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AN OPERATIONAL TECHNIQUE FOR RELATING THE MOVEMENT OF EXISTING TROPICAL CYCLONES TO PAST TRACKS [1]

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ABSTRACT

The HURRAN (hurricane analog) technique for selecting analogs for an existing tropical storm or hurricane is described. This fully computerized program examines tracks of all Atlantic tropical storms or hurricanes since 1886, and those that have designated characteristics similar to an existing storm are selected and identified. Positions of storms selected as analogs are determined at 12, 24, 36, 48, and 72 hr after the initial time. Probability ellipses are computed from the resulting arrays and plotted on an x, y (CALCOMP) offline plotter. The program also has the option of computing the probability that the storm center will be located within a fixed distance of a given point at a specific time. Operational use of HURRAN during the 1969 hurricane season, including both its utility and limitations, is described.

1. INTRODUCTION

The HURRAN (hurricane analog) technique was developed at the National Hurricane Center in Miami prior to the 1969 hurricane season and used operationally on an experimental basis during the 1969 season. The technique attempts to make maximum possible use of past tracks of Atlantic tropical storms and hurricanes since 1886. The complete record of all storms is stored on magnetic tape; and (utilizing a computer) all those with designated characteristics in common with an existing storm are identified. These characteristics relate to the geographical location, direction and speed of movement, and the date. The appropriate cases having been identified are listed, and their hourly positions from the initial hour to 72 hr are computed. Probability ellipses, assuming a bivariate normal distribution of the latitude and longitude components, are computed from the arrays at 12, 24, 36, 48, and 72 hr after the initial time, and a tape is computer-generated from which to plot the ellipses and appropriate section of map on an offline x, y, (CALCOMP) plotter. Examples of these plots are shown in figures 1 and 4. By integrating the probability density function, the probability contained in an offset circle or ellipse within any portion of the probability ellipse can be obtained. The computer program, by computing the necessary variables, expedites the use of tables that evaluate this integral (Groenewoud et al. 1967).

The idea for such an approach to hurricane climatology has been suggested previously. Haggard et al. (1965) presented a paper on storm strike probabilities at a conference on hurricanes. Techniques utilizing probability ellipses applied to a number of geophysical parameters have also been described by Rapp and Isnardi (1951), Veigas et al. (1959), Crutcher and Baer (1962), and Tracy (1966). Hope and Neumann (1968) used the concept in computing the probability that Cape Kennedy would be affected by an existing storm. A brief description of the theory and method of computing probability ellipses follows.

The bivariate normal probability density function is expressed as

$$f(x, y)=\frac{1}{2\pi\sigma_x\sigma_y\sqrt{1-\rho_{xy}^2}}e^{-G/2} \tag{1}$$

where G, the locus of which in the x, y plane describes an ellipse, is

$$G=\frac{1}{1-\rho_{xy}^2}\left[\frac{(x-\mu_x)^2}{\sigma_x^2}-\frac{2\rho_{xy}(x-\mu_x)(y-\mu_y)}{\sigma_x\sigma_y}+\frac{(y-\mu_y)^2}{\sigma_y^2}\right] \tag{2}$$

(Lindgren 1962) where the population parameters are

μ_x mean of the x (longitude) coordinates,
μ_y mean of the y (latitude) coordinates,
σ_x standard deviation of the x coordinates,
σ_y standard deviation of the y coordinates,
σ_x^2 variance of the x coordinates,
σ_y^2 variance of the y coordinates, and
ρ_{xy} correlation coefficient between the x and y coordinates.

In making computations from sample data, the population parameters are replaced by the respective sample parameters $\bar{x}$, $\bar{y}$, S_x, S_y, S_x^2, S_y^2, and r_{xy}. The probability that a randomly selected point (x, y) falls into the region S of the x, y plane is given by the integral of the probability density function

$$P(S)=\int_S\int f(x,y)dxdy \tag{3}$$

(Burington and May 1953).

