# The Variation of Track Forecast Difficulty among Tropical Cyclone Basins

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ABSTRACT

Tropical cyclone track forecast error ranges widely among individual storms, as well as globally. To study its regional variability, structurally identical climatology-and-persistence (CLIPER) track forecast models were constructed for the six major tropical cyclone basins of the world. Developmental errors of the models are compared as forecast difficulty levels (FDLs). The range of FDLs among the basins is >2:1, with the more difficult basins having the more poleward-average storm latitudes.

## 1. Introduction

Although tropical cyclone forecasts can be verified in several ways, the principal verification yardstick is given by the distance between an operationally forecast storm position and the later determined best-track position[1] that was valid at the same time. This distance, typically measured along a great circle, is referred to as tropical cyclone forecast error. The term "vector-error" is sometimes used, although that nomenclature is rather imprecise, because only the magnitude of the vector is considered. Accordingly, the term *forecast error* is used here.

Unfortunately, tropical cyclone forecast error is a rather frail statistic, because it does not address the question of skill. Skill is generally defined (American Meteorological Society, 1979) as the ability to improve upon simple techniques such as those based on climatology and persistence. Forecast errors of the Atlantic CLIPER model (Neumann and Pelissier, 1981a), which uses regression equations based only on predictors that have been derived from climatology and persistence, are a convenient definition of threshold skill level. Recent studies (Neumann, 1981; Neumann and Pelissier, 1981a,b) use this concept to assess relative skill.

It can be demonstrated that threshold skill level varies widely from one forecast situation to another (Neumann, 1981). For example, in some portions of the Atlantic tropical cyclone basin, such as the Caribbean Sea and most of the Gulf of Mexico, tropical cyclones typically adhere to persistent, climatological tracks; forecast errors are relatively low but the skill threshold is also very low. In other areas, such as the open Atlantic poleward of latitude 20°N, much more skill is needed to attain a comparably low forecast error. This study attempts to quantify the global variability of threshold skill by developing CLIPER-type models for the six major tropical cyclone regions of the world illustrated in Fig. 1 (taken from Crutcher and Quayle, 1974).

## 2. The concept of forecast difficulty

Neumann (1981) uses the concept of forecast difficulty level (FDL). He defines that quantity as the forecast error produced by the Atlantic CLIPER model using best-track, rather than operational, input data. The FDL is a measure of the inherent "difficulty" associated with a given forecast situation. Storms having persistent, climatological tracks will have low FDL, whereas those with nonpersistent, nonclimatological tracks would be expected to have high FDL.

Over the Atlantic basin, average FDL varies considerably from one year to another. During 1950 through 1986, for example, the yearly average of 24-h FDL varied from a low of 114 km for 1970 to a high of 209 km for 1972. Among individual storms, the differences of average 24-h FDL are even more pronounced, ranging from a low of 86 km for Hurricane Baker (1950) to a high of 264 km for Hurricane Dawn (1972). This comparison between individual storms includes only those storms during which at least 5 days of forecasts were available. Obviously, these differences must be accounted for when the question of skill is addressed.

This study extends the concept of FDL beyond the North Atlantic basin to other tropical cyclone basins. Are forecasts in tropical cyclone basin "A" inherently more difficult than those in tropical cyclone basin "B"? Such questions often arise in the comparison of operational forecast errors among basins. For example, unpublished National Weather Service data show that during 1979–85, the average 72-h error for North Atlantic official tropical cyclone forecasts was 665 km,

[1] The best track is defined as the accepted track of a storm after a postanalysis of all available information.

