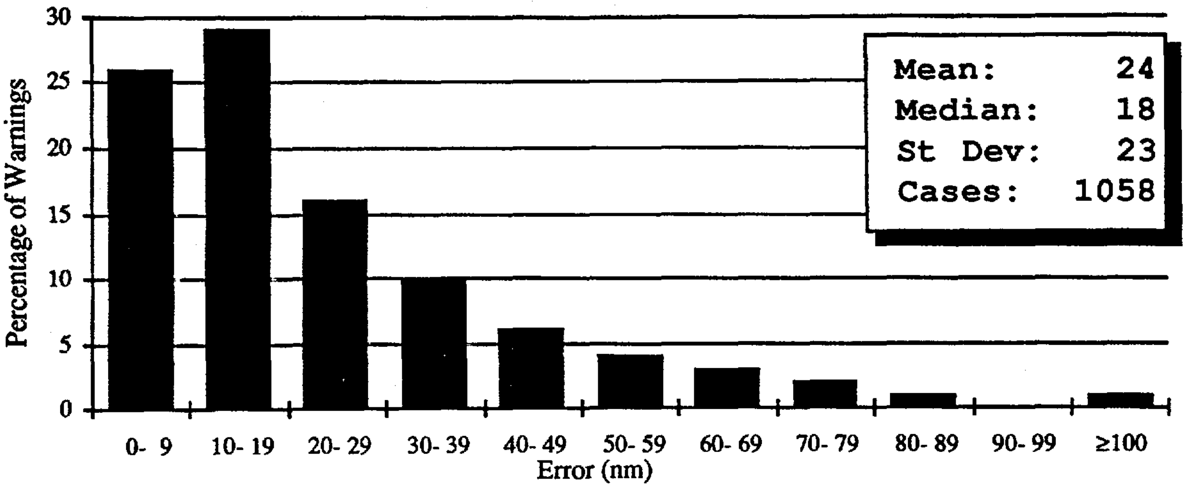


**Figure 5-2a** Frequency distribution of initial warning position errors (10-nm increments) for western North Pacific Ocean tropical cyclones in 1994. The largest error, 215 nm, occurred on Tropical Depression 01W.

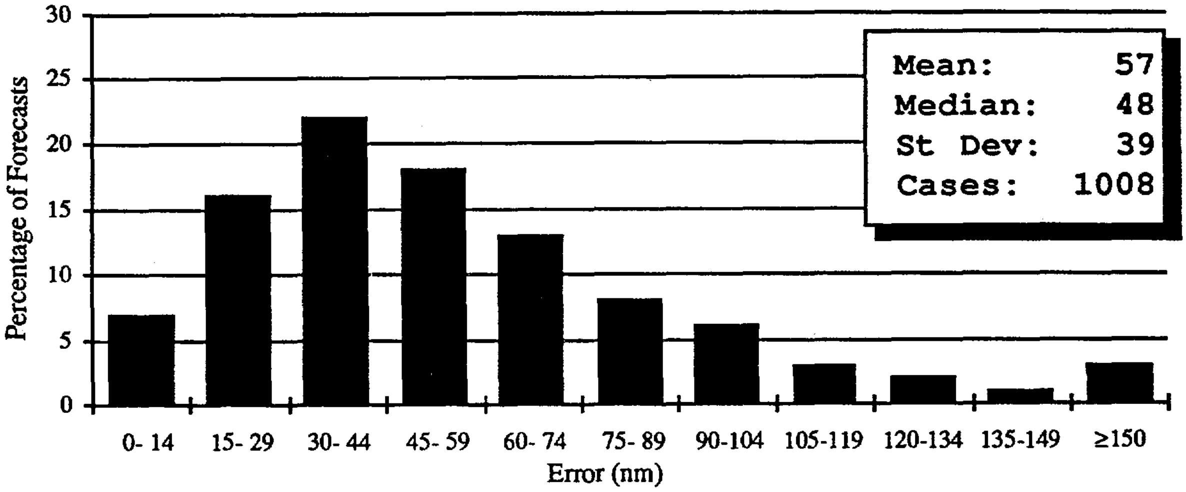


**Figure 5-2b** Frequency distribution of 12-hour track forecast errors (15-nm increments) for western North Pacific Ocean tropical cyclones in 1994. The largest error, 259 nm, occurred on Typhoon Wilda (35W).

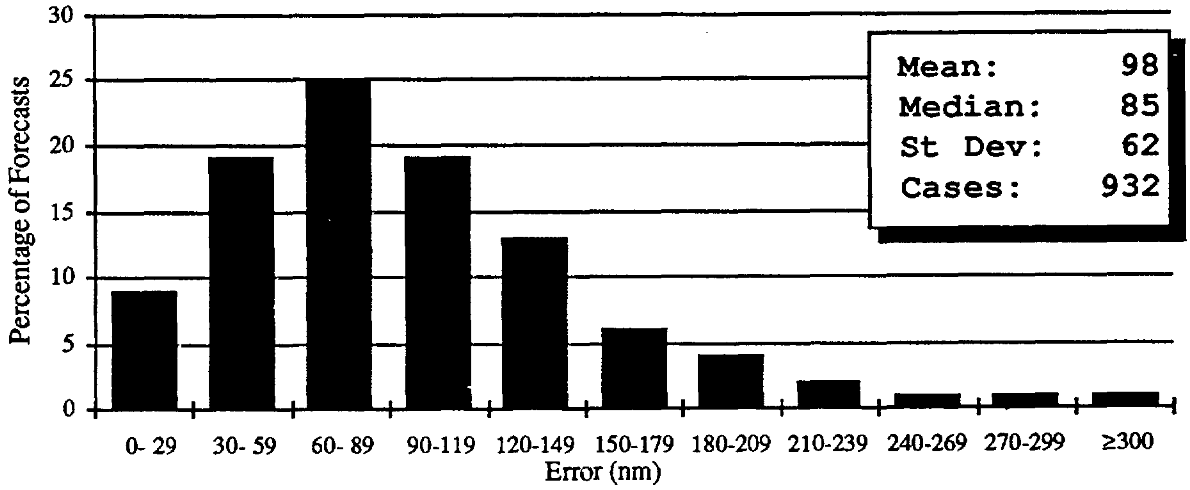


**Figure 5-2c** Frequency distribution of 24-hour track forecast errors (30-nm increments) for western North Pacific Ocean tropical cyclones in 1994. The largest error, 436 nm, occurred on Tropical Storm Ruth (30W).

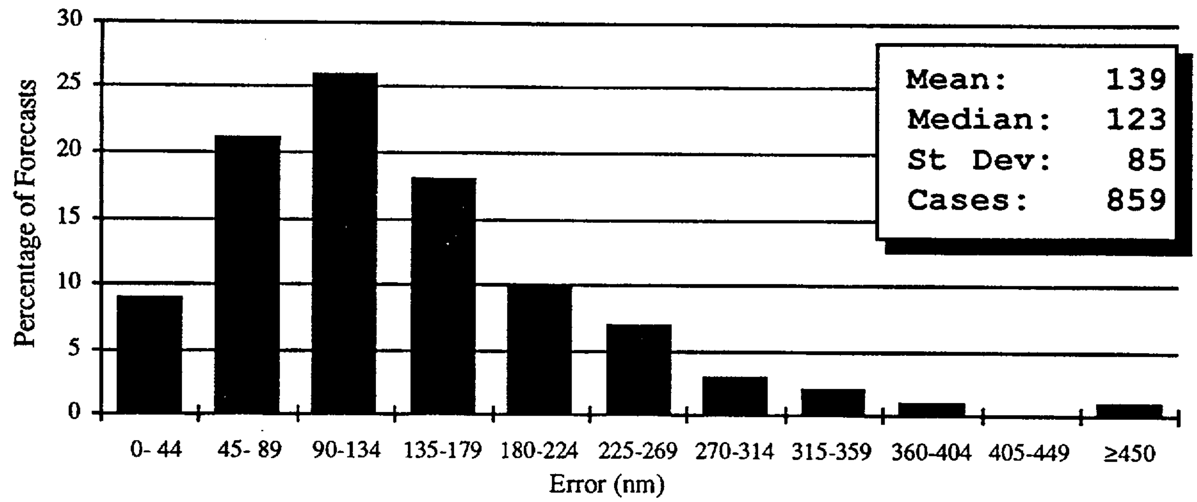


**Figure 5-2d** Frequency distribution of 36-hour track forecast errors (45-nm increments) for western North Pacific Ocean tropical cyclones in 1994. The largest error, 588 nm, occurred on Tropical Storm Vanessa (09W).

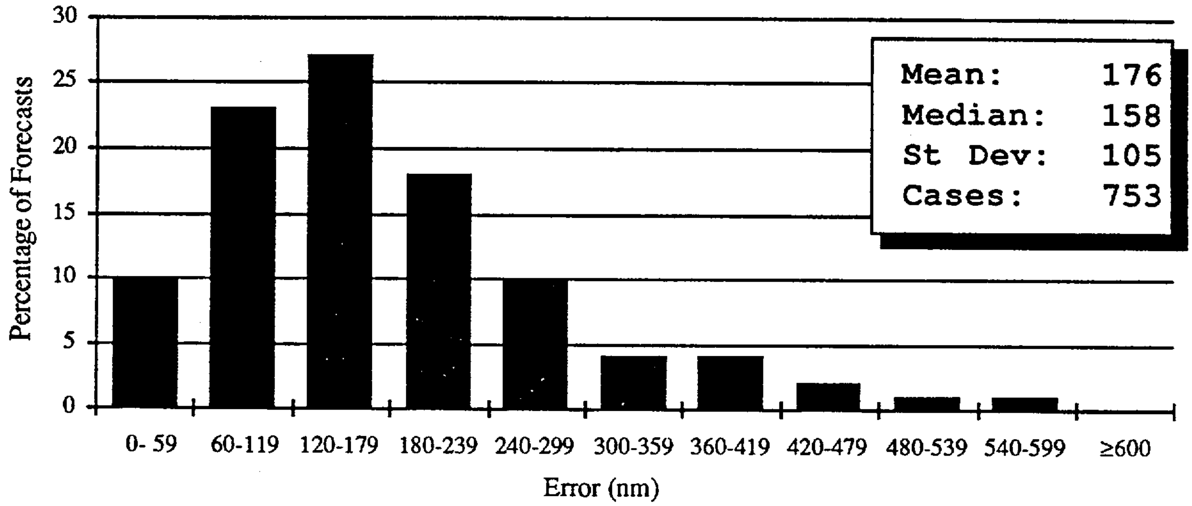


**Figure 5-2e** Frequency distribution of 48- hour track forecast errors (60-nm increments) for western North Pacific Ocean tropical cyclones in 1994. The largest error, 634 nm, occurred on Typhoon Pat (29W).

