NOTES AND CORRESPONDENCE

A Tropical Cyclone Analog Program for the North Indian Ocean

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ABSTRACT

A tropical cyclone analog program for the North Indian Ocean area is described. The program is a statistical computer technique to provide forecasts for Bay of Bengal and Arabian Sea tropical cyclones from 12 to 72 h.

1. Introduction

Since 1970 a number of tropical cyclone analog forecast techniques have been developed and have been shown to be very useful to the operational forecaster. The success of the hurricane analog approach in the western North Atlantic (Hope and Neumann, 1970; Simpson, 1971; and Neumann and Hope, 1972) and the typhoon analog approach in the western North Pacific (Hodge and McKay, 1970; Jarrell and Somervell, 1970; and Jarrell and Wagoner, 1973), gave rise to an attempt to develop the analog approach for forecasting Bay of Bengal tropical cyclones (Gupta and Datta, 1971). The analog model as presented in this paper (program name—INJAH74) is a modified version of the Gupta-Datta forecast technique and is designed to forecast tropical cyclones in the North Indian Ocean area (Bay of Bengal and the Arabian Sea).

Approximately 10–15 tropical cyclones per year occur in the North Indian Ocean area. These tropical cyclones can occur during every month of the year but the highest frequency occurs from April through December. As an example of some typical tropical cyclone tracks for this area, Fig. 1 presents the tracks for a particularly active month, October, for the period 1900–70.

The method, like other analog schemes designed to forecast the movement of tropical cyclones, is based on finding past storms that appeared during a similar time of year and geographic region and that exhibited speed and heading characteristics similar to those of the storm under consideration. By examining 956 tropical cyclones that occurred from 1900 to 1970, forecasts for 12, 24, 36, 48, 60, and 72 h are produced. The forecast positions initially include the persistence element (past 12-h movement), but this rapidly is converted to more weighting for climatology. An optimized weighting scheme was tested and devised and will be discussed in Section 4. It should be kept in mind that since direction and speed are factors in the selection process, an element of persistence is inherent in the analog program.

Incorporating the weighting scheme, to be discussed later, a distribution of weighted analog positions for each time period is used to derive a mean forecast position based on center of mass distribution (centroid). In addition, the spatial distribution of the selected storms is computed in terms of probability ellipses, assuming a normal bivariate distribution. Statistical analyses techniques (Crutcher, 1971) are used to derive probability ellipses theoretically containing 10, 30, 50, 70, and 90% of the analog storms. These ellipses have proved to be an invaluable forecast aid to the tropical cyclone forecaster, since they incorporate a measure of confidence in the analog forecast.

2. The data base

The data base was made available to the Environmental Prediction Research Facility from the Naval Weather Service Detachment, Asheville, N. C., in the form of card deck 993, Tropical Cyclone Data for the North Indian Ocean (0–35°N, 50–100°E). A total of 7,622, 12-hourly observations for 956 North Indian Ocean tropical cyclones from 1900 to 1970 was used to form the present analog data base.

The following parameters were available for each observation and used in the analog program:

Latitude—nearest tenth of degree
Longitude—nearest tenth of degree
Julian day and hour
Direction of movement (past 12 h)—nearest degree
Speed of movement (past 12 h)—nearest tenth knot.

