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THE NAVY'S ANALOG SCHEME FOR FORECASTING TROPICAL CYCLONE MOTION OVER THE NORTHEASTERN PACIFIC OCEAN

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The Navy's EPANALOG (Northeastern Pacific Analog Tropical Cyclone Tracker) forecast program is introduced. EPANALOG selects analog tropical cyclones from a 25-year Northeastern Pacific Ocean history. The selected analog tracks, statistically adjusted for position, vector motion, and date differences between them and the recent history of the tropical cyclone being forecasted, are composited into a single forecast track. Verifications of EPANALOG forecasts to 96 hours are shown for randomly selected historical tropical cyclones, as

initiated from best-track positions statistically adjusted to simulate position inaccuracies, as well as for forecasts generat from 1973 operational tropical cyclone positions. The latter are intercompared with a homogeneous set of objective persistence an MOHATT forecasts as well as subjective Official forecasts for th 24-, 48- and 72-hour intervals. The accuracy of the 1973 EPANALOG is shown to generally exceed that of the existent techniques for all forecast intervals tested.

CONTENTS

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1. INTRODUCTION

Tropical cyclone forecasting (development, movement, and intensity) is an important and time-consuming task for the operational meteorologist. Objective guidance is necessary for timely and credible results. Such guidance, at least for movement, exists for the North Atlantic Ocean (Neumann and Hope, 1973) and for the western North Pacific Ocean (WESTPAC) areas (U.S. Fleet Weather Central/Joint Typhoon Warning Center, 1973). However, few objective techniques are available for the eastern tropical North Pacific Ocean (EASTROPAC) area, shown to be a region containing the global maximum tropical cyclone density (that is, the number of tropical cyclones forming per unit area and unit time)(Crutcher and Quayle, 1974).

Starting in 1969, objective techniques for forecasting tropical cyclone tracks, using an analog concept, were developed. One such technique designed for WESTPAC, currently called TYFOON-73, was formulated at the National Weather Records Center[1] (Hodge and McKay, 1970) and subsequently modified by Jarrell and Somervell (1970) and by Jarrell and Wagoner (1973). A similar technique called HURRAN was concurrently developed by Hope and Neumann (1970) for the prediction of the movement of North Atlantic tropical cyclones. Both techniques are based on identifying historical tropical cyclones with characteristics similar to the one being forecasted. When the movements of all similar past tropical cyclones are assembled, their average movement is computed and the tropical cyclone-center positions on the average analog track are used as guidance in the issuance of forecasts. Following these earlier studies and being made feasible by the existence of a suitable data base, this technical

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[1] Present designation is National Climatic Center, Asheville, North Carolina.

report describes an analog technique designed to forecast the movement of EASTROPAC tropical cyclones for intervals to 96 hours.

2. CLIMATOLOGY

In general, EASTROPAC tropical cyclones are formed in the eastern section of the subject area and propagate westward and northward. The tropical cyclone season may be defined to extend from mid-May through October; less than 2% of the tropical cyclones form out of this season. From 1965-74 the annual average of named EASTROPAC cyclones is 14, of which 7 become hurricanes. Hansen (1972) indicates that the average track is toward 292 degrees, although this varies with latitude and the mean speed of EASTROPAC cyclones is 10 kt with a standard deviation of 3 kt. The relative incidence of recurvature is significantly less than counterparts in the North Atlantic and western North Pacific Ocean areas and most frequently occurs with those tropical cyclones near the end of the season.

3. DATA

Historical data, compiled for the Naval Weather Service by the National Climatic Center, Asheville, North Carolina, consist of best-track initial and subsequent 0000- and 1200-GMT positions for all known tropical cyclones generally having all or part of their life history in the area of study -- the North Pacific Ocean east of 180 degrees. In the period 1949-73 there are a total of 2666 positions (257 tropical cyclones) in the subject area. These data represent the set from which analog tropical cyclone candidates are selected.

4. FORECAST TECHNIQUE DEVELOPMENT

The assumption is made that a pure analog forecast scheme will not perform satisfactorily. A pure analog scheme is defined as one for which history is searched for a situation analogous to an existing situation. When an analog is found, the subsequent behavior of this analog is used directly as a forecast. Pure analog schemes, for tropical cyclone forecasting, have failed for two reasons. First, good analog pairs (those whose past and future are closely parallel) are not common enough to presuppose a single good analog could be found for most forecast situations. Secondly, there are no known methods for reliably discriminating poor analogs from good or near-perfect analogs.

One solution to the dilemma is to use screening parameters to stratify the analogs into groups, ranging from the best to the worst. In a statistical sense this is possible; that is, one can separate the analogs into groups which are better (or worse) than average performers. Generally, analog schemes have tried to separate analogs into two groups: "good enough" and "not good enough". The "not good enough" group is then ignored and the "good enough" group forms the basis of the forecast. Usually these are composited into a single analog forecast using an ordinary or weighted average after each has been adjusted for any systematic, and hence predictable, differences between it and the cyclone being forecasted.