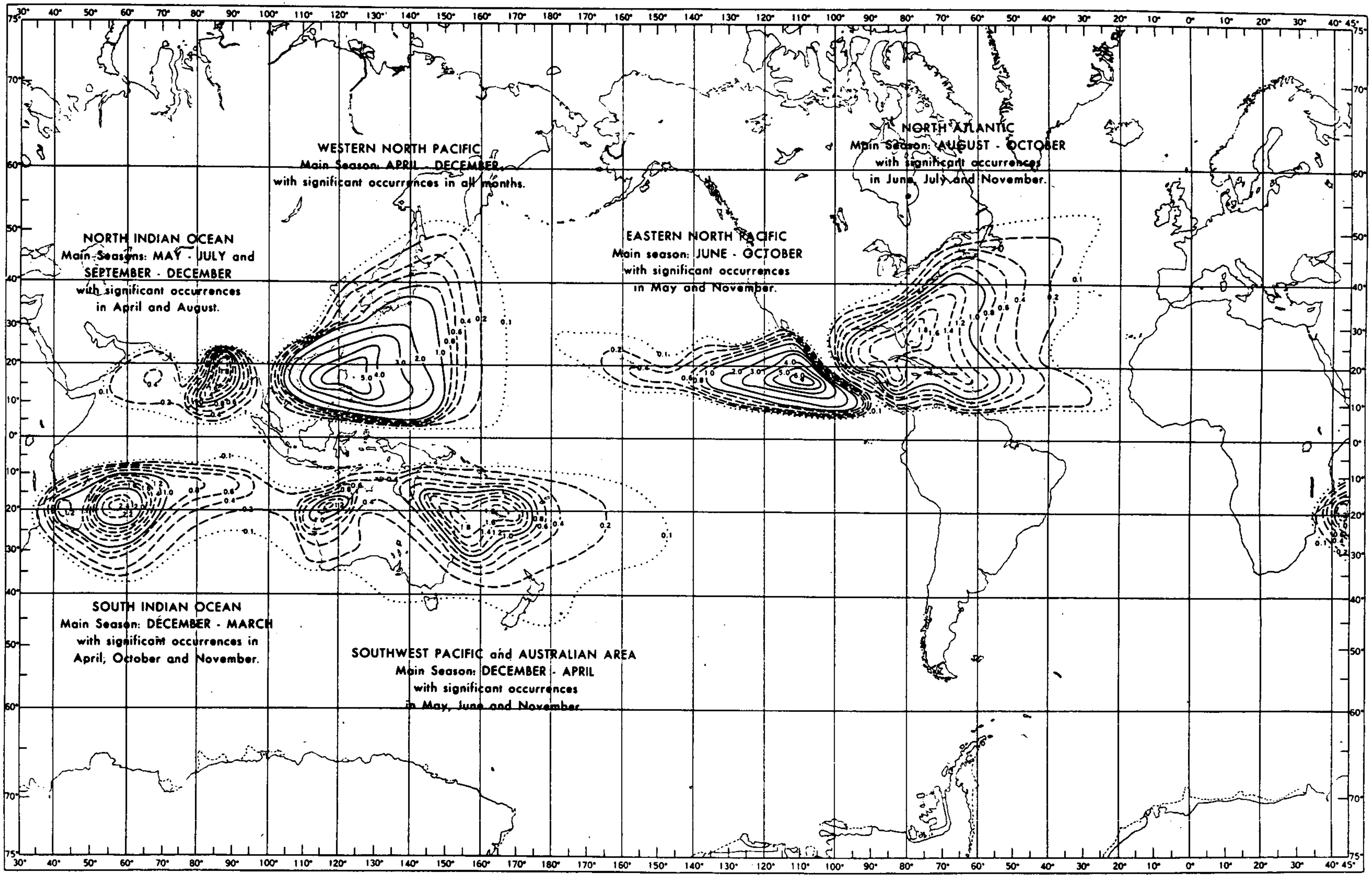


FIG. 1. The six major tropical cyclone basins of the world, in terms of number of storms per 5° square per year (Crutcher and Quayle, 1974). Southwest, rather than south, Indian Ocean is used in the text.