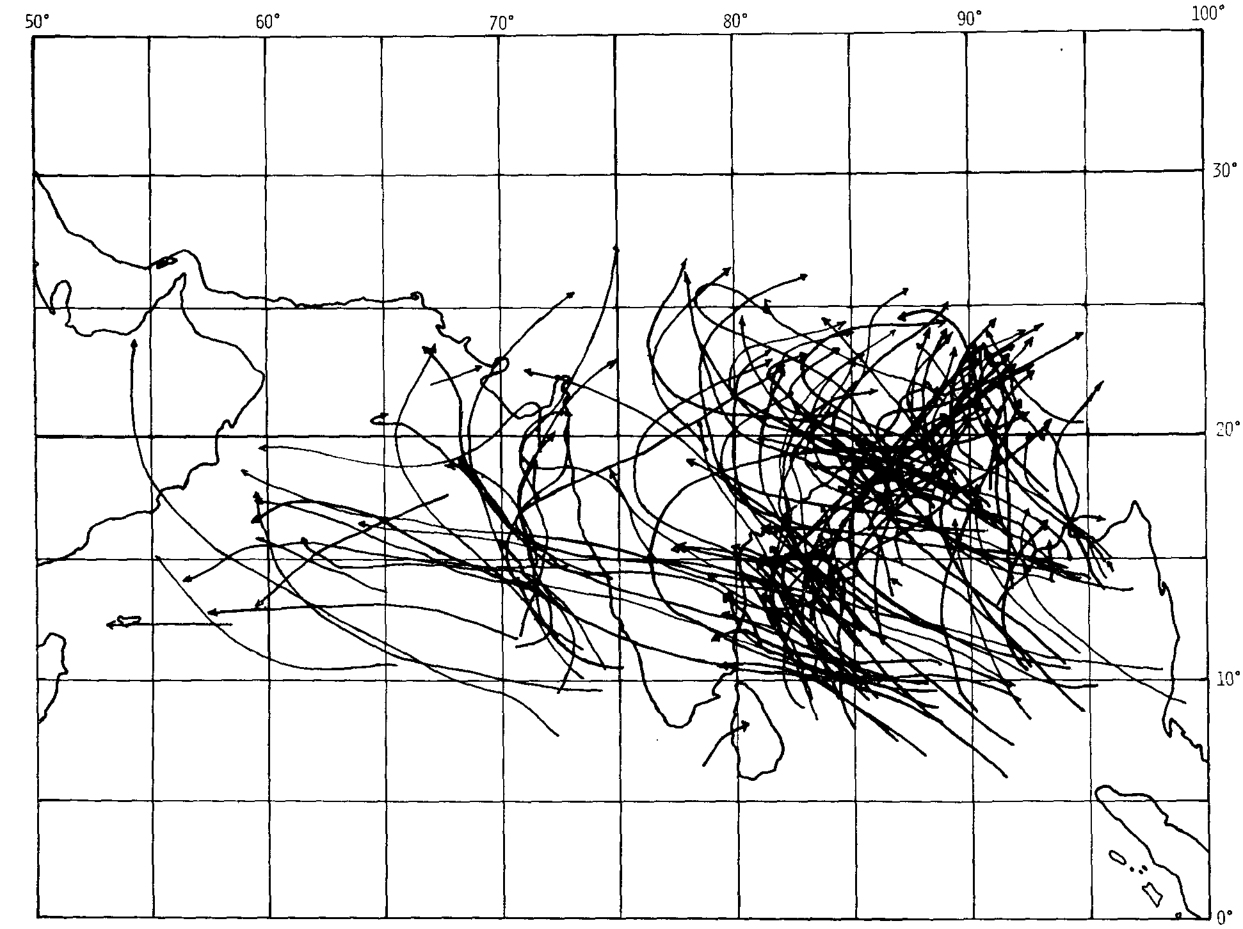

FIG. 1. October tropical cyclone tracks for the North Indian Ocean (1900–70). Number of tropical cyclones—141.

3. Description of the method

The input for the storm to be forecast consists of position and movement as well as the date. The program then searches the history file and selects those storm positions that meet the following criteria:

a) Within ±30 days of current storm
b) Within ±3.0° latitude/longitude of current storm
c) Within ±30° of current storm heading (past 12-h direction)
d) The speed selection (past 12 h) is as follows:
   1) ±3 kt if current storm speed is ≤7 kt
   2) $\frac{1}{2}$ to twice current speed if current storm speed is >7 but ≤13.5 kt
   3) $\frac{2}{3}$ to $\frac{3}{2}$ current speed if current storm is >13.5 kt.

If there are fewer than two acceptable analog candidates, the "window" of acceptance is increased to ±3.5° latitude/longitude. If this criterion fails to gain at least two analogs, no forecast will be produced.

After each analog storm is selected, a 12-h vector is computed based on the speed and heading of the current storm (persistence) and of the analog storm (climatology). The magnitude of each 12-h vector displacement is defined as

$$\text{DISP}=12(W_c\cdot C_s+W_a\cdot A_s), \qquad (1)$$

where

W_c = persistence weighting factor
C_s = mean past 12-h speed of current storm (kt)
W_a = climatology weighting factor
A_s = 12-h speed of analog storm (kt).

The direction of the vector is defined as

$$\text{DIR}=W_c\cdot C_h+W_a\cdot A_h, \qquad (2)$$

where

C_h = mean past 12-h heading of current storm
A_h = heading of analog storm.[1]

This vector is transposed to the location of the current storm position and a new latitude and longitude are determined. The centroid of the new latitude and longitude positions is the forecast position. Up to 72 h

[1] Appropriate corrections are made in the program for 360° circle vector additions and it should be noted that $W_c+W_a=1$.