The variations between analog schemes fall into three areas: (1) how are criteria established to eliminate unacceptable (i.e., "not good enough") analogs; (2) how are discernable differences between the existing cyclone and an acceptable analog cyclone adjusted; and (3) how is the group of adjusted "good enough" analog tracks composited.

a. <u>Criteria for Determining an Acceptable Analog Candidate</u>

The differences in the date and location (latitude and longitude) of any two tropical cyclone positions as well as the difference in the recent 12-hour motion of the two tropical cyclones (items i to v, List 1, in the Appendix) were accepted as parameters relating to the future behavior of either of the tropical cyclones. A regression approach was used to establish the maximum value of each of these parameters (called screen setting or envelope value) which allows the best explanation of future differences in the two cyclone tracks. The parameters in the Appendix were used in multiple non-linear regression equations to generate 35 date, location and history (12-hour only) predictors for specifying predictands defined to be the zonal and meridional differences between the two tropical cyclones 48 hours after a common starting point. (See the translation process in Figure 1 for establishing the common starting point between the two cyclones). The variance in the predictands (actually the sum of zonal and meridional components) not explained by the predictors is then a measure of the dissimilarity of the tracks of the cyclone pairs.

The screen parameters, whose optimal settings were determined by the regression analysis, are identical to the first five predictors. The selection was patterned after earlier work by Jarrell and Somervell (1970). Several hundred different combinations of symmetric cut-off values for these screens were subjected to the regression analysis. Recorded for each such test were the unexplained variance and the number of tropical cyclone pairs passing through all five screens. The probability that a single analog will pass all screens can be varied by adjusting the screen limit. For instance, all screens set at $\pm$ 0 (perfect analogs only) would allow the acceptance of a near-zero percentage of analog candidates while screen settings with essentially no limitations would have an acceptance rate close to 100%.

From hundreds of test runs, screen settings were determined which provided an acceptance rate of a predetermined value with minimum unexplained total variance in the test cyclone. Table 1 lists optimal screen settings for acceptance rates of 5 to 50%. It is to be noted that the latitude difference (TY) and past 12-hour relative motion (BY and BX) are the most sensitive screen parameters, i.e., small changes in these parameters markedly increase the number of tropical cyclones accepted as analog candidates. Date difference was so insensitive that a screen value of 180 days (no screen) was set for all acceptance rates. Unexplained variance of the predictand (not shown) increases steadily with the acceptance rate. Shown also in Table 1 are average and root mean square (RMS) errors, for acceptance rates up to 30%, for a sample of 371 48-hour forecasts, as a function of selected screen settings on date, location and 12-hour history motion differences between the two tropical cyclones. An acceptance rate near 15% appears to be the point of optimum trade-off between increasing the number of analogs and accepting poorer analogs.

The column labeled "Failures" in Table 1 indicates the number of cases in which an insufficient number of analogs were found to support a reliable forecast. Here, the minimum number of analog tropical cyclones allowed to make a forecast was arbitrarily set at 3. Later this cut off was reset at a more realistic value of 10. The number of failures at an acceptance rate of 15% (namely 34) was deemed to be excessive, considering this number would certainly increase when the minimal criterion was increased to more than 3. For this reason, an acceptance rate of 30% was selected.

A system of weighting the selected analogs. discussed in c below, has the effect of reducing the screen dimensions back toward those of the optimum acceptance rate of 15%.

Table 1. Optimum screen settings for each of five parameters obtained by changing the percentage of positions selected as analog candidates. The 48-hr forecast test results for 371 forecasts are included for those percentages between five and thirty. Failures indicate the forecasts were not made due to an insufficient number of analogs.

Average Acceptance rate (%)	Parameter					48-Hour Forecast Test Results		
	TY (°lat)	TX (°lat)	BY (°lat)	BX (°lat)	DD (days)	Ave. Error (n mi)	RMS Error (n mi)	No.(%) of Failures
5	0.8	12.0	0.1	0.6	180	171	196	132 (36)
10	1.2	12.0	0.5	0.8	180	161	184	42 (11)
15	1.5	12.0	0.5	1.6	180	159	181	34 (9)
20	1.5	12.0	0.6	1.6	180	163	189	29 (8)
25	1.5	21.0	0.6	1.6	180	164	188	23 (6)
30	1.5	72.0	0.6	1.8	180	173	199	8 (2)
35	1.8	72.0	0.7	1.8	180	-	-	-
40	1.8	72.0	0.8	1.8	180	-	-	-
45	1.8	72.0	0.9	2.0	180	-	-	-
50	1.8	72.0	1.1	2.4	180	-	-	-

b. Adjusting the Analog Tropical Cyclone for Best Comparison to the Existing Cyclone

Once the acceptance region (envelope) is set in accordance with the optimum screen settings, it is necessary to solve the problem of adjusting the accepted analog tropical cyclone tracks to remove discernable differences between them and the tropical cyclone to be forecasted.

The obvious first difference is that of tropical cyclone position, which is the basis of two of the screens. To account for this difference, all the points (past, present and future) on the analog track are "translated" or adjusted (Figure 1) by the amount of the vector from the analog's origin position to the origin of the current tropical cyclone (magnitude = $[(TY)^2 + (TX)^2]^{\frac{1}{2}}$).