TABLE 1. Periods and case numbers by basin for track forecast difficulty study.

| Basin | Period | Cases 12 h | 24 h | 36 h | 48 h | 60 h | 72 h |
|---|---|---|---|---|---|---|---|
| North Atlantic | 1946–1982 | 2424 | 2122 | 1854 | 1617 | 1410 | 1168 |
| Eastern North Pacific | 1949–1982 | 2182 | 1855 | 1565 | 1314 | 1095 | 913 |
| Western North Pacific | 1946–1982 | 6818 | 5982 | 5209 | 4518 | 3883 | 3211 |
| North Indian | 1877–1982 | 1334 | 975 | 696 | 497 | 351 | 254 |
| Southwest Indian | 1946–1982 | 2393 | 2107 | 1850 | 1613 | 1415 | 1244 |
| Southwest Pacific–Australian | 1946–1982 | 2944 | 2601 | 2298 | 2020 | 1742 | 1510 |

while that for official forecasts in the eastern North Pacific basin was only 460 km. However, the latter basin has a lower mean FDL than the Atlantic, because its storm tracks are much more persistent and adhere better to climatology than do those of the Atlantic storms. When FDL is accounted for, the mean errors of the two basins, in terms of skill, can be shown to be very comparable.

Note that FDL as discussed here relates only to the intrinsic nature of the actual storm tracks and does not take into account operational variables, such as the availability and accuracy of center fixes from reconnaissance aircraft and satellite imagery. Even with a low value of FDL, the inability to assess the initial storm motion and how it has been changing would prevent one from realizing the full variance-reducing potential of persistence in tropical cyclone forecasting. Also, FDL fails to address inherent warning problems, such as raising coastal warnings, recommendation of coastal evacuation of residents, storm surge potential, or nearness to shipping lanes.

## 3. CLIPER models for the six major basins

Figure 1 shows that tropical cyclone activity is concentrated in six major ocean basins: North Atlantic, eastern North Pacific, western North Pacific, North Indian, southwest Indian, and southwest Pacific–Australian. Each basin has a distinct climatology that may vary considerably within the basin.[2] Operational CLIPER models have been developed for each of these basins, except the Australian basin. These models are Atlantic (Neumann, 1972), eastern North Pacific (Neumann and Leftwich, 1977), western North Pacific (Xu and Neumann, 1985), North Indian (Neumann and Mandal, 1978) and southwest Indian (Neumann and Randrianarison, 1976).

If a CLIPER model had been developed for the one missing basin (southwest Pacific–Australian), operational models would have been available for each basin which, in turn, could have been used to compute FDLs. However, each of the five CLIPER models was formulated with a somewhat different methodology and data set. Since it was not apparent how these heterogeneities would have affected the comparability of the FDLs, we decided to construct a new CLIPER model for each of the six basins.

CLIPER-class models require only historical tropical cyclone tracks as developmental data. No synoptic or prognostic data are used. A tropical cyclone data tape containing worldwide storm tracks from as early as the nineteenth century and extending through 1982 was obtained from the National Climatic Data Center in Asheville, North Carolina. These data were subdivided into the six major basins and storm positions were given every 12 h. In this study, only storm stages that were estimated to have at least gale force winds of 18 m $s^{-1}$ were included. The period of record used for each basin, and the resulting case numbers at 12–72 h, are shown in Table 1. Only data from the post-World War II period were used, except for the North Indian basin. There, low storm frequencies required the use of the entire period of record to obtain an adequate sample.

[2] It can be shown, for example, that the FDL north of Australia is lower than the FDL east of that continent.

TABLE 2. Average forecast difficulty level (FDL) in kilometers, ranked by basin from most to least difficult. Mean latitude (degrees) of storms for each basin also shown.

| Rank and basin | Mean storm latitude | FDL 12 h | 24 h | 36 h | 48 h | 60 h | 72 h |
|---|---|---|---|---|---|---|---|
| 1. Southwest Pacific–Australian | 20.1°S | 117 | 241 | 370 | 503 | 618 | 728 |
| 2. North Atlantic | 27.6°N | 95 | 210 | 337 | 463 | 576 | 680 |
| 3. Western North Pacific | 20.4°N | 83 | 184 | 299 | 416 | 528 | 632 |
| 4. Southwest Indian | 18.4°S | 77 | 161 | 250 | 339 | 422 | 500 |
| 5. Eastern North Pacific | 17.9°N | 70 | 144 | 222 | 295 | 367 | 431 |
| 6. North Indian | 15.7°N | 60 | 117 | 176 | 230 | 288 | 328 |
| Mean of all basins | | 84 | 176 | 276 | 374 | 466 | 550 |