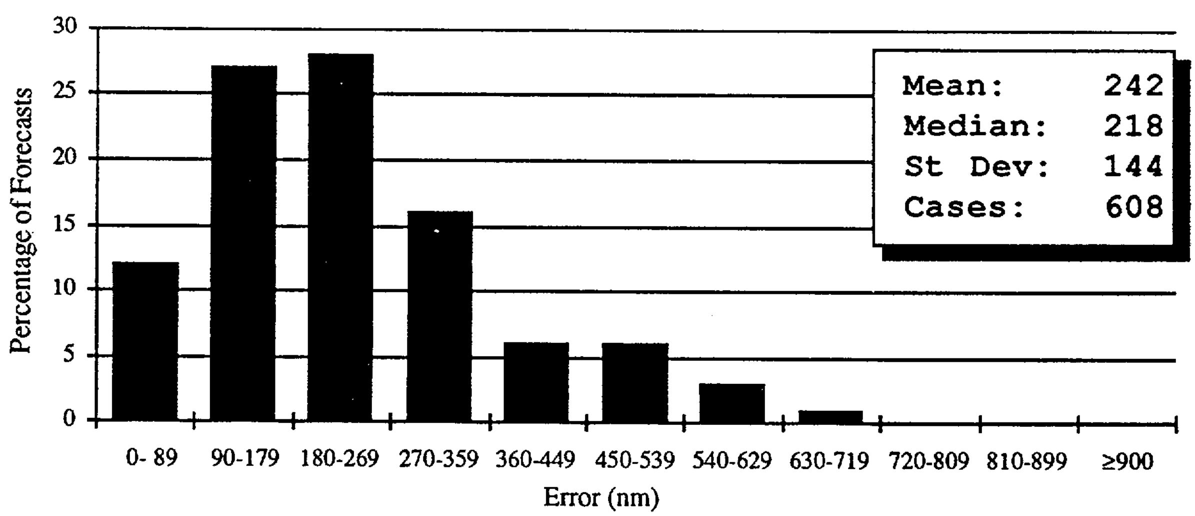


**Figure 5-2f** Frequency distribution of 72-hour track forecast errors (90-nm increments) for western North Pacific Ocean tropical cyclones in 1994. The largest error, 837 nm, occurred on Super Typhoon Melissa (26W).

**Table 5-1** INITIAL WARNING POSITION AND FORECAST ERRORS (NM) FOR THE WESTERN NORTH PACIFIC 1978-1994.

| YEAR | NUMBER OF WARNINGS | INITIAL POSITION | NUMBER OF FORECASTS (24-HOUR) | 24-HOUR TRACK | 24-HOUR ALONG | 24-HOUR CROSS | NUMBER OF FORECASTS (48-HOUR) | 48-HOUR TRACK | 48-HOUR ALONG | 48-HOUR CROSS | NUMBER OF FORECASTS (72-HOUR) | 72-HOUR TRACK | 72-HOUR ALONG | 72-HOUR CROSS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1978 | 696 | 21 | 556 | 126 | 87 | 71 | 420 | 274 | 194 | 151 | 295 | 411 | 296 | 218 |
| 1979 | 695 | 25 | 589 | 125 | 81 | 76 | 469 | 227 | 146 | 138 | 366 | 316 | 214 | 182 |
| 1980 | 590 | 28 | 491 | 127 | 86 | 76 | 369 | 244 | 165 | 147 | 267 | 391 | 266 | 230 |
| 1981 | 584 | 25 | 466 | 124 | 80 | 77 | 348 | 221 | 146 | 131 | 246 | 334 | 206 | 219 |
| 1982 | 786 | 19 | 666 | 113 | 74 | 70 | 532 | 238 | 162 | 142 | 425 | 342 | 223 | 211 |
| 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 | 932 | 98 | 85 | 62 | 753 | 176 | 158 | 105 | 608 | 242 | 218 | 144 |
| AVERAGE 1978-1993 | 687 | 22 | 578 | 116 | 79 | 67 | 452 | 227 | 157 | 131 | 348 | 345 | 238 | 198 |

Note: 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 and along-track errors after-the-fact to extend the data base. See Figure 5-1 for the definitions of cross-track and along-track errors.

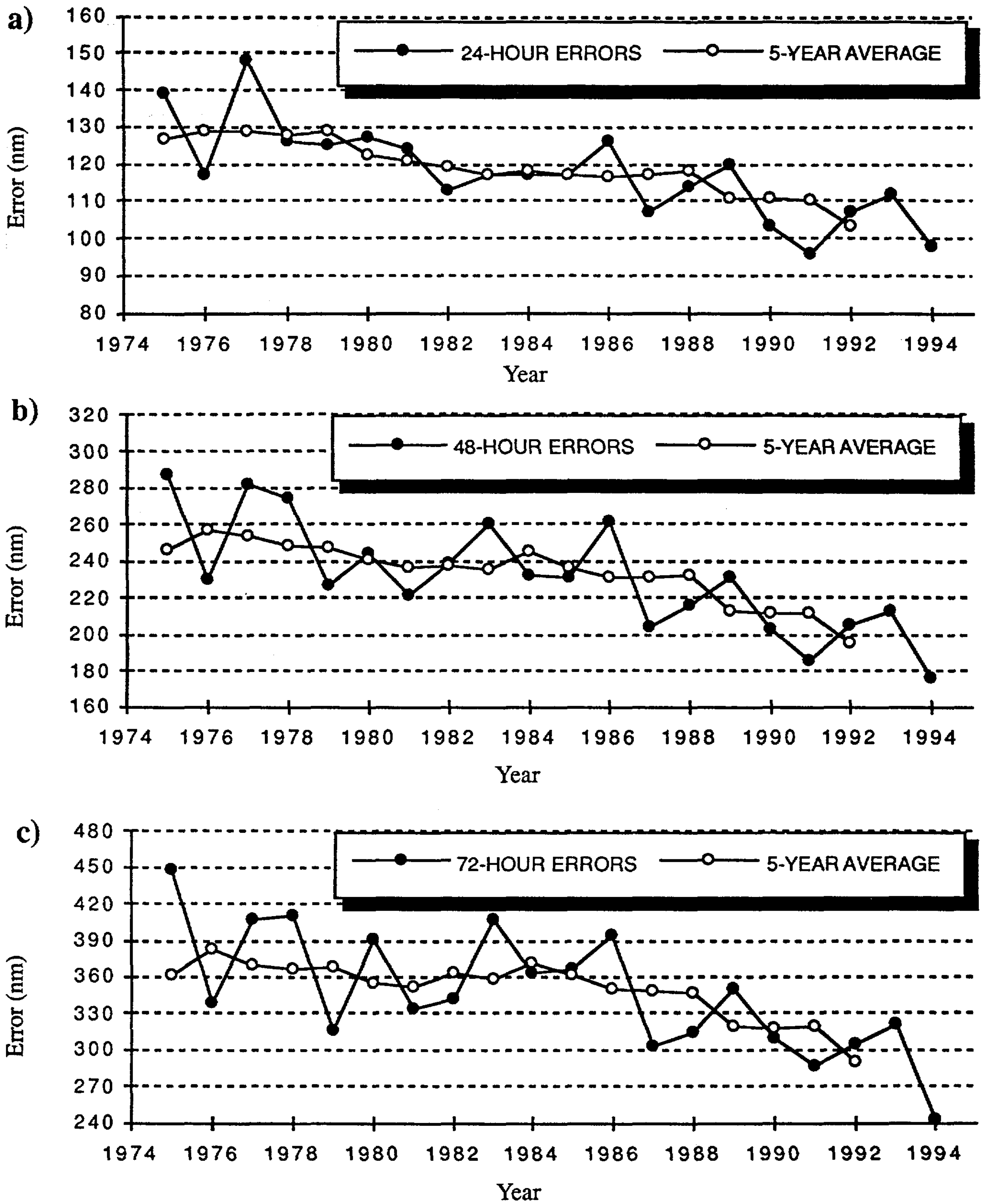


**Figure 5-3** Mean track forecast error (nm) and 5-year running mean for a) 24 hours, b) 48 hours and c) 72 hours for western North Pacific Ocean tropical cyclones for the period 1975 to 1994.

**Table 5-2** MEAN FORECAST TRACK ERRORS (NM) FOR WESTERN NORTH PACIFIC TROPICAL CYCLONES 1959-1994

| | 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 | 123 | 77 | 80 | 215 | 220 | 131 | 146 | 342 | 334 | 219 | 206 |
| 1982 | 114 | 113 | 70 | 74 | 229 | 237 | 142 | 162 | 337 | 341 | 211 | 223 |
| 1983 | 110 | 117 | 73 | 76 | 247 | 259 | 164 | 169 | 384 | 405 | 263 | 259 |
| 1984 | 110 | 117 | 64 | 84 | 228 | 233 | 131 | 163 | 361 | 363 | 216 | 238 |
| 1985 | 112 | 117 | 68 | 80 | 228 | 231 | 138 | 153 | 355 | 367 | 227 | 230 |
| 1986 | 117 | 121 | 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 | 70 | 81 | 191 | 203 | 138 | 162 | 299 | 310 | 211 | 242 |
| 1991 | 93 | 96 | 53 | 69 | 187 | 185 | 97 | 137 | 298 | 286 | 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 | 98 | 53 | 71 | 172 | 176 | 101 | 123 | 244 | 242 | 146 | 163 |

1. Forecasts were verified when tropical cyclone intensities were at least 35 kt (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 the data base. See Figure 5-1 for the definitions of cross-track and along-track.

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

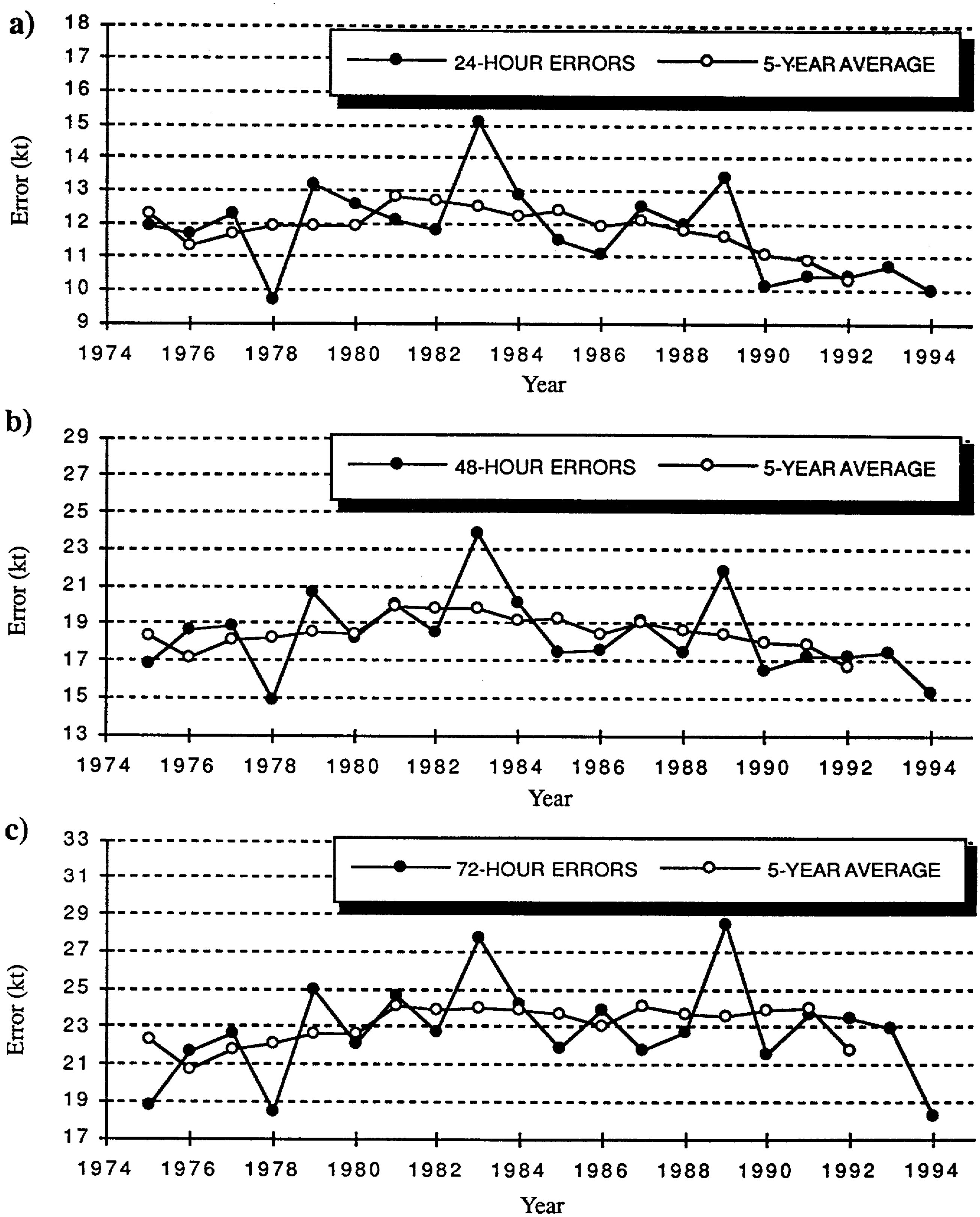


**Figure 5-4** Mean intensity forecast errors (kt) and 5-year running mean for a) 24 hours, b) 48 hours and c) 72 hours for western North Pacific Ocean tropical cyclones for the period 1975 to 1994.