The next obvious difference in the tracks of the analog tropical cyclone and the tropical cyclone to be forecasted is the past movement. Both the 12- and 24-hour past movement differences (hereafter called history biases) were calculated. The previously discussed regression approach was again used, this time to determine the proper history-bias correction to the translation-adjusted analog track in order to obtain the best correspondence of it to the cyclone track whose future is being estimated. In this case the regression equations for the meridional and zonal components of the predictand were developed from the dependent data sample according to time since last fix (simulated to be 3, 9, 15 and 21 hours), the cyclone history positions (none, 12- or 24-hour), and each of the four forecast intervals (24, 48, 72 and 96 hours). Forty-nine parameters were available for entry into the regression equations (See Appendix). However, only the most significant three or four were used, i.e., those which explained 1% or more of the total variance of the predictand, again defined as the difference between the translation-adjusted analog and the second of the pair of tropical cyclones (taken

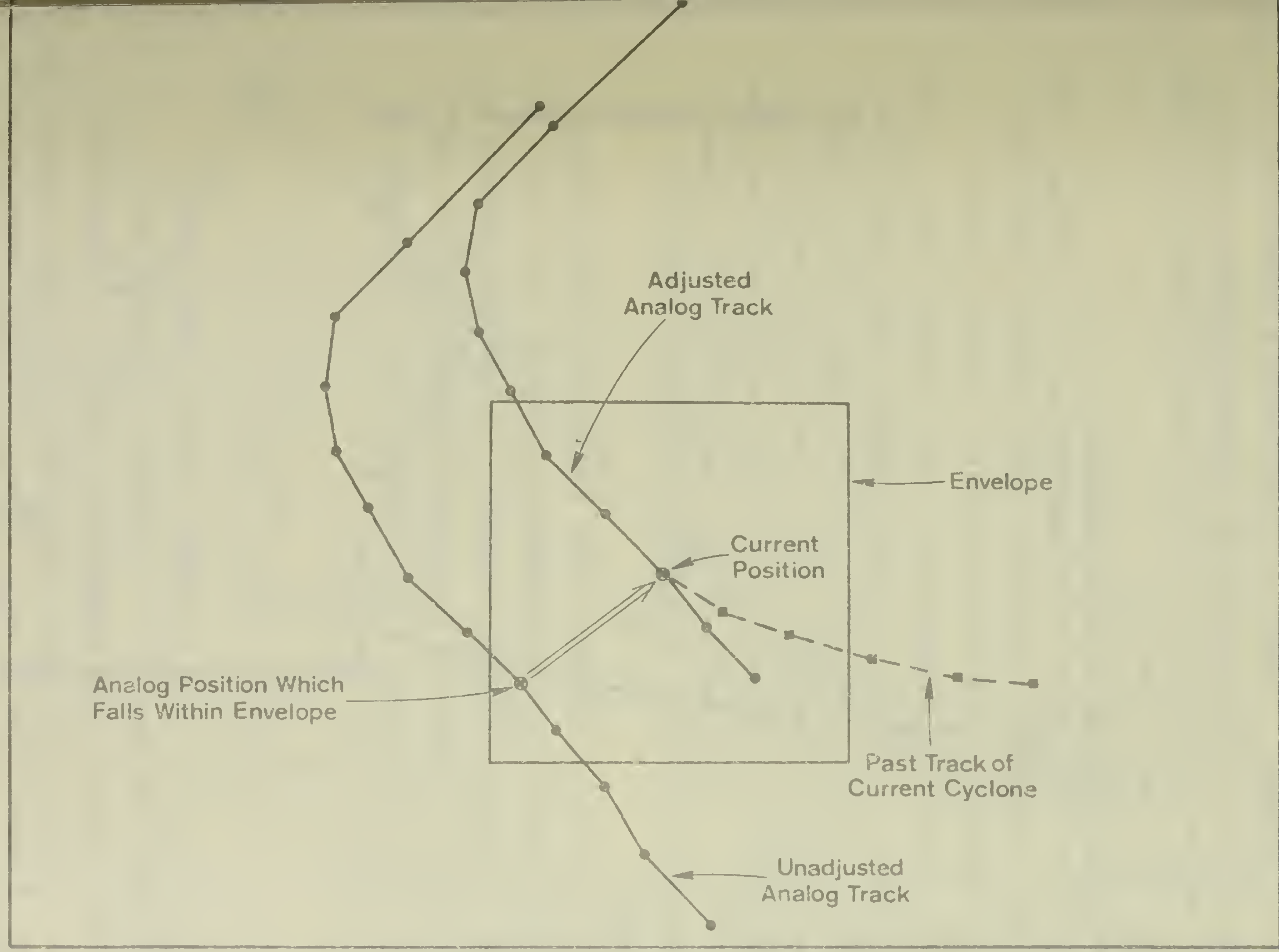

Figure 1. Fxample of translation adjustment to an analog track. The translation vector is directed from the acceptable analog position to the position of a tropical cyclone (current position) whose track is to be forecasted. This adjustment is applied to 12- and 24-hour history and all future positions of the analog tropical cyclone.

as the tropical cyclone being forecasted). Over half of these bias-correction equations were subsequently abandoned as not contributing significantly to the forecast accuracy of the analog scheme. Figure 2 illustrates a simplified bias correction to the translation-adjusted analog cyclone, namely the vector equivalent of the 12-hour history bias for each 12-hour forecast interval.

c. Compositing Analogs in the Forecast

When the history file is exhausted and all analogs have been screened and those considered "good enough" have been adjusted for position and history bias, the problem of finding some method of compositing the cyclones into a single forecast remains. Previous analog schemes have composited the acceptable analog tropical cyclone tracks into a simple or weighted average forecast track. The latter method was used in EASTROPAC to compensate for the excessive dimensions of the screens. To accomplish the compositing, two types of weighting factors were multiplied together to form a single weight.