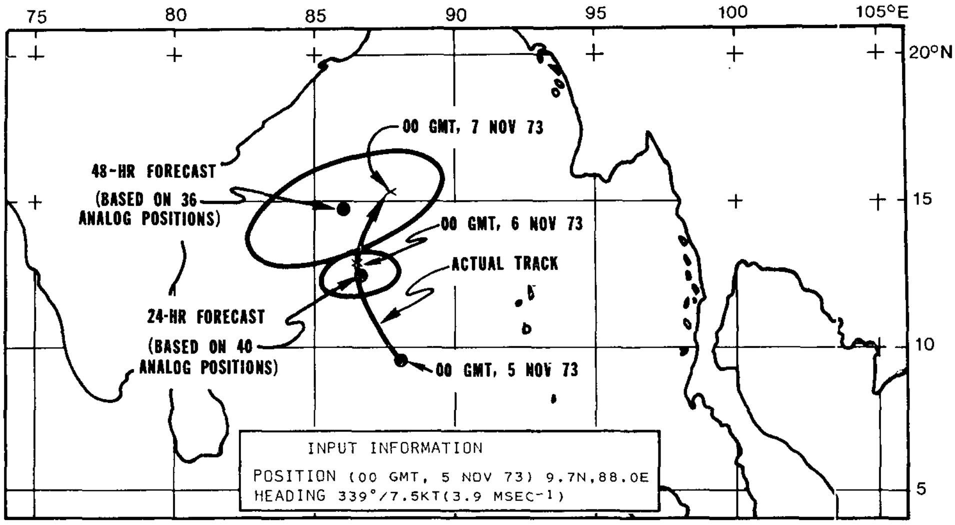

FIG. 2. Example of 24- and 48-h forecasts, including 50% probability ellipses for INJAH74.

of observational information is stored for each selected analog storm and, since the forecast technique is based on 12-h incremental vectors, the 24-h forecast position is derived from the centroid of the 12-h vector positions, and so on out to 72 h. The spatial distribution of the positions defines probability ellipses, which are also included as output for INJAH74. Figure 2 shows an example of a 24- and a 48-h forecast, including probability ellipses (50%) for INJAH74.

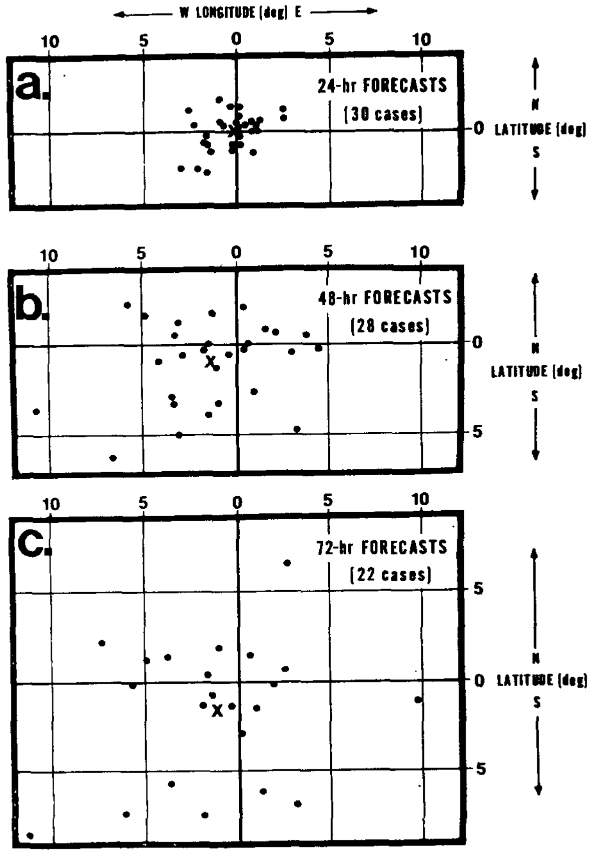

FIG. 3. Distribution of forecast positions relative to actual verifying position for; (a) 24-h, (b) 48-h, and (c) 72-h forecast test cases. Note: The X's indicate the centers of the distributions.