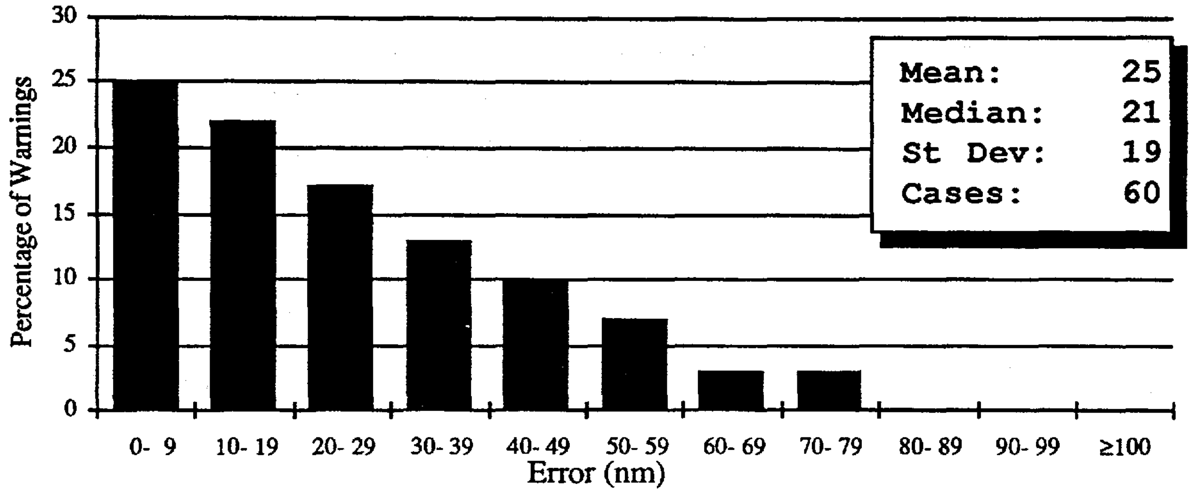


**Figure 5-5a** Frequency distribution of initial warning position errors (10-nm increments) for North Indian Ocean tropical cyclones in 1994. The largest error, 78 nm, was on TC01B.

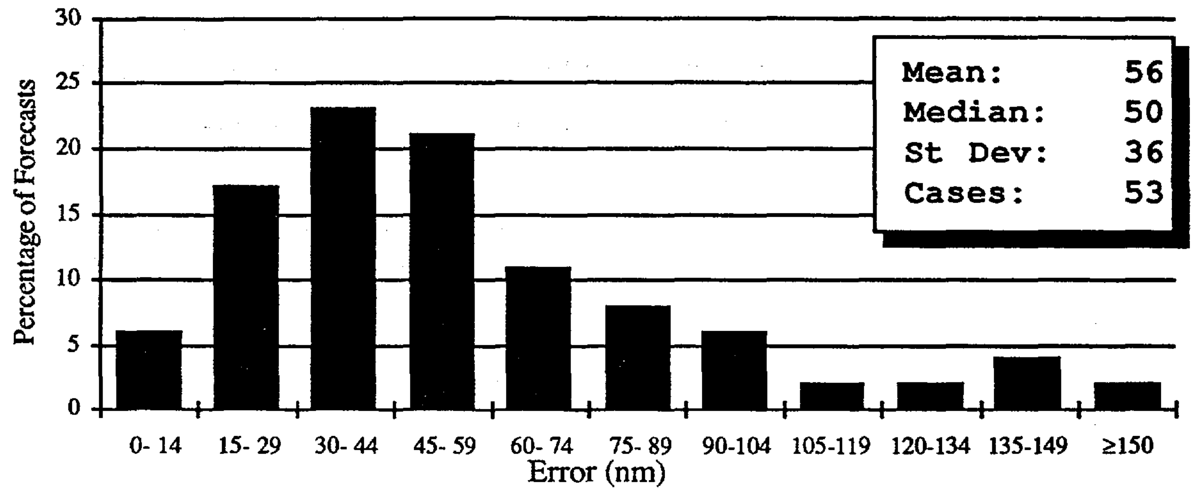


**Figure 5-5b** Frequency distribution of 12-hour track forecast errors (15-nm increments) for North Indian Ocean tropical cyclones in 1994. The largest error, 183 nm, was on TC01B.

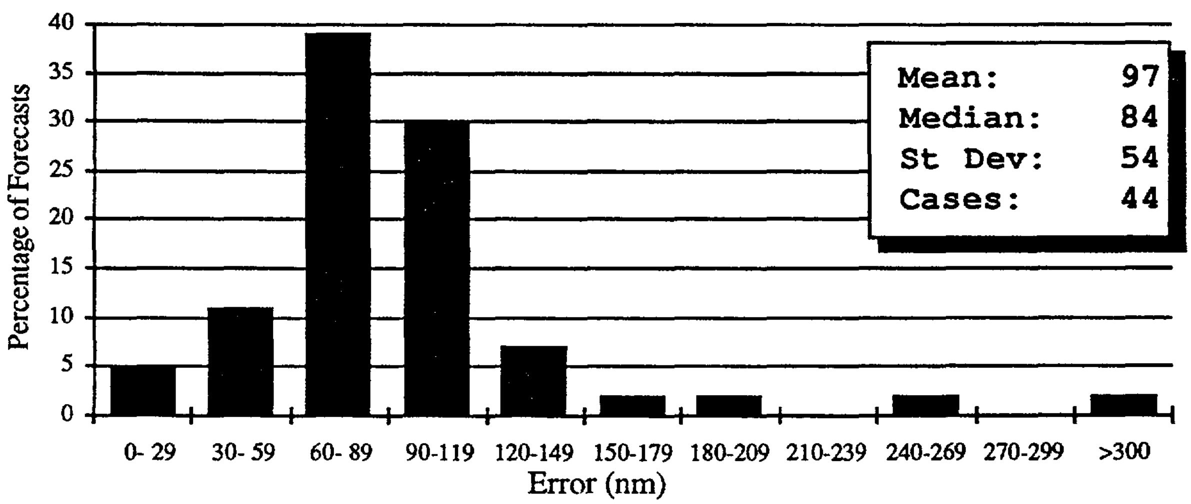


**Figure 5-5c** Frequency distribution of 24-hour track forecast errors (30-nm increments) for North Indian Ocean tropical cyclones in 1994. The largest error, 318 nm, was on TC01B.

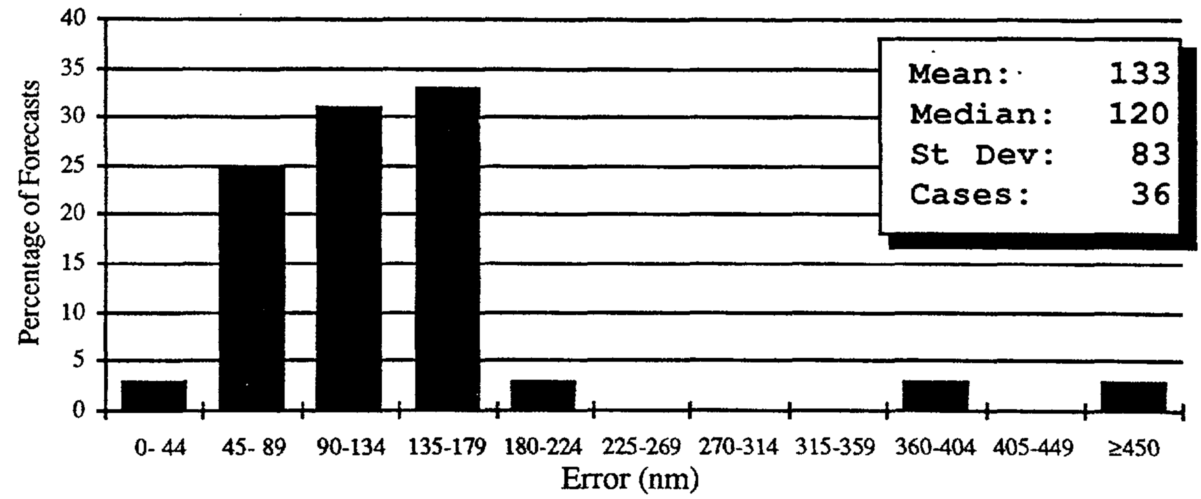


**Figure 5-5d** Frequency distribution of 36-hour track forecast errors (45-nm increments) for North Indian Ocean tropical cyclones in 1994. The largest error, 484 nm, was on TC01B.

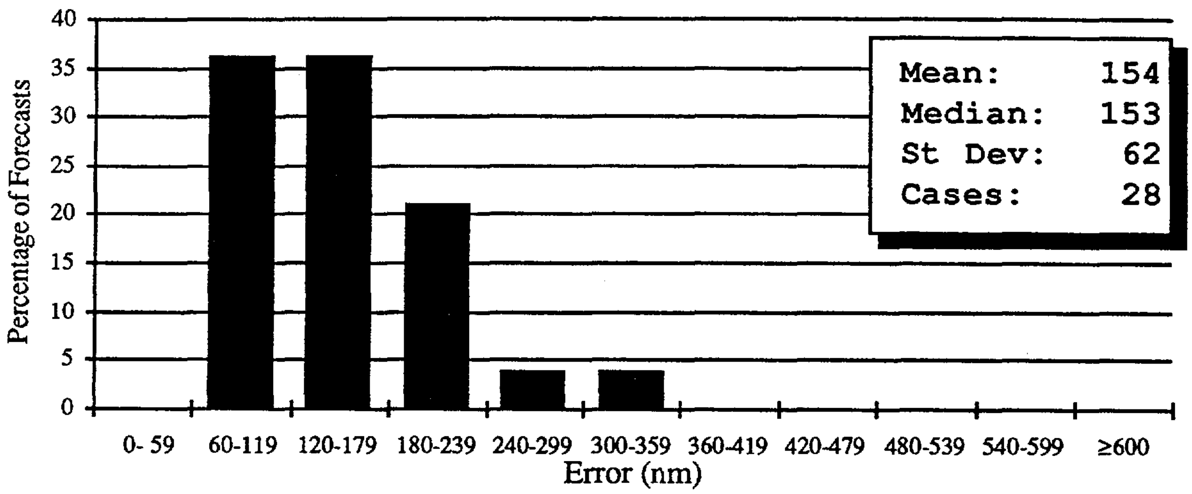


**Figure 5-5e** Frequency distribution of 48-hour track forecast errors (60-nm increments) for North Indian Ocean tropical cyclones in 1994. The largest error, 303 nm, was on TC01B.