The first factor reflects the fact that those analogs nearer to the center of the acceptance region are likely to be superior to those farther removed. It has the effect of minimizing the influence of those analogs passing the 30% acceptance-rate screen but unable to pass the 15% screen. This weight factor takes the form

$$W = \prod_{j=1}^{5} p_{i,j} \, P_{Gi,j} \, (P_{Bi,j})^{-1}, \qquad (1)$$

where $P_{Gi,j}$ ($P_{Bi,j}$) is the probability of a good (bad) agreement given that the i,jth class has occurred and $P_{i,j}$ is the probability of that occurrence. The j reflects the 5 different screens and i reflects that each screen acceptance interval is divided into 5 equal parts. A small reduction in the total RMS error resulted. In particular, for those cases

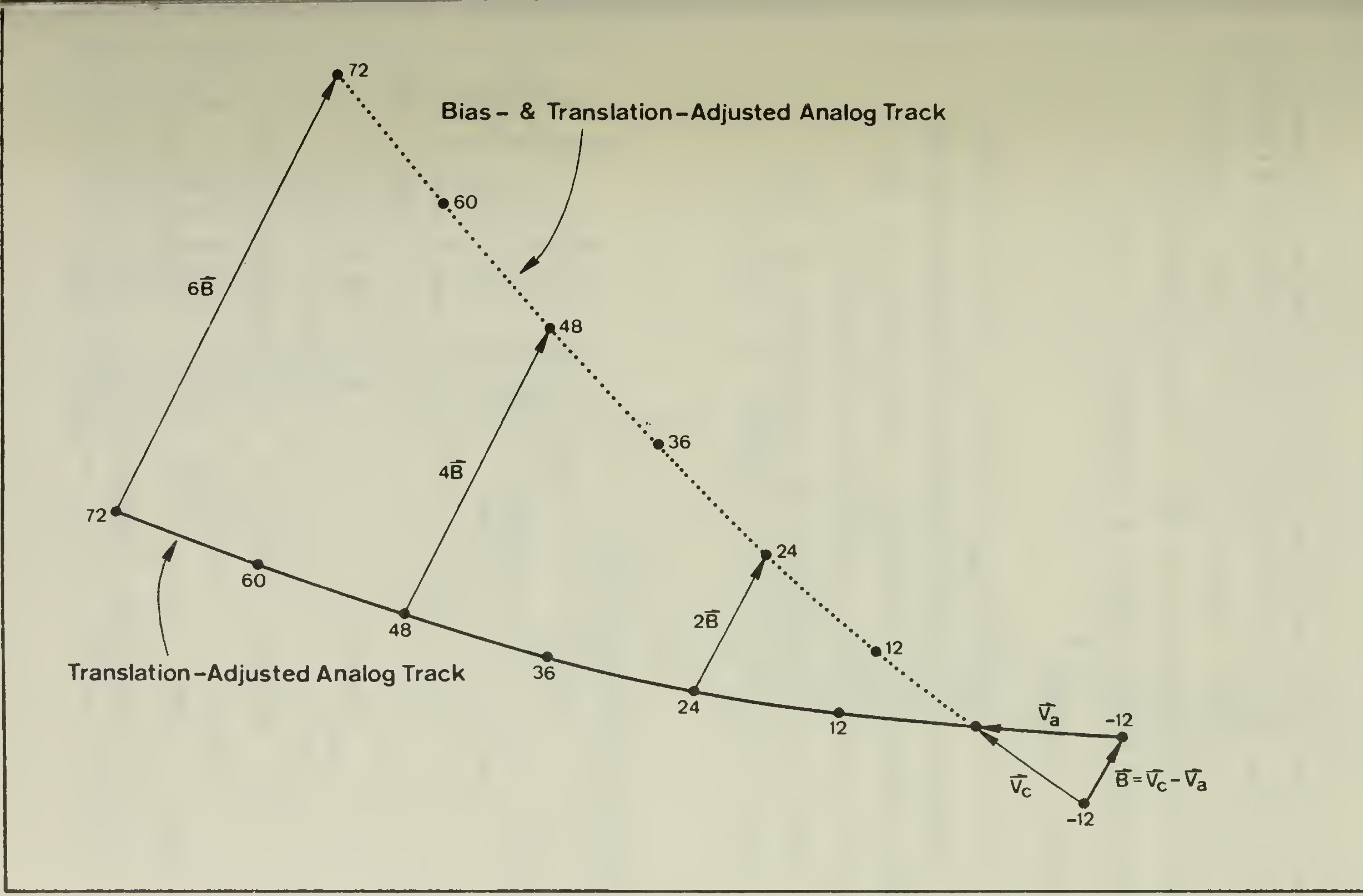

Figure 2. The history-bias adjustment to an analog track which has been previously adjusted for translation. $\vec{V}_c$ is the previous 12-hour movement of the current cyclone and $\vec{V}_a$ is the previous 12-hour movement vector of the analog tropical cyclone.

with a small number of analog cyclones (10 to 20), the forecast accuracy generally improved, so that their error distribution resembles that of cases composed of large numbers of analogs.

The second factor reflects the supposed lesser accuracy of analogs which have no past history or only 12-hour history. In this case, the weighting factors consist of the reciprocal of the variance of error from the non-linear regression equations discussed in subsection b, above.