TABLE 3. Average normalized forecast difficulty level (FDL), ranked by basin from most to least difficult.

| Rank and basin | Normalized FDL 12 h | 24 h | 36 h | 48 h | 60 h | 72 h |
|---|---|---|---|---|---|---|
| 1. Southwest Pacific–Australian | 1.39 | 1.37 | 1.34 | 1.34 | 1.33 | 1.32 |
| 2. North Atlantic | 1.13 | 1.19 | 1.22 | 1.24 | 1.24 | 1.24 |
| 3. Western North Pacific | 0.99 | 1.05 | 1.08 | 1.11 | 1.13 | 1.15 |
| 4. Southwest Indian | 0.92 | 0.91 | 0.91 | 0.91 | 0.91 | 0.91 |
| 5. Eastern North Pacific | 0.83 | 0.82 | 0.80 | 0.79 | 0.79 | 0.78 |
| 6. North Indian | 0.71 | 0.66 | 0.64 | 0.61 | 0.62 | 0.60 |
| Mean of all basins | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

Each CLIPER model had identical structural characteristics, except for sample size, so that the interbasin comparisons could be validated. The seven primary predictors were day number, initial latitude, initial longitude, past 12 h meridional motion, past 12 h zonal motion, past 12–24 h meridional motion, and past 12–24 h zonal motion. The range of day number was limited to 15 May through 15 December in the Northern Hemisphere and 1 November through 1 June in the Southern Hemisphere. Initial maximum wind speed (intensity) was not used, because it was unavailable for many systems, especially outside the North Atlantic and western North Pacific basins. All first and second-order prediction terms, plus an intercept, were used for the separate meridional and zonal displacement forecasts, making 36 predictors for each direction. Forecast equations were developed at 12 h intervals from 12–72 h.

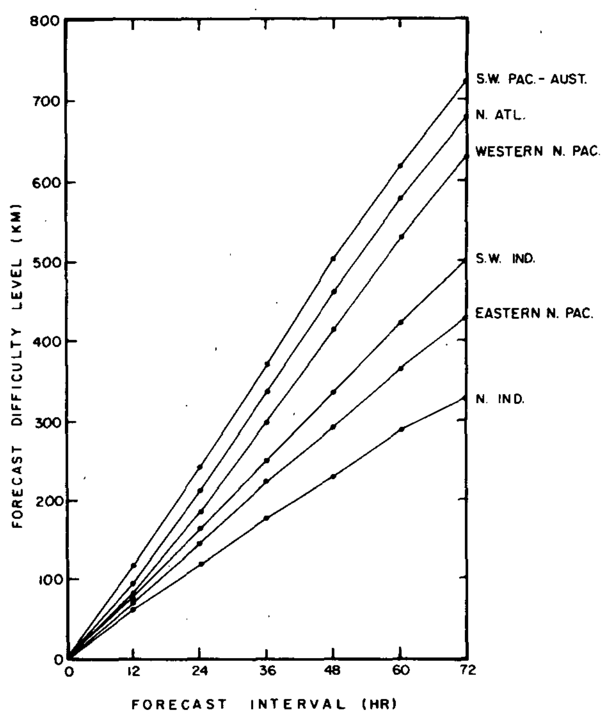


FIG. 2. Forecast difficulty levels as functions of forecast interval for the six major tropical cyclone basins.

## 4. Comparison of forecast difficulty levels

The forecast difficulty level (FDL) is defined as the forecast error of a CLIPER model run on best-track initial data, i.e., on developmental data. The average FDL in a particular basin is an estimate of the typical forecast difficulty in that basin. The FDL may be normalized by division by the mean of the FDLs for all basins. The average FDL and normalized FDL at 12–72 h for the six basins in this study, ranked from most difficult to least difficult, are shown in Tables 2 and 3, respectively.