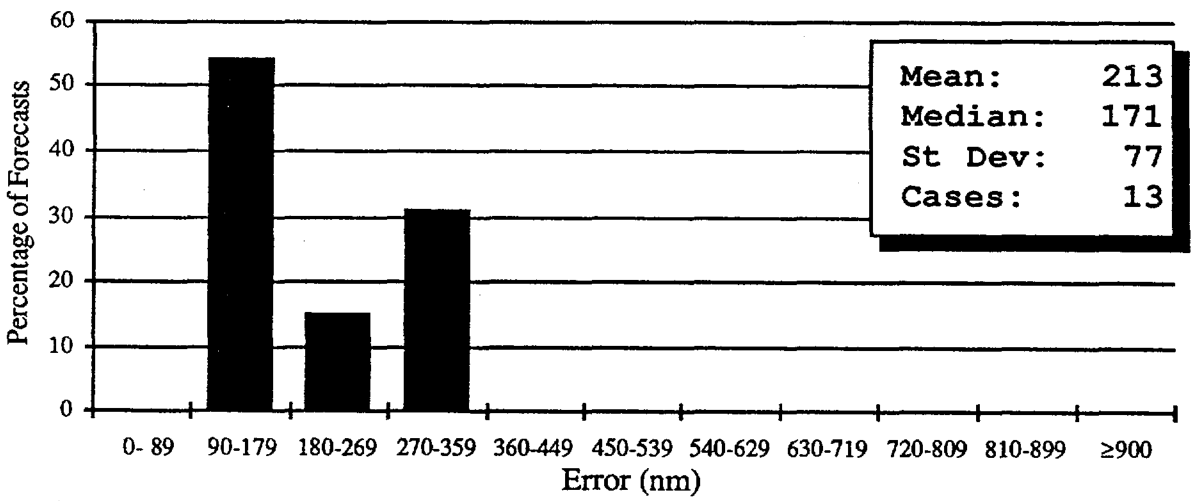


**Figure 5-5f** Frequency distribution of 72-hour track forecast errors (90-nm increments) for North Indian Ocean tropical cyclones in 1994. The largest error, 354 nm, was on TC02B.

**Table 5-3** INITIAL POSITION AND FORECAST POSITION ERRORS (NM) FOR THE NORTH INDIAN OCEAN 1978-1994

| YEAR | NUMBER OF WARNINGS | INITIAL POSITION | NUMBER OF FORECASTS | 24-HOUR TRACK | 24-HOUR ALONG | 24-HOUR CROSS | NUMBER OF FORECASTS | 48-HOUR TRACK | 48-HOUR ALONG | 48-HOUR CROSS | NUMBER OF FORECASTS | 72-HOUR TRACK | 72-HOUR ALONG | 72-HOUR CROSS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1978 | 32 | 43 | 28 | 133 | 90 | 82 | 19 | 202 | 147 | 109 | N/A | | | |
| 1979 | 93 | 46 | 63 | 151 | 96 | 95 | 17 | 278 | 193 | 161 | 17 | 437 | 251 | 320 |
| 1980 | 14 | 41 | 7 | 115 | 81 | 71 | 38 | 93 | 25 | 88 | 1 | 167 | 97 | 137 |
| 1981 | 41 | 28 | 29 | 109 | 76 | 63 | 2 | 176 | 120 | 109 | 5 | 197 | 150 | 111 |
| 1982 | 55 | 35 | 37 | 138 | 110 | 68 | 17 | 368 | 292 | 209 | 7 | 762 | 653 | 332 |
| 1983 | 18 | 38 | 7 | 117 | 90 | 50 | 18 | 153 | 137 | 53 | 0 | | | |
| 1984 | 67 | 33 | 42 | 154 | 124 | 67 | 20 | 274 | 217 | 139 | 16 | 388 | 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 | 91 | 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 |
| AVERAGE 1978-1993 | 56 | 36 | 40 | 129 | 90 | 74 | 24 | 212 | 142 | 127 | 13 | 360 | 258 | 196 |

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 and along-track errors after-the-fact to extend the data base. See Figure 5-1 for the definitions of cross-track and along-track errors.

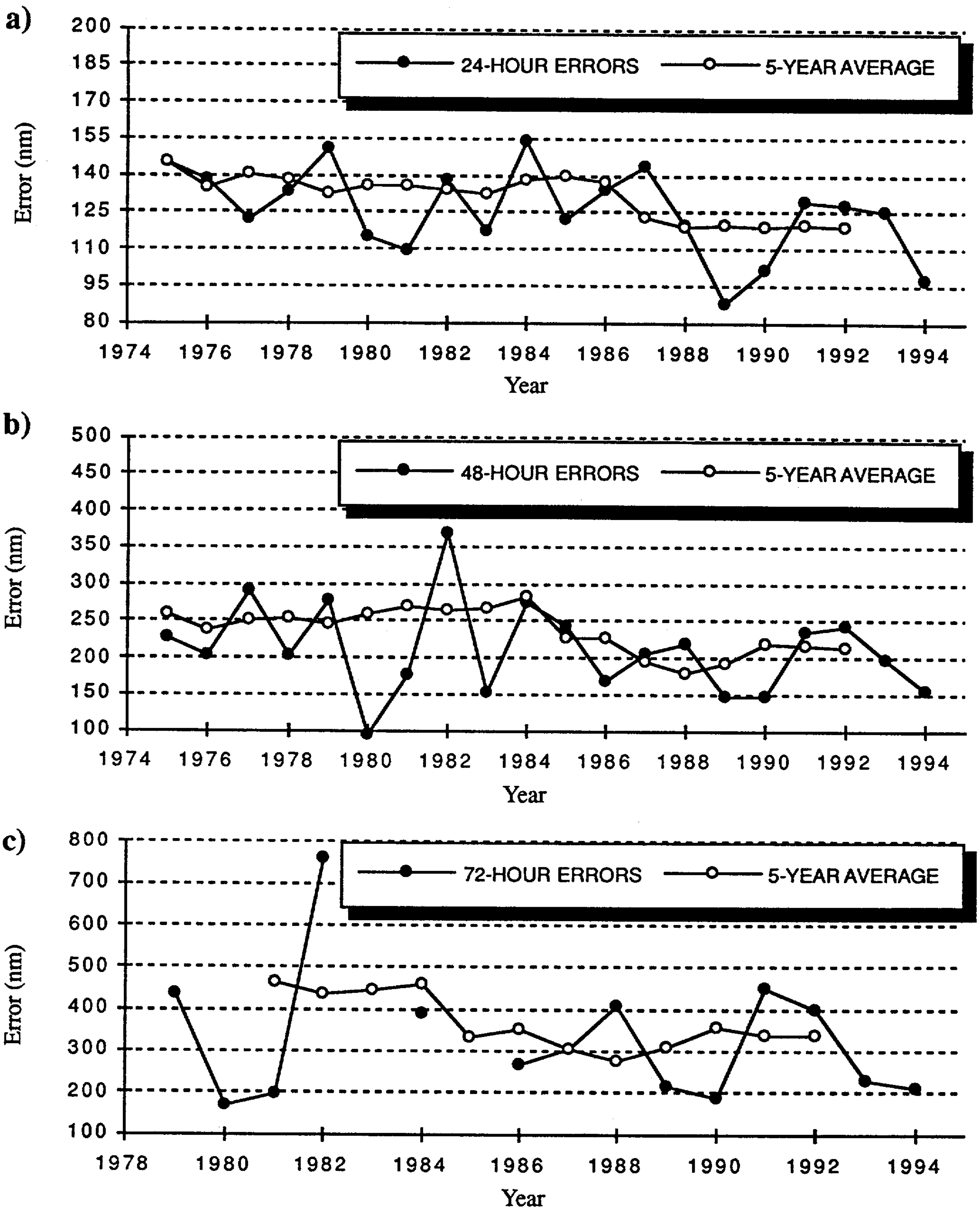


**Figure 5-6** Mean track forecast errors (nm) and 5-year running mean for a) 24 hours, b) 48 hours and c) 72 hours for North Indian Ocean tropical cyclones for the period 1975 to 1994. Note: no 72-hour forecasts verified prior to 1979, and in 1983 and 1985.

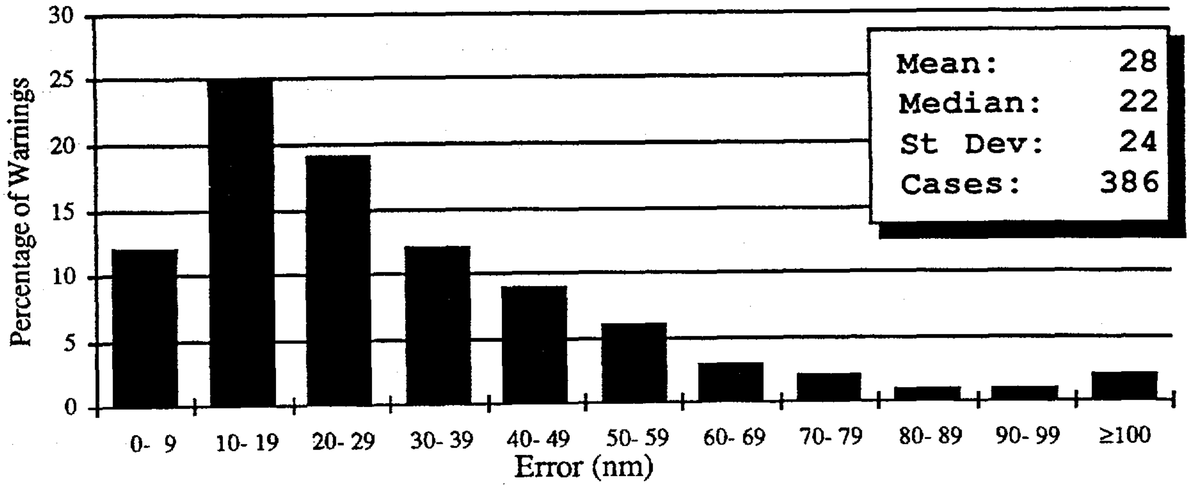


**Figure 5-7a** Frequency distribution of initial warning position errors (10-nm increments) for South Pacific and South Indian Ocean tropical cyclones in 1994. The largest error, 157 nm, occurred on Tropical Cyclone 01S (Alexina).

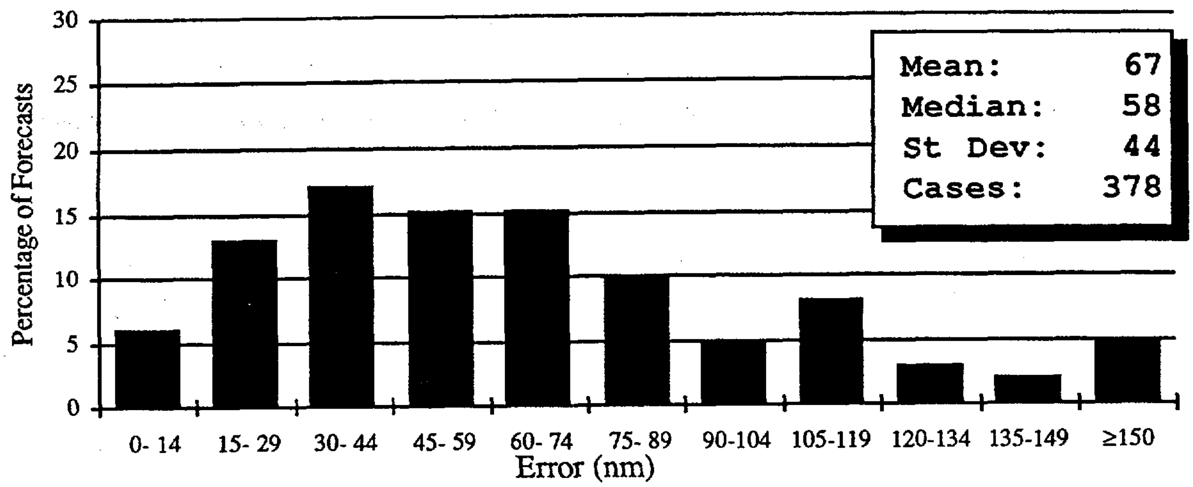


**Figure 5-7b** Frequency distribution of 12-hour track forecast errors (15-nm increments) for South Pacific and South Indian Ocean tropical cyclones in 1994. The largest error, 345 nm, occurred on Tropical Cyclone 29P.