However, the locus of $G=c^2$, where c is a constant, defines an equi-probability ellipse where, for each value of c, $f(x, y)$ is a constant. For example, when $c=1.1774$, $P=0.50$. In general, the probability defined by a parti-

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cular value of c is given by

$$P=1-\exp(-c^2/2). \tag{4}$$

The semi-lengths of the major and minor axes of the ellipses thus obtained are computed by multiplying the standard deviation along these axes by the value of c for the particular probability desired. For obtaining the standard deviation along the major and minor axes, however, the ellipses must be rotated first through an angle ψ relative to the latitude-longitude grid to eliminate the cross product term in eq (2). The components along the rotated axes are then uncorrelated. The angle ψ is determined by considering the general equation of an ellipse centered at the origin

$$Ax^2+Bxy+Cy^2+F=0 \tag{5}$$

and rotating the axes through an angle ψ defined by

$$\tan 2\psi=\frac{B}{A-C}$$

that in terms of eq (2) becomes

$$\tan 2\psi=\frac{2r_{xy}S_xS_y}{S_x^2-S_y^2} \tag{6}$$

(Groenewoud et al. 1967).

The variances along the rotated axes K_a^2 and K_b^2 are computed from the determinantal equation (Hald 1952)

$$\begin{vmatrix} S_x^2-K^2 & r_{xy}S_xS_y \\ r_{xy}S_xS_y & S_y^2-K^2 \end{vmatrix}=0. \tag{7}$$

Solving for K^2, one obtains

$$K^2=\frac{S_x^2+S_y^2\pm\sqrt{(S_x^2+S_y^2)^2-4S_x^2S_y^2(1-r_{xy}^2)}}{2} \tag{8}$$

where the larger value K_a^2 is the variance along the major axis and the smaller value K_b^2 is the variance along the minor axis.

The semi-length of the rotated axes is determined by multiplying the standard deviations K_a and K_b by the appropriate value of c obtained from eq (4). For example, suppose that for a particular distribution of analog storms 48 hr after the initial time the mean latitude was 31.1° N. and the mean longitude was 70.2° W. This point is the centroid of the distribution from which the ellipses are to be computed. Suppose further that the standard deviation of the longitude coordinates S_x is 1.49° of latitude, the standard deviation of the latitude coordinates S_y is 2.08° of latitude, the correlation coefficient between the longitude and latitude coordinates is −0.896, the angle of rotation ψ by eq (6) is −55.3°, and the standard deviations *along the rotated axes* K_a and K_b by eq (8) are 2.50° and 0.55° of latitude, respectively. The appropriate value of c is determined from eq (4). In this example, if the 0.50 ellipse is computed, the value of c is 1.1774. The semi-length of the major and minor axes is given by $1.1774\times 2.50=2.95$ and $1.1774\times 0.55=0.65$ degrees of latitude. The axes lengths for any probability values desired are computed in similar fashion.

Application of the Kolmogorov-Smirnov one-sample test (Siegel 1956) indicated that the assumption of a bivariate normal distribution should not be rejected. In applying the HURRAN technique, ellipses were not computed when fewer than five analog storms were available.

2. DATA

The basic data source was the North Atlantic tropical cyclone deck, originally compiled by the National Weather Records Center at Asheville, N.C., and included storm data through 1964. The original deck was based on tracks given by Cry et al. (1959). The authors extended the deck to include tracks through the 1968 season and have carefully examined it and applied corrections where necessary. In particular, differences between some of the tracks in the original work and a later publication (Cry 1965) were resolved.

The magnetic history tape gives positions of storms back to 1886 at either 12- or 24-hr intervals, the 12-hr positions being limited to post-1930 storms. The HURRAN technique requires that positions be available every 3 hr. It was necessary, therefore, to devise an interpolation scheme to compute the required intermediate positions each time the program is run.

During the 1969 hurricane season, a linear interpolation subroutine was used to define the 3-hr positions. However, for accelerating or recurving storms, the linear interpolation introduced some serious problems. These involved accepting as analogs some storms that probably should have been rejected because they did not meet the speed and direction criteria, or, conversely, rejecting some storms that should have been accepted. To offset this difficulty, a nonlinear interpolation scheme was devised.

The nonlinear method involves application of Newton's forward and backward formulas (Kelly 1967) carried to the third place in both the U and V components of the 12- or 24-hr storm positions. Since this technique leaves a slight discontinuity at the anchor points, some weighted smoothing was accomplished at these points. The 1969 season was rerun using the new interpolation scheme. In most cases, verification improved; and in general, there was a slight increase in the number of analogs selected, while the ellipses usually were decreased in size. An example of the difference in the results of the two interpolation schemes based on analogs for hurricane Camille is shown in figure 1. The ellipses, grid, and labeling were drawn by the x, y plotter. When using the centroid of the ellipses as the forecast position, the 72-hr vector error using linear interpolation was 273 n.mi. while that obtained using the nonlinear scheme was 225 n.mi.