5. ANALOG FORECAST FORMAT

The 24-, 48-, 72- and 96-hour tropical cyclone-center forecasts are output as the most-probable location and the envelope of 50% probability locations; the former is the intersection of the minor and major axes of the 50% probability ellipse and the latter is determined by the end points of these axes. See the example in Figure 3.

6. RESULTS

a. Analog Forecast Verifications

The final forecast technique, henceforth referred to as EPANALOG (Northeastern Pacific Analog Tropical Cyclone Tracker), was subjected to two types of testing. First, 551 simulated forecasts, not all of which could be verified, were made for comparative purposes. The verification results of these tests are given in Table 2. EPANALOG forecasts were made for 24, 48, 72 and 96 hours under 4 classes of simulated initial position errors. The following results are apparent. First, the forecast errors compare favorably to those of other forecast techniques in this and other oceans. Second, error sensitivity to initial position inaccuracies (time since last fix) is inversely related to forecast interval.

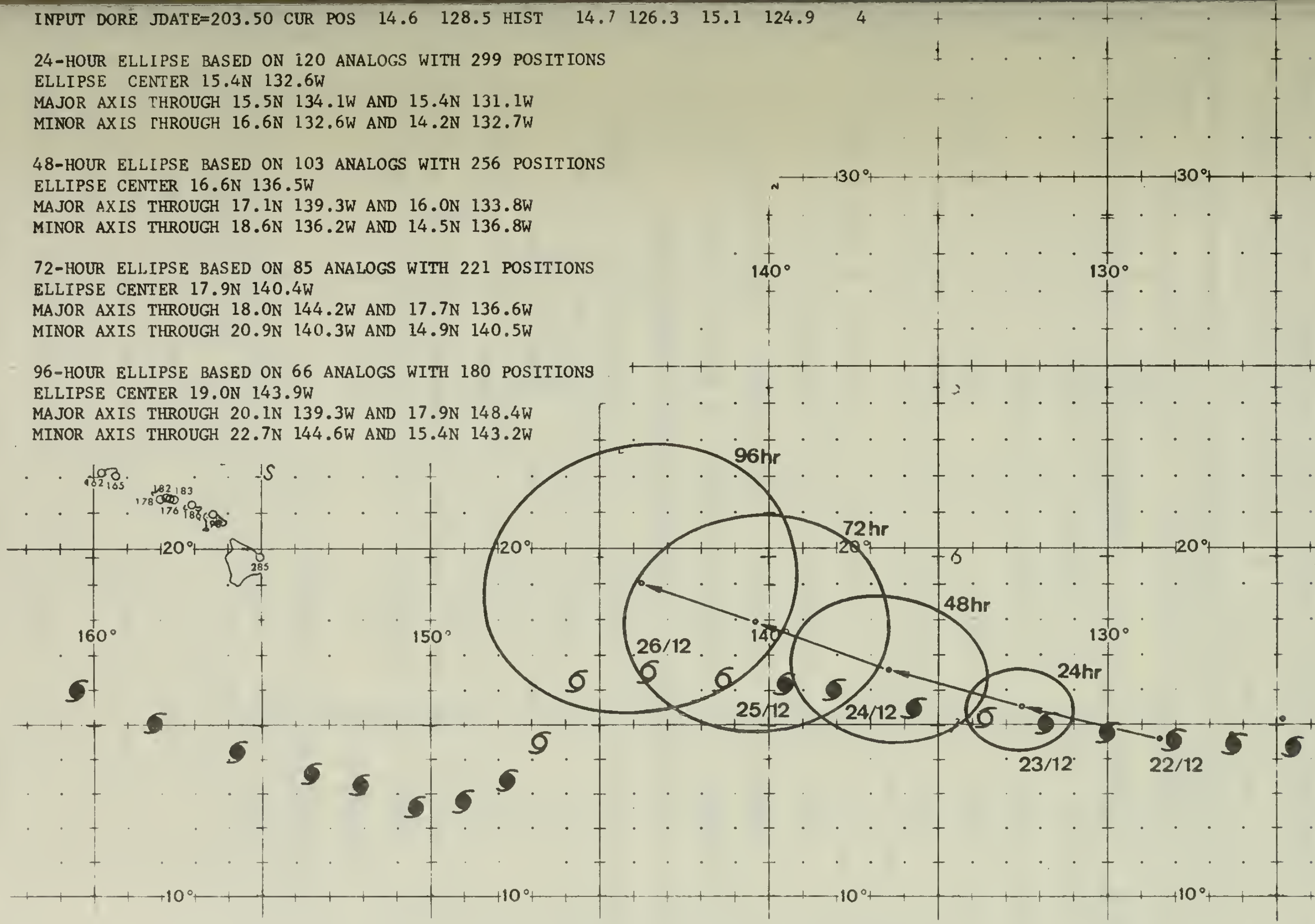

Figure 3. The 24-, 48-, 72- and 96-hour analog forecasts of Hurricane Doreen, starting from the operational 1200 GMT 22 July 1973 position. Most probable forecast positions are centers of 50% probability ellipses. Best-track tropical cyclone locations at 12-hour intervals, coded for stage, are shown for comparison. Insert: Associated computer-produced EPANALOG forecast message.

In order to further investigate the validity of the above results, the 1973 best-track data were removed from the history file and the forecast technique was run on 1973 operational positions for which Official and MOHATT (Renard *et al*., 1973) forecasts existed. The homogeneous test set consisted of warning positions for 9 named tropical cyclones and 2 tropical depressions. All operational warning-time positions were ones for which at least a 24-hour forecast could be verified. Tables 3 and 4 summarize the results of this test. Table 3 lists the average forecast errors stratified by forecast interval and according to tropical cyclone stage and nature of track. Table 4 shows the average forecast errors for each tropical cyclone as well as the average initial position error.