Confidence in the ranking of FDL by basin is provided by the consistency of the rankings at all time intervals. See Figs. 2 and 3 for graphical comparisons of FDL and normalized FDL, respectively. The FDLs in this study are not comparable with those from optimized models such as Atlantic CLIPER, which was developed for single-basin use with a different database and structure, lacking the similarity constraints of this study. However, the normalized FDLs should be representative.

For each basin, FDL increases rapidly and approximately linearly with forecast interval, while normalized FDL changes slowly with time. Note the considerable variation of normalized FDL among the basins. The most "difficult" (southwest Pacific–Australian) basin

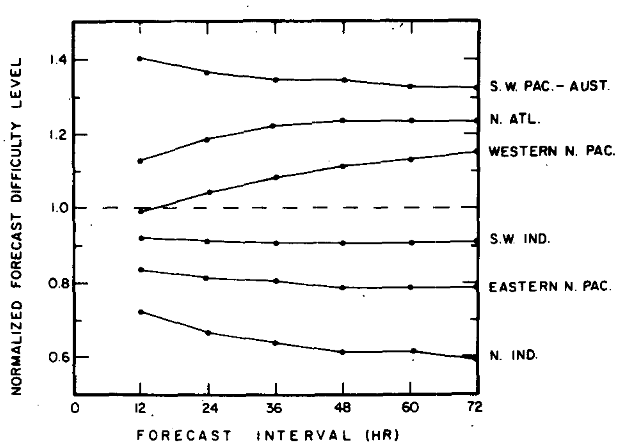


FIG. 3. Normalized forecast difficulty levels as functions of forecast interval for the six major tropical cyclone basins.

is at least twice as difficult as the least difficult North Indian basin. The FDL and normalized FDL reported for the North Indian basin may be artificially low because of a small sample size and the inclusion of some unrealistically smooth storm tracks from earlier years.

The normalized FDL tends to decrease slightly with time in all basins except the North Atlantic and western North Pacific, where it increases. Those two basins are the only ones in which aircraft fixes have been made routinely, resulting in more accurate best tracks. There, improvements in best-track initial position and motion have reduced CLIPER errors proportionately more at the shorter forecast intervals, when persistence dominates this type of model.

There are many factors that influence forecast difficulty, but probably the most important is latitude. In each hemisphere, forecast errors increase with latitude. The farther away from the equator a storm is, the more likely it is to recurve and/or accelerate markedly. Neumann and Pelissier (1981b) discuss the relationship of Atlantic operational forecast errors to latitude. Table 2 shows that, in this study, when the Northern and Southern Hemisphere basins are considered separately, FDL and average storm latitude have perfect rank correlations.

## 5. Discussion

This study only begins to address the complex subject of forecast error variability for tropical cyclones on a worldwide basis. Probably the simplest possible geographical stratification is used, as well as one of the simplest types of objective forecast model. The increase of error with distance from the equator is clear in both hemispheres. Application of the CLIPER method with a finer spatial stratification within a carefully edited data base should reveal areal variations in forecast difficulty within individual basins. In addition to CLIPER, use of a dynamical or statistical–dynamical model, sensitive to its synoptic input, could reveal the regional variability of analysis quality.

Meanwhile, the data in Table 3 should be useful in normalizing regional operational forecast errors among the basins, since the FDL and operational error are highly correlated (Neumann, 1981). Persistence and regionally variable climatology form the foundation for tropical cyclone forecasting. Mean operational forecast error divided by the normalized FDL is an estimate of what the error would be if the FDL were the same, worldwide. Normalized forecast errors of this type should be directly comparable globally. Such a procedure might help to highlight problem areas in tropical cyclone forecasting at specific locations. Insufficient initial storm data and lack of accurate guidance from dynamical forecasts of the environmental steering flow especially come to mind.

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