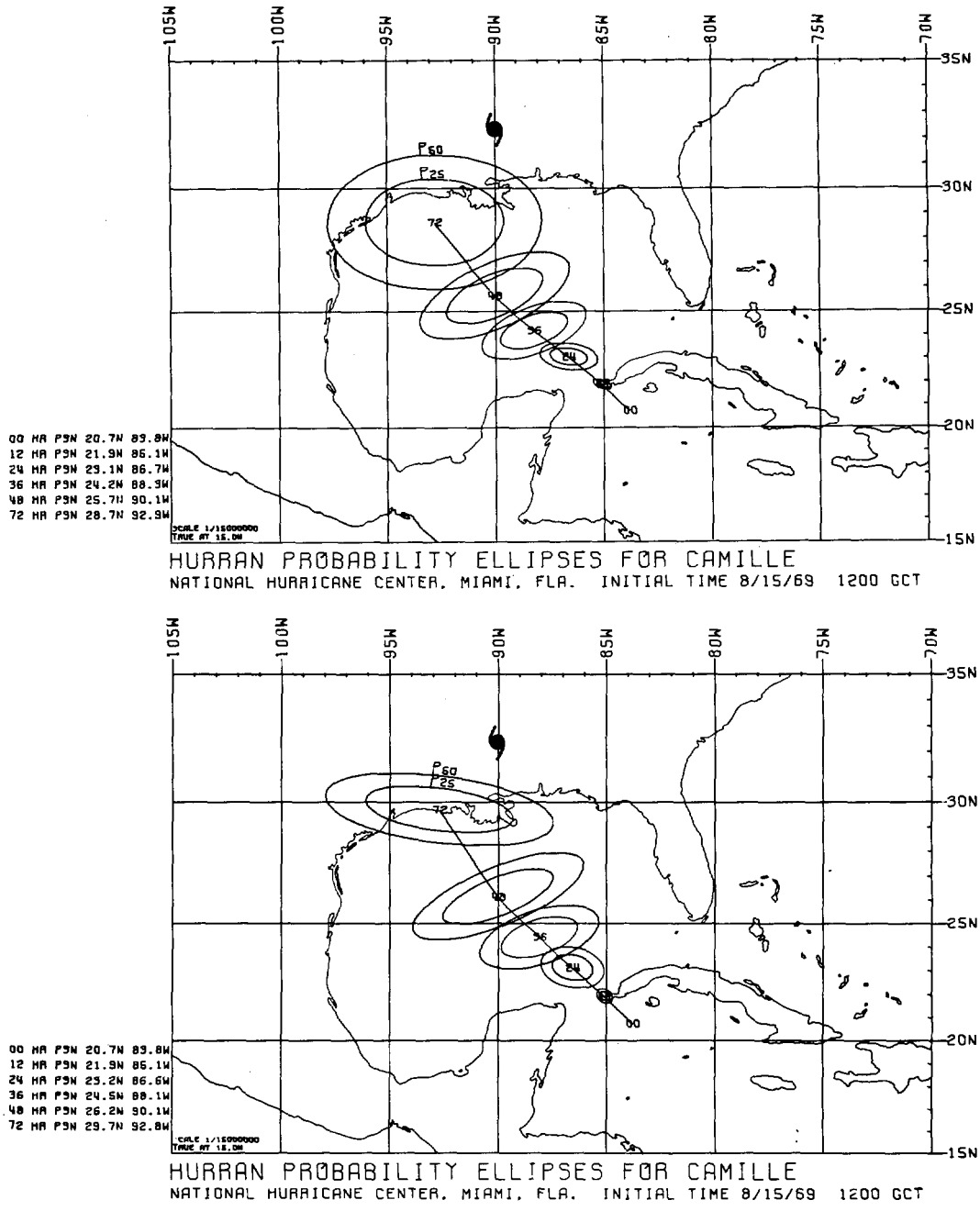

FIGURE 1.—Probability ellipses generated from hurricane Camille analogs based on its 1200 GMT position on Aug. 15, 1969, illustrating the difference in results obtained from using linear interpolation (top) and quadratic interpolation (bottom) for determining intermediate storm positions. The hurricane symbol shows the actual location of Camille at the 72-hr verification time.