The information of Table 3 is consistent with expectation in tropical cyclone forecasting, namely that: (1) forecast accuracy generally improves as tropical cyclones become better developed, at least through 48 hours, and (2) forecasts for post-recurvature verifying positions are usually less accurate than those for pre-recurvature points. The former differences may be partially attributed to poor initial positioning for formative cyclones, particularly when positioning is based on satellite pictures. The latter difference is related to the difficulty of assessing the time of recurvature and the subsequent greater speed along the track after recurvature.

b. Tropical Storms Claudia and Jennifer

The average errors shown in Table 4 are fairly consistent from tropical cyclone to tropical cyclone with two notable exceptions, tropical storms Claudia and Jennifer. Since neither attained hurricane intensity, they were particularly subject to the effects of poor initial positioning. In fact the ratio of 24-hour average forecast error to initial position error for Claudia (204/76) is not unlike the ratio for the

Table 2. The results of the EPANALOG forecast technique on the randomly selected test cases incorporating a simulated initial position error.

Time Since Last Fix (hr)	Forecast Interval (hr)	Forecasts Verified	Average Error (n mi)	RMS Error (n mi)
3	24	521	92	108
	48	405	172	202
	72	309	247	289
	96	219	316	365
9	24	516	107	125
	48	397	181	213
	72	307	255	297
	96	217	325	376
15	24	511	128	150
	48	396	202	239
	72	298	265	312
	96	212	333	387
21	24	495	149	174
	48	378	222	264
	72	286	274	324
	96	204	346	403

Table 3. EPANALOG 1973 forecast errors (n mi) by forecast interval according to tropical cyclone stage and nature of track at verifying time. Operational position data were used to initiate forecasts. The number of forecasts is contained in parentheses.

Stage	Forecast Interval (hr)		
	24	48	72
Tropical Depression	143 (34)	246 (22)	253 (14)
Tropical Storm	129 (79)	212 (61)	285 (57)
Hurricane	80 (86)	167 (73)	251 (52)
Before Recurvature	102 (189)	181 (148)	258 (119)
After Recurvature	263 (10)	467 (8)	518 (4)

Table 4. 1973 operational initial-position and EPANALOG forecast errors (n mi) by tropical cyclone and forecast interval. Operational position data were used to initiate forecasts. The number of cases is contained in parentheses.

TROPICAL CYCLONE	Initial Error	Forecast Interval (hr) 24	48	72
AVA	39 (42)	125 (25)	231 (23)	323 (21)
CLAUDIA	76 (14)	204 (7)	307 (3)	
DOREEN	29 (66)	87 (46)	166 (42)	237 (38)
TD-5	55 (9)	42 (5)		
EMILY	24 (30)	86 (23)	134 (19)	146 (15)
FLORENCE	36 (24)	78 (15)	98 (11)	133 (7)
GLENDA	50 (27)	108 (15)	147 (11)	152 (8)
TD-10	45 (12)	146 (6)		
IRAH	29 (20)	111 (12)	230 (8)	328 (4)
JENNIFER	74 (15)	347 (6)	673 (4)	1156 (1)
KATHERINE	30 (37)	100 (30)	235 (25)	394 (23)
LILLIAN	49 (20)	97 (13)	170 (10)	197 (6)
TOTAL	41 (316)	110 (199)	196 (156)	267 (123)

corresponding values considering all 1973 cases (110/41). Even Jennifer's errors look more reasonable from this point of view.

There are other factors involved in the anomalously poor Claudia and Jennifer forecasts. First, both tracks are brief and climatologically unusual. Claudia followed a slow northwest track at low latitudes (10-17N) and Jennifer, starting at 13N, described a fast northeast (i.e., post-recurvature) track after a period of being virtually stationary. Since analog forecasting is closely related to climatological forecasting, it should not be expected to handle climatologically unusual cases well.

There is one additional factor which tends to diminish forecast accuracy for the recurving tropical cyclone in the EASTROPAC area. Because of the presence of cold water to the north of the tropical cyclone area, those tropical cyclones which recurve also dissipate rapidly; the historical tracks of such tropical cyclones abruptly end along a relatively sharp northern boundary. If the tropical cyclone to be forecast is stationary or moving northward slowly on a pre-recurvature track, screening is likely to include historical tropical cyclones which subsequently tracked toward directions ranging from westward to northeastward. Of these tracks, those that persist longest are the ones that move westward; consequently, the mean analog forecast track becomes progressively more westward.

A similar effect was noted by Jarrell and Wagoner (1973) for typhoons approaching the China mainland, an area where historical tracks had been abruptly discontinued. There the effect was forestalled by artificially extending the historical tracks by extrapolation. No attempt has been made to apply such a modification to Northeastern Pacific tracks because the frequency of recurvature and the rather striking symptoms of the problem make a subjective treatment by the forecaster rather straightforward.

c. Hurricane Doreen

Figure 4 illustrates some of the operational EPANALOG forecasts made on Hurricane Doreen (18 July - 3 August 1973). These are not intended to be representative forecasts, but rather were selected to illustrate certain points.