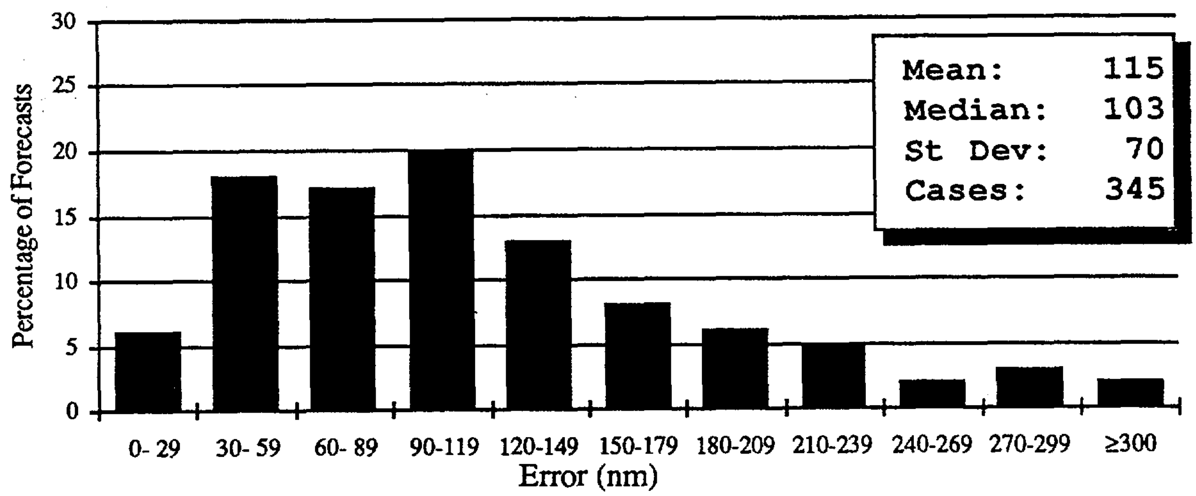


**Figure 5-7c** Frequency distribution of 24-hour track forecast errors (30-nm increments) for in the South Pacific and South Indian Ocean tropical cyclones in 1994. The largest error, 347 nm, occurred on Tropical Cyclone 05P (Rewa).

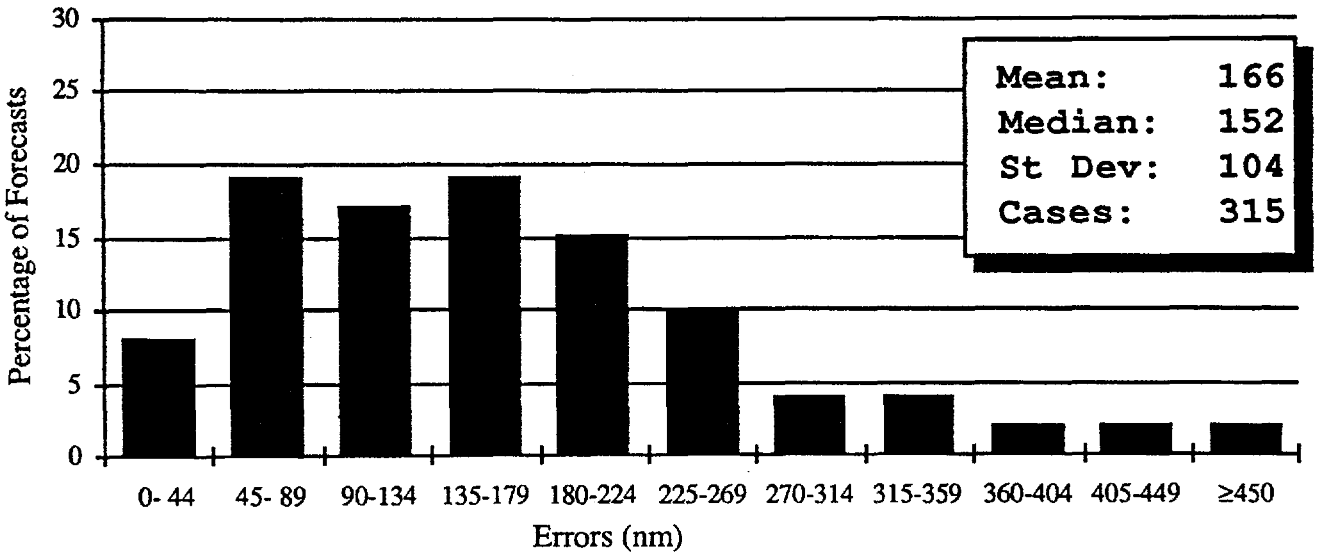


**Figure 5-7d** Frequency distribution of 36-hr track forecast errors (45-nm increments) for in the South Pacific and South Indian Ocean tropical cyclones in 1994. The largest error, 568 nm, occurred on Tropical Cyclone 05P (Rewa).

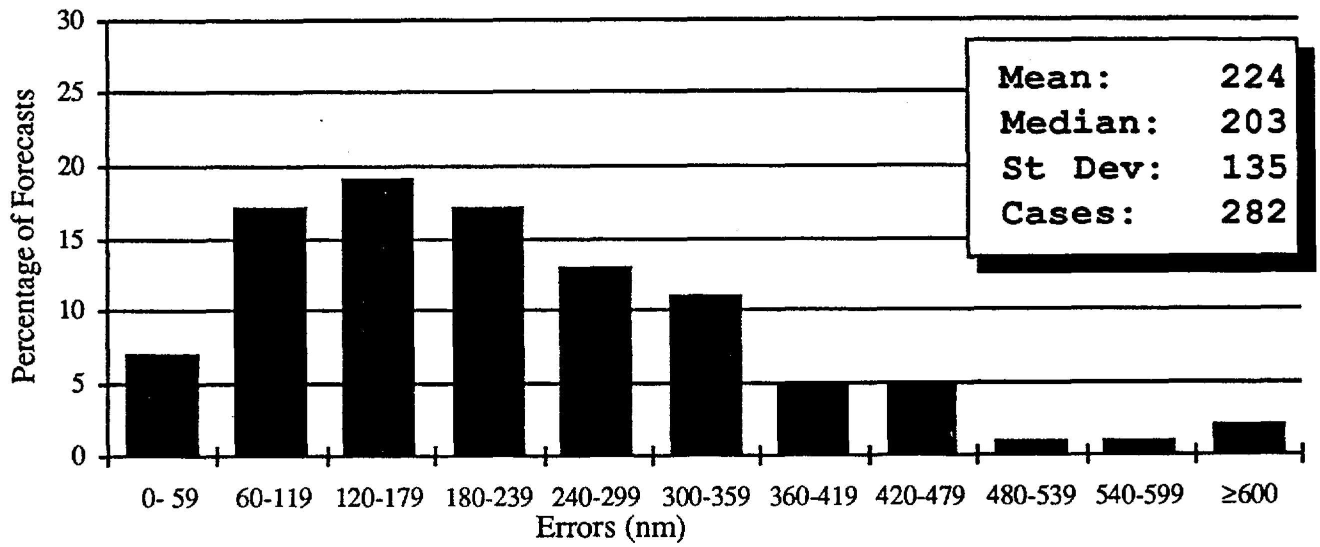


**Figure 5-7e** Frequency distribution of 48-hour track forecast errors (60-nm increments) for in the South Pacific and South Indian Ocean tropical cyclones in 1994. The largest error, 701 nm, occurred on Tropical Cyclone 05P (Rewa).

**Table 5-4** INITIAL POSITION AND FORECAST POSITION ERRORS (NM) FOR THE SOUTHERN HEMISPHERE 1981-1994

| YEAR | NUMBER OF WARNINGS | INITIAL POSITION | NUMBER OF FORECASTS (24-HOUR) | TRACK (24-HOUR) | ALONG (24-HOUR) | CROSS (24-HOUR) | NUMBER OF FORECASTS (48-HOUR) | TRACK (48-HOUR) | ALONG (48-HOUR) | CROSS (48-HOUR) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1981 | 226 | 48 | 190 | 165 | 103 | 106 | 140 | 315 | 204 | 201 |
| 1982 | 275 | 38 | 238 | 144 | 98 | 86 | 176 | 274 | 188 | 164 |
| 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 |
| AVERAGE 1981-1993 | 255 | 34 | 209 | 132 | 90 | 57 | 160 | 248 | 170 | 144 |

*These statistics are for JTWC forecasts only. NPMOC statistics are not included.

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 and along-track errors after-the-fact to extend the data base. See Figure 5-1 for the definitions of cross-track and along-track errors.

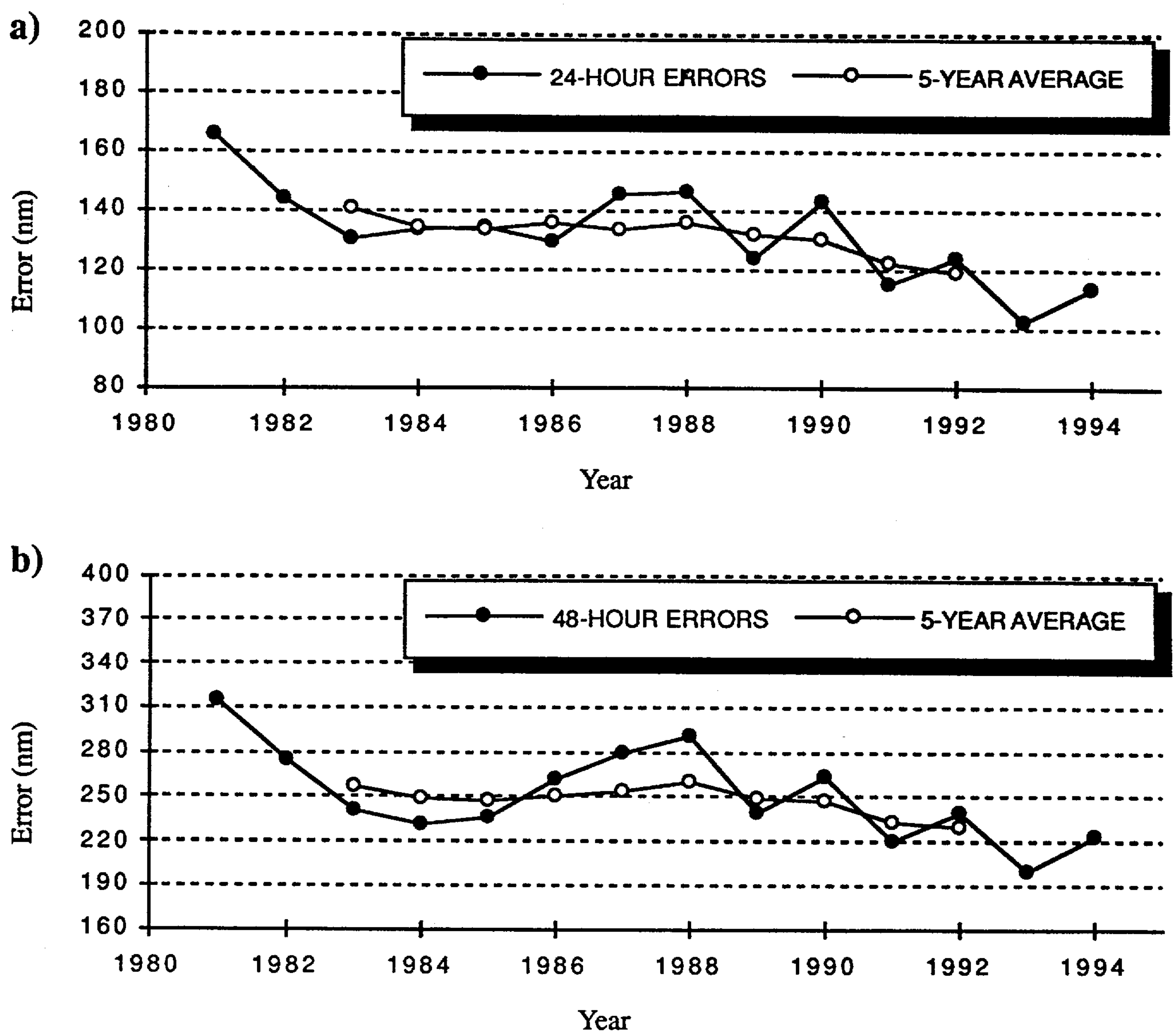


**Figure 5-8** Mean track forecast errors (nm) and 5-year running mean for a) 24 hours and b) 48 hours for South Pacific and South Indian Ocean tropical cyclones for the period 1981 to 1994.