4. Some additional considerations

In order to determine the general accuracy of the INJAH74 forecast technique, a series of test cases were run for available tropical cyclone data from 1971–73. Thirty forecast situations for 10 Bay of Bengal tropical cyclones were used as the basis for the test.[2]

It became apparent that the technique was sensitive to variations in the weighting scheme (that is, the persistence versus climatology weight for each forecast time). The importance of the climatological factor seemed to be always evident—even, surprisingly, in the early forecast stages.

Not all the test results will be presented or discussed, but Table 1 shows some representative 24-, 48-, and 72-h forecast errors for four distinct weighting schemes. A comparison of total persistence (Column D) with total climatology (Column C)[3] shows the importance of climatology even at 24 hours. Columns A and B show the errors for two tests with an element of persistence for just the first 12 hours. The forecasts thereafter revert toward climatology. Column B with even less

[2] Best track information was used for input and for verification. It should be noted that in an operational mode best track information is not available and this would reduce the accuracy of the forecasts because of possible incorrect analog selections and incorrect motion vectors. The comparative results, in particular with respect to persistence, are nevertheless quite informative and revealing.

[3] Since persistence is inherent in the selection of analogs, this would be a selective climatology. Total climatology as defined here implies no weight for persistence; it is just the centroids of the selected analogs at the specified forecast times.

TABLE 1. Forecast errors for INJAH74 for four separate forecast weighting schemes.

	A	B	C	D
Hours	12 24 36 48 60 72	12 24 36 48 60 72	12 24 36 48 60 72	12 24 36 48 60 72
Persistence (%)	85 0 0 0 0 0	55 0 0 0 0 0	0 0 0 0 0 0	100 100 100 100 100 100
Climatology (%)	15 100 100 100 100 100	45 100 100 100 100 100	100 100 100 100 100 100	0 0 0 0 0 0
24-Hr Mean Vector Error (nm) [km]	(88.2) [163.4]	(86.7) [160.7]	(84.5) [156.6]	(104.3) [193.3]
Number of Cases	30	30	30	30
Standard Deviation (nm) [km]	(54.0) [101.1]	(52.1) [96.6]	(51.5) [95.4]	(60.0) [111.2]
48-Hr Mean Vector Error (nm) [km]	(213.3) [395.3]	(211.5) [391.7]	(207.8) [385.1]	(288.1) [533.9]
Number of Cases	28	28	28	28
Standard Deviation (nm) [km]	(142.2) [263.5]	(139.0) [257.6]	(138.8) [257.2]	(163.8) [303.6]
72-Hr Mean Vector Error (nm) [km]	(300.2) [556.3]	(299.5) [555.0]	(300.5) [556.9]	(425.6) [788.7]
Number of Cases	22	22	22	22
Standard Deviation Error (nm) [km]	(204.0) [378.1]	(204.6) [379.1]	(203.5) [377.1]	(195.3) [361.9]

weight for persistence in the first 12 hours (55% persistence, 45% climatology) does slightly better, in general, than a heavier weighting toward persistence as in Column A (85% persistence, 15% climatology). Even though total climatology tended to be best in general, for this sample, the weights given in Column B were selected for the final version of INJAH74; for there are times of the year and regions in the North Indian Ocean that will yield very few analogs, and it is at those times that the persistence element becomes important.

To determine if there was any bias in forecast positions relative to the actual verifying positions, a plot was made of the distribution of forecasts for the thirty test cases; this can be seen in Fig. 3. The forecasts for 24 hours seemed to indicate little if any bias. The mean bias for 48 and 72 hours seemed to be more obvious with forecasts tending to be both south and west of the verifying positions. The forecaster might want to subjectively keep in mind the above bias if he is incorporating INJAH74 in his operational forecast.

The forecast method as presented in this paper is a statistical climatological computer forecast technique that can provide objective forecasts for tropical cyclones significantly better than persistence. The importance of climatology is very evident in this tropical cyclone analog technique for this area of the world. Without a significant improvement in the synoptic data base in this region, it is doubtful whether further significant improvements can be achieved from those results presented previously.

INJAH74 is presently running operationally at the U. S. Fleet Weather Central/Joint Typhoon Warning Center at Guam, the forecast agency responsible for providing tropical cyclone warnings to U. S. Navy and Department of Defense contracted vessels and installations in the western Pacific and Indian Ocean. As the technique is operationally tested, forecast experience will dictate the needs for further modification, development, and tuning of INJAH74.

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