Most notable along the track of Doreen is the southward motion starting on 26 July, which took her on a path well south of the Hawaiian Islands. Notable also is the lack of EPANALOG forecasts during this period. The reason for this forecast void is that screening on past motion prohibited selection of a sufficient number of analogs to support a reliable forecast. Failure to anticipate the southward move by EPANALOG is to be expected since this is a relatively unusual track. It may appear that forecast error comparisons would be inflated in EPANALOGS's favor since it is unable to make forecasts when they are difficult. For this reason homogeneous comparisons with other forecast techniques have been carefully documented. Additionally, it must be noted that the large forecast errors occur in forecasts initiated before the unusual movement and that once such a movement is revealed in the track, forecasts again become routine.

There is clearly a bias in the forecasts of this storm as all forecasts are too far north and most are too fast. The anomaly is at least partially due to the operational positions generally being poleward of the best track.

d. Intercomparison of forecast techniques

The next step in the verification phase was a homogeneous comparison of EPANALOG forecast errors to those of two objective techniques, persistence and MOHATT (Renard, et al., 1973), and the largely subjective official forecasts. The persistence forecasts are linear extrapolations of the most recent 24- or 12-hour history, the latter used only

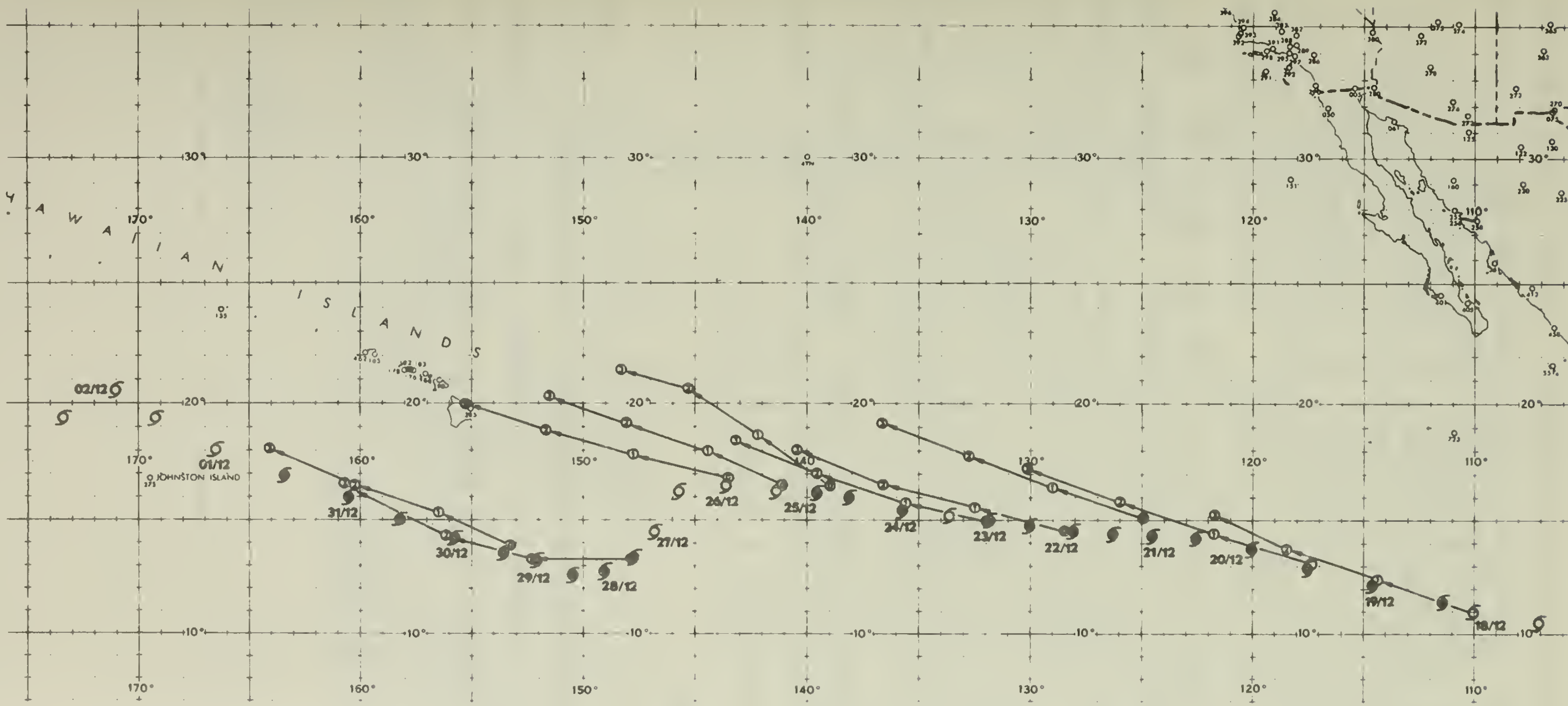

Figure 4. Hurricane Doreen, 18 July to 3 August 1973. Best track positions at 0000- and 1200-GMT are indicated by standard hurricane (୨) or tropical storm (୨) symbols. Sample EPANALOG forecasts for 1-, 2- and 3-day intervals are indicated by numbered points connected by line segments. The origin of each of these forecasts (point 0) is the position specified in the operational tropical cyclone advisory; such positions may not be the same as the best-track locations for the same times.

when the former was not available. In the case of the MOHATT forecasts, both the 850-mb and 700-mb steering modes were evaluated. Table 5 contains the results.