## 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 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 storm to determine which historical storms will be used to compute the forecast. The historical data base is 1945-1981 for the Northwest Pacific, and 1900 to 1990 for the rest of JTWC's AOR. A second climatology-based technique exists on JTWC's Macintosh®™ computers. It employs data bases from 1945 to 1992 and from 1970 to 1994. The latter is referred to as the satellite-era data base. Objective intensity forecasts are available from these data bases. Scatter diagrams of expected tropical cyclone motion at bifurcation points are also available from these data bases.

5.2.2.2 ANALOGS — JTWC's analog and climatology techniques use the same historical data base, except that the analog approach imposes more restrictions on which storms will be used to compute the forecast positions. Analogs in all basins must satisfy time, location, speed, and direction windows, although the window definitions are distinctly different in the Northwest Pacific. In this basin, acceptable analogs are also ranked in terms of a similarity index that includes the above parameters and: storm size and size change, intensity and intensity change, and heights and locations of the 700-mb subtropical ridge and upstream midlatitude trough. In other basins, all acceptable analogs receive equal weighting and a persistence bias is explicitly added to the forecast. In the western North Pacific basin, analog weighting is varied using the similarity index, and a persistence bias is implicitly incorporated by rotating the analog tracks so that they initially match the 12-hr old motion of the current storm. In the AOR, a forecast based on all acceptable straight-running analogs called STRT, as well as a forecast based only on historical recurvers called RECR are available.

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 Northwest 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 FNOC based on the updated 1900-1989 data base.

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 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 Northwest 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) — This objective technique follows the movement of the point of minimum height on the 1000 mb pressure surface analyzed and predicted by NOGAPS. A search in the expected vicinity of the storm is conducted every six hours through 72 hours, even if the tracking routine temporarily fails to discern a minimum height point. Explicit insertion of a tropical cyclone bogus by JTWC began in mid-1990, and has improved the ability of the NOGAPS technique to track the vortex.

5.2.4.2 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).

5.2.4.3 FNOC BETA AND ADVECTION MODEL (FBAM) — This model is an adaptation of the Beta and Advection model used by NMC. 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 CLIMATOLOGY (HPAC) — Forecast positions are 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 simle 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 Northwest 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, 762 cases available for a (homogeneous) comparison, the average forecast error at 12 hours was 74 nm (137 km) for JT92 and 78 nm (145 km) for

**TABLE 5-5** 1994 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE NORTHWEST PACIFIC (1 JAN 1994 - 31 DEC 1994)

12-HOUR MEAN FORECAST ERROR (NM)

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

| | JTWC | | CLIP | | OTCM | | CSUM | | HPAC | | JT92 | | FBAM | | NGPS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JTWC | 1009 | 57 | | | | | | | | | | | | | | |
| | 57 | 0 | | | | | | | | | | | | | | |
| CLIP | 994 | 58 | 1023 | 75 | | | | | | | | | | | | |
| | 74 | 16 | 75 | 0 | | | | | | | | | | | | |
| OTCM | 974 | 57 | 1002 | 73 | 1003 | 76 | | | | | | | | | | |
| | 75 | 18 | 76 | 3 | 76 | 0 | | | | | | | | | | |
| CSUM | 991 | 58 | 1019 | 75 | 1000 | 76 | 1020 | 75 | | | | | | | | |
| | 74 | 16 | 75 | 0 | 74 | -2 | 75 | 0 | | | | | | | | |
| HPAC | 990 | 58 | 1019 | 75 | 999 | 76 | 1016 | 75 | 1019 | 79 | | | | | | |
| | 78 | 20 | 79 | 4 | 77 | 1 | 79 | 4 | 79 | 0 | | | | | | |
| JT92 | 989 | 57 | 1017 | 75 | 998 | 76 | 1015 | 75 | 1014 | 79 | 1018 | 69 | | | | |
| | 68 | 11 | 69 | -6 | 68 | -8 | 69 | -6 | 69 | -10 | 69 | 0 | | | | |
| FBAM | 977 | 58 | 1004 | 75 | 985 | 76 | 1002 | 75 | 1001 | 79 | 1002 | 69 | 1005 | 70 | | |
| | 69 | 11 | 70 | -5 | 69 | -7 | 70 | -5 | 70 | -9 | 70 | 1 | 70 | 0 | | |
| NGPS | 679 | 51 | 678 | 65 | 677 | 68 | 677 | 66 | 676 | 69 | 659 | 59 | 666 | 61 | 686 | 88 |
| | 87 | 36 | 88 | 23 | 88 | 20 | 88 | 22 | 88 | 19 | 88 | 29 | 88 | 27 | 88 | 0 |

24-HOUR MEAN FORECAST ERROR (NM)

| | JTWC | | CLIP | | OTCM | | CSUM | | HPAC | | JT92 | | FBAM | | NGPS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JTWC | 933 | 98 | | | | | | | | | | | | | | |
| | 98 | 0 | | | | | | | | | | | | | | |
| CLIP | 921 | 99 | 953 | 129 | | | | | | | | | | | | |
| | 128 | 29 | 129 | 0 | | | | | | | | | | | | |
| OTCM | 869 | 96 | 899 | 125 | 900 | 119 | | | | | | | | | | |
| | 117 | 21 | 119 | -6 | 119 | 0 | | | | | | | | | | |
| CSUM | 918 | 99 | 949 | 130 | 897 | 119 | 950 | 130 | | | | | | | | |
| | 128 | 29 | 130 | 0 | 127 | 8 | 130 | 0 | | | | | | | | |
| HPAC | 917 | 99 | 949 | 130 | 896 | 119 | 946 | 130 | 949 | 136 | | | | | | |
| | 134 | 35 | 136 | 6 | 132 | 13 | 136 | 6 | 136 | 0 | | | | | | |
| JT92 | 918 | 99 | 949 | 129 | 897 | 119 | 947 | 130 | 946 | 136 | 950 | 116 | | | | |
| | 115 | 16 | 116 | -13 | 114 | -5 | 116 | -14 | 116 | -20 | 116 | 0 | | | | |
| FBAM | 907 | 99 | 937 | 129 | 885 | 119 | 935 | 129 | 934 | 136 | 936 | 116 | 938 | 115 | | |
| | 113 | 14 | 115 | -14 | 113 | -6 | 115 | -14 | 115 | -21 | 115 | -1 | 115 | 0 | | |
| NGPS | 591 | 91 | 589 | 118 | 573 | 107 | 588 | 117 | 588 | 122 | 587 | 104 | 579 | 104 | 594 | 125 |
| | 125 | 34 | 125 | 7 | 126 | 19 | 125 | 8 | 125 | 3 | 125 | 21 | 125 | 21 | 125 | 0 |

**Table 5-5 (CONTINUED)** 1994 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES
IN THE NORTHWESTERN PACIFIC (1 JAN 1994 - 31 DEC 1994)

36-HOUR MEAN FORECAST ERROR (NM)

| | JTWC | | CLIP | | OTCM | | CSUM | | HPAC | | JT92 | | FBAM | | NGPS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JTWC | 860 | 140 | | | | | | | | | | | | | | |
| | 140 | 0 | | | | | | | | | | | | | | |
| CLIP | 850 | 140 | 883 | 190 | | | | | | | | | | | | |
| | 187 | 47 | 190 | 0 | | | | | | | | | | | | |
| OTCM | 777 | 138 | 806 | 183 | 807 | 168 | | | | | | | | | | |
| | 165 | 27 | 168 | -15 | 168 | 0 | | | | | | | | | | |
| CSUM | 847 | 140 | 879 | 190 | 804 | 168 | 880 | 187 | | | | | | | | |
| | 183 | 43 | 187 | -3 | 183 | 15 | 187 | 0 | | | | | | | | |
| HPAC | 846 | 140 | 879 | 190 | 803 | 168 | 876 | 187 | 879 | 192 | | | | | | |
| | 189 | 49 | 192 | 2 | 188 | 20 | 192 | 5 | 192 | 0 | | | | | | |
| JT92 | 847 | 140 | 879 | 190 | 804 | 167 | 877 | 187 | 876 | 192 | 880 | 170 | | | | |
| | 167 | 27 | 170 | -20 | 165 | -2 | 170 | -17 | 170 | -22 | 170 | 0 | | | | |
| FBAM | 838 | 140 | 869 | 189 | 795 | 167 | 867 | 186 | 866 | 192 | 868 | 169 | 870 | 172 | | |
| | 169 | 29 | 172 | -17 | 171 | 4 | 172 | -14 | 172 | -20 | 172 | 3 | 172 | 0 | | |
| NGPS | 503 | 131 | 500 | 176 | 471 | 151 | 499 | 173 | 499 | 176 | 499 | 155 | 492 | 159 | 504 | 161 |
| | 161 | 30 | 161 | -15 | 161 | 10 | 161 | -12 | 161 | -15 | 161 | 6 | 161 | 2 | 161 | 0 |

48-HOUR MEAN FORECAST ERROR (NM)

| | JTWC | | CLIP | | OTCM | | CSUM | | HPAC | | JT92 | | FBAM | | NGPS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JTWC | 754 | 176 | | | | | | | | | | | | | | |
| | 176 | 0 | | | | | | | | | | | | | | |
| CLIP | 745 | 177 | 806 | 251 | | | | | | | | | | | | |
| | 243 | 66 | 251 | 0 | | | | | | | | | | | | |
| OTCM | 657 | 173 | 712 | 244 | 713 | 213 | | | | | | | | | | |
| | 206 | 33 | 213 | -31 | 213 | 0 | | | | | | | | | | |
| CSUM | 742 | 177 | 802 | 252 | 710 | 213 | 803 | 241 | | | | | | | | |
| | 229 | 5 | 241 | -11 | 235 | 22 | 241 | 0 | | | | | | | | |
| HPAC | 741 | 177 | 802 | 251 | 709 | 213 | 799 | 242 | 802 | 247 | | | | | | |
| | 238 | 61 | 247 | -4 | 242 | 29 | 247 | 5 | 247 | 0 | | | | | | |
| JT92 | 742 | 177 | 802 | 251 | 711 | 213 | 800 | 241 | 799 | 246 | 803 | 228 | | | | |
| | 222 | 45 | 228 | -23 | 223 | 10 | 228 | -13 | 228 | -18 | 228 | 0 | | | | |
| FBAM | 736 | 175 | 794 | 251 | 703 | 214 | 792 | 241 | 791 | 247 | 793 | 228 | 795 | 232 | | |
| | 226 | 49 | 232 | -19 | 229 | 15 | 233 | -8 | 232 | 15 | 232 | 4 | 232 | 0 | | |
| NGPS | 431 | 166 | 430 | 233 | 398 | 194 | 429 | 223 | 429 | 221 | 430 | 209 | 424 | 215 | 434 | 196 |
| | 196 | 30 | 196 | -37 | 197 | 3 | 196 | -27 | 196 | -25 | 196 | -13 | 197 | -18 | 196 | 0 |