The usual fix time for 1973 in EASTROPAC was near 1800 GMT. This once-per-day fix impacts on forecast errors differently for each technique. Both MOHATT modes are predictably poorest near fix time since past 6- and 12-hour movements are least reliable then. Generally the other forecast approaches are best at 1800 and 0000 GMT and poorest at 1200 GMT. Without exception, EPANALOG's mean error was better than that of the other objective techniques. A comparison of EPANALOG with the official forecast gives the edge, except for 0600 GMT, to EPANALOG. If sensitivity to errors associated with initiation time can be inferred from the difference between average errors at the poorest and best synoptic times for each technique, then EPANALOG is least sensitive to these errors. This is a highly desirable attribute in an area where inaccurate tropical cyclone positioning is a fact of life.

7. CONCLUSIONS

Based on the results described above it may be concluded that the EPANALOG technique is a valuable aid in forecasting the movement of EASTROPAC tropical cyclones. The EPANALOG forecasts are operationally produced at the U.S. Fleet Weather Central, Pearl Harbor, Hawaii. Further evaluations and an updating of EPANALOG will be forthcoming as a result of its operational use.

Table 5. [illegible] 1·7 [illegible] northeastern Pacific [illegible] cyclone average forecast [illegible] s (r n:) between EPANALOG, Official, Persistence, MOHATT (850-mb steering) and MOHATT (700-mb steering)

Forecast Interval (hr)	Verification time (GMT)	No. of Forecasts	EPANALOG	Official	Persistence	MH850	MH700
24	0000	48	101	104	111	120	109
	0600	47	112	108	124	145	144
	1200	53	128	139	145	151	159
	1800	51	99	106	109	154	150
	ALL	199	110	115	123	143	141
48	0000	36	172	203	223	213	232
	0600	36	204	202	233	270	299
	1200	41	213	234	277	282	264
	1800	33	176	219	209	305	253
	ALL	146	192	215	237	267	262
72	0000	29	254	278	336	312	309
	0600	27	278	299	340	356	356
	1200	30	250	337	386	398	410
	1800	24	254	271	322	485	363
	ALL	110	259	298	347	384	360

REFERENCES

Crutcher, H.L. and R.G. Quayle, 1974: Mariners Worldwide Climatic Guide to Tropical Storms at Sea. NAVAIR 50-16-61 (by direction of Naval Weather Services Command) Superintendnet of Documents, Washington, D.C., 426 pp.

Hansen, H. L., 1972: The climatology and nature of tropical cyclones of the eastern North Pacific Ocean. M.S. Thesis, Department of Meteorology, Naval Postgraduate School, Monterey, California, 178 pp.

Hodge, W. T., and G. F. McKay, 1970: A computer program to select typhoon analogs and print out their descriptions, including subsequent changes. First Progress Report to NAVWEARSCHFAC, Norfolk, Virginia, Project Order PO-90003, National Weather Records Center, Asheville, N.C., 40 pp.

Hope, J. R., and C. J. Neumann, 1970: An operational technique for relating the movement of existing tropical cyclones to past tracks. Mon. Wea. Rev., 98, 925-933.

Jarrell, J. D., 1972: Selective reconnaissance at JTWC. In Tropical Cyclone Conference, Proceedings Report, Environmental Group, Pacific Command, FPO San Francisco, California, 192 pp.

Jarrell, J. D., and W. L. Somervell, 1970: A computer technique for using typhoon analogs as a forecast aid. Tech. Paper No. 6-70, U.S. Navy Weather Research Facility, Norfolk, Virginia, 39 pp.

Jarrell, J. D., and R. A. Wagoner, 1973: The 1972 typhoon analog program (TYFOON-72). Tech. Paper No. 1-73, Environmental Prediction Research Facility, Monterey, California, 38 pp.

Neumann, C. J., and J. R. Hope, 1973: A diagnostic study on the statistical predictability of tropical cyclone motion. J. Appl. Meteor., 12, 62-73.

Renard, R. J., S. G. Colgan, M. J. Daley, and S. K. Rinard, 1973: Forecasting the motion of North Atlantic tropical cyclones by the objective MOHATT scheme. Mon.Wea.Rev., 101, 206-214.

U.S. Fleet Weather Central/Joint Typhoon Warning Center, 1973: Annual typhoon report, 1973. COMNAVMARIANAS, FPO San Francisco, California, 98 pp.

APPENDIX

The predictors used in the multiple curvilinear regression analyses described in Section 4b were obtained by multiplying each of the parameters contained in List 1 by each of those appearing in List 2.

List 1

i. Longitude difference between the two tropical cyclone locations (TX)

ii. Latitude difference between the two tropical cyclone locations (TY)

iii. Relative zonal movement between the two tropical cyclones over the 12 hours prior to locations in i and ii above (BX)

iv. Relative meridional movement between the two tropical cyclones over the 12 hours prior to locations in i and ii above (BY)

v. Difference in Julian dates associated with the tropical cyclone locations in i and ii above (DD)

vi. Same as iii for 24 hours (BX 24)

vii. Same as iv for 24 hours (BY 24)

List 2

i. 1.0

ii. Longitude of the tropical cyclone whose position is not translated (XCO)

iii. Latitude of the tropical cyclone whose position is not translated (YCO)

iv. Julian date of the tropical cyclone whose position is not translated (D)

v. $(YCO)^2$

vi. $(XCO)^2$

vii. D^2