72-HOUR MEAN FORECAST ERROR (NM)

| | JTWC | | CLIP | | OTCM | | CSUM | | HPAC | | JT92 | | FBAM | | NGPS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JTWC | 609 | 242 | | | | | | | | | | | | | | |
| | 242 | 0 | | | | | | | | | | | | | | |
| CLIP | 602 | 242 | 663 | 361 | | | | | | | | | | | | |
| | 346 | 104 | 361 | 0 | | | | | | | | | | | | |
| OTCM | 503 | 237 | 550 | 358 | 551 | 309 | | | | | | | | | | |
| | 294 | 57 | 308 | -50 | 309 | 0 | | | | | | | | | | |
| CSUM | 599 | 242 | 659 | 361 | 548 | 308 | 660 | 343 | | | | | | | | |
| | 330 | 88 | 344 | -17 | 338 | 30 | 343 | 0 | | | | | | | | |
| HPAC | 598 | 242 | 659 | 361 | 547 | 308 | 656 | 344 | 659 | 348 | | | | | | |
| | 332 | 90 | 348 | -13 | 349 | 41 | 348 | 4 | 348 | 0 | | | | | | |
| JT92 | 529 | 238 | 581 | 363 | 481 | 301 | 579 | 340 | 578 | 349 | 582 | 342 | | | | |
| | 334 | 96 | 342 | -21 | 333 | 32 | 342 | 2 | 342 | -7 | 342 | 0 | | | | |
| FBAM | 594 | 244 | 652 | 362 | 543 | 309 | 650 | 343 | 649 | 349 | 577 | 342 | 653 | 345 | | |
| | 332 | 88 | 344 | -18 | 342 | 33 | 345 | 2 | 344 | -5 | 339 | -3 | 345 | 0 | | |
| NGPS | 300 | 232 | 298 | 350 | 271 | 278 | 297 | 334 | 297 | 316 | 265 | 322 | 295 | 331 | 300 | 254 |
| | 254 | 22 | 254 | -96 | 257 | -21 | 255 | -79 | 253 | -63 | 255 | -67 | 254 | -77 | 254 | 0 |

**TABLE 5-6** 1994 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE NORTH INDIAN OCEAN (1 JAN 1994 - 31 DEC 1994)

### 12-HOUR MEAN FORECAST ERROR (NM)

| | JTWC | | CLIP | | OTCM | | HPAC | | FBAM | | CLIM | | NGPS | | STRT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JTWC | 53 | 57 | | | | | | | | | | | | | | |
| | 57 | 0 | | | | | | | | | | | | | | |
| CLIP | 53 | 57 | 53 | 67 | | | | | | | | | | | | |
| | 67 | 10 | 67 | 0 | | | | | | | | | | | | |
| OTCM | 53 | 57 | 53 | 67 | 53 | 61 | | | | | | | | | | |
| | 61 | 4 | 61 | -6 | 61 | 0 | | | | | | | | | | |
| HPAC | 52 | 57 | 52 | 67 | 52 | 61 | 52 | 68 | | | | | | | | |
| | 68 | 11 | 68 | 1 | 68 | 7 | 68 | 0 | | | | | | | | |
| FBAM | 52 | 56 | 52 | 64 | 52 | 59 | 51 | 66 | 52 | 62 | | | | | | |
| | 62 | 6 | 62 | -2 | 62 | 3 | 61 | -5 | 62 | 0 | | | | | | |
| CLIM | 53 | 57 | 53 | 67 | 53 | 61 | 52 | 68 | 52 | 62 | 53 | 72 | | | | |
| | 72 | 15 | 72 | 5 | 72 | 11 | 72 | 4 | 69 | 7 | 72 | 0 | | | | |
| NGPS | 21 | 53 | 21 | 51 | 21 | 47 | 20 | 55 | 21 | 53 | 26 | 56 | 21 | 120 | | |
| | 120 | 67 | 120 | 69 | 120 | 73 | 117 | 62 | 120 | 67 | 77 | 64 | 120 | 0 | | |
| STRT | 33 | 52 | 33 | 60 | 33 | 58 | 33 | 64 | 33 | 60 | 33 | 68 | 12 | 96 | 33 | 88 |
| | 88 | 36 | 88 | 28 | 88 | 30 | 88 | 24 | 88 | 28 | 88 | 20 | 70 | -26 | 88 | 0 |

### 24-HOUR MEAN FORECAST ERROR (NM)

| | JTWC | | CLIP | | OTCM | | HPAC | | FBAM | | CLIM | | NGPS | | STRT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JTWC | 44 | 97 | | | | | | | | | | | | | | |
| | 97 | 0 | | | | | | | | | | | | | | |
| CLIP | 44 | 97 | 44 | 106 | | | | | | | | | | | | |
| | 106 | 9 | 106 | 0 | | | | | | | | | | | | |
| OTCM | 44 | 97 | 44 | 106 | 44 | 86 | | | | | | | | | | |
| | 86 | -11 | 86 | -20 | 86 | 0 | | | | | | | | | | |
| HPAC | 43 | 98 | 43 | 107 | 43 | 86 | 43 | 108 | | | | | | | | |
| | 108 | 10 | 108 | 1 | 108 | 22 | 108 | 0 | | | | | | | | |
| FBAM | 44 | 97 | 44 | 106 | 44 | 86 | 43 | 108 | 44 | 102 | | | | | | |
| | 102 | 5 | 102 | -4 | 102 | 16 | 101 | -7 | 102 | 0 | | | | | | |
| CLIM | 44 | 97 | 44 | 106 | 44 | 86 | 43 | 108 | 44 | 102 | 44 | 118 | | | | |
| | 118 | 21 | 118 | 12 | 118 | 32 | 118 | 10 | 118 | 16 | 118 | 0 | | | | |
| NGPS | 16 | 94 | 16 | 87 | 16 | 82 | 15 | 97 | 16 | 91 | 16 | 99 | 16 | 208 | | |
| | 208 | 114 | 208 | 121 | 208 | 126 | 209 | 112 | 208 | 117 | 208 | 109 | 208 | 0 | | |
| STRT | 27 | 92 | 27 | 91 | 27 | 74 | 27 | 102 | 27 | 98 | 27 | 115 | 8 | 187 | 27 | 150 |
| | 150 | 56 | 150 | 59 | 150 | 76 | 150 | 48 | 150 | 52 | 150 | 35 | 113 | -74 | 150 | 0 |

### 36-HOUR MEAN FORECAST ERROR (NM)

| | JTWC | | CLIP | | OTCM | | HPAC | | FBAM | | CLIM | | NGPS | | STRT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JTWC | 36 | 134 | | | | | | | | | | | | | | |
| | 134 | 0 | | | | | | | | | | | | | | |
| CLIP | 36 | 134 | 36 | 154 | | | | | | | | | | | | |
| | 154 | 20 | 154 | 0 | | | | | | | | | | | | |
| OTCM | 35 | 124 | 35 | 145 | 35 | 123 | | | | | | | | | | |
| | 123 | -1 | 123 | -22 | 123 | 0 | | | | | | | | | | |
| HPAC | 35 | 136 | 35 | 155 | 34 | 122 | 35 | 159 | | | | | | | | |
| | 159 | 23 | 159 | 4 | 151 | 29 | 159 | 0 | | | | | | | | |
| FBAM | 36 | 134 | 36 | 154 | 35 | 123 | 35 | 159 | 36 | 159 | | | | | | |
| | 159 | 25 | 159 | 5 | 150 | 27 | 157 | -2 | 159 | 0 | | | | | | |
| CLIM | 36 | 134 | 36 | 154 | 35 | 123 | 35 | 159 | 36 | 159 | 36 | 193 | | | | |
| | 193 | 59 | 193 | 39 | 184 | 61 | 194 | 35 | 193 | 34 | 193 | 0 | | | | |
| NGPS | 12 | 110 | 12 | 113 | 12 | 125 | 11 | 131 | 12 | 105 | 12 | 173 | 12 | 313 | | |
| | 313 | 203 | 313 | 200 | 313 | 188 | 321 | 190 | 313 | 208 | 313 | 140 | 313 | 0 | | |
| STRT | 21 | 121 | 21 | 133 | 21 | 112 | 21 | 151 | 21 | 151 | 21 | 209 | 5 | 279 | 21 | 214 |
| | 214 | 93 | 214 | 81 | 214 | 102 | 214 | 63 | 214 | 63 | 214 | 5 | 188 | -91 | 214 | 0 |

**TABLE 5-6 (CONTINUED) 1994 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE NORTH INDIAN OCEAN (1 JAN 1994 - 31 DEC 1994)**

48-HOUR MEAN FORECAST ERROR (NM)

| | JTWC | CLIP | OTCM | HPAC | FBAM | CLIM | NGPS | STRT |
|---|---|---|---|---|---|---|---|---|
| JTWC | 28 154 | | | | | | | |
| | 154 0 | | | | | | | |
| CLIP | 28 154 | 28 197 | | | | | | |
| | 197 43 | 197 0 | | | | | | |
| OTCM | 26 148 | 26 186 | 26 172 | | | | | |
| | 172 24 | 172 -14 | 172 0 | | | | | |
| HPAC | 27 156 | 27 200 | 25 171 | 27 219 | | | | |
| | 219 63 | 219 19 | 216 45 | 219 0 | | | | |
| FBAM | 28 154 | 28 197 | 26 172 | 27 219 | 28 194 | | | |
| | 194 40 | 194 -3 | 182 10 | 190 -29 | 194 0 | | | |
| CLIM | 28 154 | 28 197 | 26 172 | 27 219 | 28 194 | 28 268 | | |
| | 268 114 | 268 71 | 271 99 | 268 49 | 268 74 | 268 0 | | |
| NGPS | 9 128 | 9 173 | 9 202 | 8 208 | 9 137 | 9 235 | 9 412 | |
| | 412 284 | 412 239 | 412 210 | 437 229 | 412 275 | 412 177 | 412 0 | |
| STRT | 15 152 | 15 184 | 15 156 | 15 234 | 15 200 | 15 330 | 2 327 | 15 288 |
| | 288 136 | 288 104 | 288 132 | 288 54 | 288 88 | 288 -42 | 220 -107 | 288 0 |

72-HOUR MEAN FORECAST ERROR (NM)

| | JTWC | CLIP | OTCM | HPAC | FBAM | CLIM | NGPS | STRT |
|---|---|---|---|---|---|---|---|---|
| JTWC | 13 213 | | | | | | | |
| | 213 0 | | | | | | | |
| CLIP | 13 213 | 13 345 | | | | | | |
| | 345 132 | 345 0 | | | | | | |
| OTCM | 12 220 | 12 347 | 12 345 | | | | | |
| | 345 125 | 345 -2 | 345 0 | | | | | |
| HPAC | 12 217 | 12 353 | 11 356 | 12 419 | | | | |
| | 419 202 | 419 66 | 435 79 | 419 0 | | | | |
| FBAM | 13 213 | 13 345 | 12 345 | 12 419 | 13 270 | | | |
| | 270 57 | 270 -75 | 277 -68 | 261 -158 | 270 0 | | | |
| CLIM | 13 213 | 13 345 | 12 345 | 12 419 | 13 270 | 13 469 | | |
| | 469 256 | 469 124 | 481 136 | 463 44 | 469 199 | 469 0 | | |
| NGPS | 6 173 | 6 357 | 5 304 | 5 366 | 6 219 | 6 431 | 6 488 | |
| | 488 315 | 488 131 | 459 155 | 574 208 | 488 269 | 488 57 | 488 0 | |
| STRT | 6 233 | 6 325 | 6 254 | 6 486 | 6 342 | 6 574 | 1 105 | 6 453 |
| | 453 220 | 453 128 | 453 199 | 453 -33 | 453 111 | 453 -121 | 274 169 | 453 0 |

CLIP. The difference of 4 nm (7 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 5-7** 1994 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE SOUTHERN HEMISPHERE (1 JUL 1993 - 30 JUN 1994)

12-HOUR MEAN FORECAST ERROR (NM)

| | JTWC | | CLIP | | OTCM | | HPAC | | FBAM | | CLIM | | NGPS | | STRT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JTWC | 378 | 67 | | | | | | | | | | | | | | |
| | 67 | 0 | | | | | | | | | | | | | | |
| CLIP | 350 | 67 | 493 | 95 | | | | | | | | | | | | |
| | 103 | 36 | 95 | 0 | | | | | | | | | | | | |
| OTCM | 350 | 67 | 493 | 95 | 493 | 92 | | | | | | | | | | |
| | 99 | 32 | 92 | -3 | 92 | 0 | | | | | | | | | | |
| HPAC | 350 | 67 | 493 | 95 | 493 | 92 | 493 | 90 | | | | | | | | |
| | 96 | 29 | 90 | -5 | 90 | -2 | 90 | 0 | | | | | | | | |
| FBAM | 334 | 67 | 474 | 97 | 474 | 93 | 474 | 91 | 474 | 90 | | | | | | |
| | 96 | 29 | 90 | -7 | 90 | -3 | 90 | -1 | 90 | 0 | | | | | | |
| CLIM | 350 | 67 | 493 | 95 | 493 | 92 | 493 | 90 | 474 | 90 | 493 | 100 | | | | |
| | 105 | 38 | 100 | 5 | 100 | 8 | 100 | 10 | 100 | 10 | 100 | 0 | | | | |
| NGPS | 161 | 64 | 202 | 81 | 202 | 81 | 202 | 78 | 197 | 75 | 202 | 88 | 267 | 116 | | |
| | 117 | 53 | 118 | 37 | 118 | 37 | 118 | 40 | 117 | 42 | 118 | 30 | 116 | 0 | | |
| STRT | 247 | 69 | 349 | 95 | 349 | 96 | 349 | 92 | 336 | 94 | 349 | 100 | 147 | 120 | 349 | 111 |
| | 117 | 48 | 111 | 16 | 111 | 15 | 111 | 19 | 113 | 19 | 111 | 11 | 98 | -22 | 111 | 0 |

24-HOUR MEAN FORECAST ERROR (NM)

| | JTWC | | CLIP | | OTCM | | HPAC | | FBAM | | CLIM | | NGPS | | STRT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JTWC | 345 | 115 | | | | | | | | | | | | | | |
| | 115 | 0 | | | | | | | | | | | | | | |
| CLIP | 324 | 115 | 471 | 154 | | | | | | | | | | | | |
| | 161 | 46 | 154 | 0 | | | | | | | | | | | | |
| OTCM | 309 | 114 | 453 | 153 | 453 | 144 | | | | | | | | | | |
| | 150 | 36 | 144 | -9 | 144 | 0 | | | | | | | | | | |
| HPAC | 324 | 115 | 471 | 154 | 453 | 144 | 471 | 141 | | | | | | | | |
| | 145 | 30 | 141 | -13 | 140 | -4 | 141 | 0 | | | | | | | | |
| FBAM | 309 | 116 | 453 | 155 | 436 | 145 | 453 | 141 | 453 | 146 | | | | | | |
| | 152 | 36 | 146 | -9 | 145 | 0 | 146 | 5 | 146 | 0 | | | | | | |
| CLIM | 324 | 115 | 471 | 154 | 453 | 144 | 471 | 141 | 453 | 146 | 471 | 169 | | | | |
| | 172 | 57 | 169 | 15 | 169 | 25 | 169 | 28 | 168 | 22 | 169 | 0 | | | | |
| NGPS | 145 | 112 | 184 | 138 | 179 | 136 | 184 | 133 | 179 | 133 | 184 | 161 | 244 | 180 | | |
| | 176 | 64 | 179 | 41 | 176 | 40 | 179 | 46 | 178 | 45 | 179 | 18 | 180 | 0 | | |
| STRT | 232 | 112 | 337 | 145 | 324 | 142 | 337 | 134 | 324 | 146 | 337 | 159 | 132 | 175 | 337 | 175 |
| | 176 | 64 | 175 | 30 | 177 | 35 | 175 | 4 1 | 177 | 31 | 175 | 16 | 161 | -14 | 175 | 0 |

36-HOUR MEAN FORECAST ERROR (NM)

| | JTWC | | CLIP | | OTCM | | HPAC | | FBAM | | CLIM | | NGPS | | STRT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JTWC | 315 | 166 | | | | | | | | | | | | | | |
| | 166 | 0 | | | | | | | | | | | | | | |
| CLIP | 299 | 168 | 437 | 188 | | | | | | | | | | | | |
| | 192 | 24 | 188 | 0 | | | | | | | | | | | | |
| OTCM | 278 | 166 | 410 | 189 | 410 | 191 | | | | | | | | | | |
| | 191 | 25 | 191 | 2 | 191 | 0 | | | | | | | | | | |
| HPAC | 299 | 168 | 437 | 188 | 410 | 191 | 437 | 179 | | | | | | | | |
| | 178 | 10 | 179 | -9 | 181 | -10 | 179 | 0 | | | | | | | | |
| FBAM | 285 | 168 | 240 | 188 | 394 | 192 | 420 | 179 | 420 | 201 | | | | | | |
| | 196 | 28 | 201 | 13 | 198 | 6 | 201 | 22 | 201 | 0 | | | | | | |
| CLIM | 299 | 168 | 437 | 188 | 410 | 191 | 437 | 179 | 420 | 201 | 437 | 218 | | | | |
| | 216 | 48 | 218 | 30 | 221 | 30 | 218 | 39 | 217 | 16 | 218 | 0 | | | | |
| NGPS | 127 | 171 | 164 | 193 | 156 | 200 | 164 | 194 | 159 | 203 | 164 | 230 | 221 | 242 | | |
| | 228 | 57 | 240 | 47 | 234 | 34 | 240 | 46 | 239 | 36 | 240 | 10 | 242 | 0 | | |
| STRT | 224 | 161 | 326 | 174 | 303 | 176 | 326 | 163 | 314 | 195 | 326 | 200 | 116 | 228 | 326 | 225 |
| | 215 | 54 | 225 | 51 | 230 | 54 | 225 | 62 | 226 | 31 | 225 | 25 | 231 | 3 | 225 | 0 |

**TABLE 5-7 (CONTINUED)**

1994 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES
IN THE SOUTHERN HEMISPHERE (1 JUL 1993 - 30 JUN 1994)

48-HOUR MEAN FORECAST ERROR (NM)

| | JTWC | | CLIP | | OTCM | | HPAC | | FBAM | | CLIM | | NGPS | | STRT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JTWC | 282 | 224 | | | | | | | | | | | | | | |
| | 224 | 0 | | | | | | | | | | | | | | |
| CLIP | 266 | 226 | 400 | 240 | | | | | | | | | | | | |
| | 241 | 15 | 240 | 0 | | | | | | | | | | | | |
| OTCM | 239 | 222 | 365 | 240 | 365 | 261 | | | | | | | | | | |
| | 256 | 34 | 261 | 21 | 261 | 0 | | | | | | | | | | |
| HPAC | 266 | 226 | 400 | 240 | 365 | 261 | 400 | 236 | | | | | | | | |
| | 232 | 6 | 236 | -4 | 237 | -24 | 236 | 0 | | | | | | | | |
| FBAM | 256 | 227 | 388 | 241 | 354 | 264 | 388 | 237 | 388 | 276 | | | | | | |
| | 264 | 37 | 276 | 35 | 270 | 6 | 276 | 39 | 276 | 0 | | | | | | |
| CLIM | 266 | 226 | 400 | 240 | 365 | 261 | 400 | 236 | 388 | 276 | 400 | 277 | | | | |
| | 271 | 45 | 277 | 37 | 282 | 21 | 277 | 41 | 277 | 1 | 277 | 0 | | | | |
| NGPS | 112 | 241 | 143 | 256 | 128 | 279 | 143 | 266 | 140 | 280 | 143 | 297 | 190 | 310 | | |
| | 297 | 56 | 307 | 51 | 295 | 16 | 307 | 40 | 305 | 25 | 307 | 10 | 310 | 0 | | |
| STRT | 204 | 214 | 303 | 225 | 273 | 240 | 303 | 216 | 294 | 269 | 303 | 259 | 99 | 292 | 303 | 294 |
| | 279 | 65 | 294 | 69 | 297 | 57 | 294 | 78 | 296 | 27 | 294 | 35 | 310 | 18 | 294 | 0 |

72-HOUR MEAN FORECAST ERROR (NM)

| | CLIP | | OTCM | | HPAC | | FBAM | | CLIM | | NGPS | | STRT | | RECR | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CLIP | 334 | 334 | | | | | | | | | | | | | | |
| | 334 | 0 | | | | | | | | | | | | | | |
| OTCM | 277 | 338 | 277 | 371 | | | | | | | | | | | | |
| | 371 | 33 | 371 | 0 | | | | | | | | | | | | |
| HPAC | 334 | 334 | 277 | 371 | 334 | 335 | | | | | | | | | | |
| | 335 | 1 | 333 | -38 | 335 | 0 | | | | | | | | | | |
| FBAM | 325 | 338 | 269 | 375 | 325 | 339 | 325 | 445 | | | | | | | | |
| | 445 | 107 | 425 | 50 | 445 | 106 | 445 | 0 | | | | | | | | |
| CLIM | 334 | 334 | 277 | 371 | 334 | 335 | 325 | 445 | 334 | 374 | | | | | | |
| | 374 | 40 | 388 | 17 | 374 | 39 | 376 | -69 | 374 | 0 | | | | | | |
| NGPS | 104 | 363 | 78 | 412 | 104 | 392 | 102 | 438 | 104 | 412 | 135 | 423 | | | | |
| | 427 | 64 | 417 | 5 | 427 | 35 | 430 | -8 | 427 | 15 | 423 | 0 | | | | |
| STRT | 259 | 327 | 216 | 350 | 259 | 315 | 252 | 433 | 259 | 362 | 77 | 432 | 259 | 429 | | |
| | 429 | 102 | 418 | 68 | 429 | 114 | 431 | -2 | 429 | 67 | 484 | 52 | 429 | 0 | | |
| RECR | 306 | 333 | 257 | 367 | 306 | 329 | 297 | 441 | 306 | 383 | 97 | 437 | 244 | 413 | 306 | 373 |
| | 373 | 40 | 375 | 8 | 373 | 44 | 379 | -62 | 373 | -10 | 426 | -11 | 356 | -57 | 373 | 0 |