3. SELECTION OF ANALOGS

The logic of the computer program used to select analogs is illustrated in figure 2. The variables supplied to the computer each time the program is run are the name of the existing storm, its direction and speed of movement, the current date and time, the distance from the existing storm for which analogs are to be sought, and the ranges of heading and speed for which storms may qualify as analogs. All the storms on the history tape are eventually read in and tested to determine if they satisfy the criteria for analog selection. The following is an example of the way the selection process works. At 1200 GMT on Aug. 20, 1969, hurricane Debbie was located at 25.1° N., 63.3° W., moving on a heading of 297° at 14 kt. Variables were read in so that the computer selected all storms that had passed between August 5 and September 4 within 2½° of latitude of 25.1° N., 63.3° W., on a heading between 274.5° and 319.5° and at a speed between 7 and 21 kt. A total of six storms passed all the selection tests in this case. In general, after considerable experimentation, the criteria in table 1 were used for selection during the 1969 season. All the

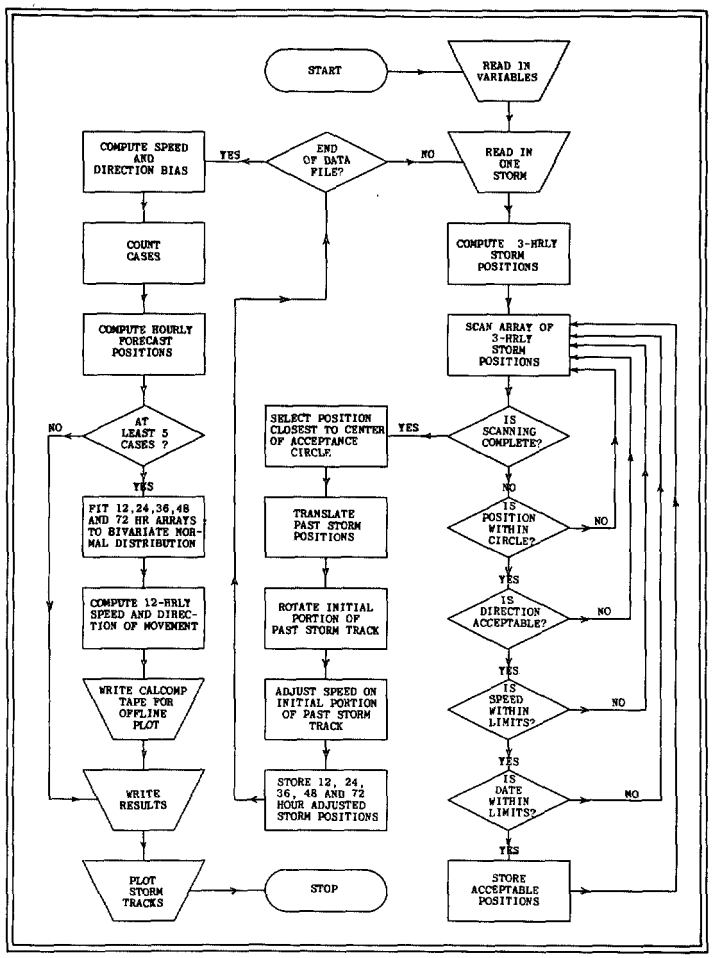

FIGURE 2.—Flow chart illustrating the logic of the HURRAN technique computer program.

criteria in table 1 can be varied. In general, when the ranges are increased, the number of storms selected decreases; but the average distance between the mean of the distribution (centroid) and the existing storm increases. The size of the ellipses also increases when the acceptance criteria are expanded. After the analogs have been selected, the mean latitudes and longitudes are computed hourly out to 72 hr. At the initial hour, all analog storms are translated to the position of the current or existing storm. Each storm is started out at the same heading and speed as the current storm, but the persistence factor is reduced by $\frac{1}{36}$ each hour so that by the 12th hour, for example, the displacement is due $\frac{2}{3}$ to persistence and $\frac{1}{3}$ to the actual movement of the analog storm. After 36 hr then, there is no persistence factor used, and the displacement is entirely that of the analog storm itself. It is to be emphasized that, since the heading and speed of the storm selected is restricted initially so that only those whose movement is similar to that of the existing storm are selected, the persistence factor does not greatly alter the result. However, it has been found that the inclusion of this factor does produce a distribution whose mean is generally closer to the position of the current storm for the first 36 hr. It was found also that no advantage was achieved by maintaining the persistence factor after 36 hr. The translation of analog storms and

TABLE 1.—*Criteria used for computer-selected storms during the 1969 season*

Criteria	Range
Radius of acceptance circle (distance from existing storm)	2½° of latitude
Dates	Current date ± 15 days
Acceptance sector (heading)	22½° either side of heading of existing storm
Speed	If speed of existing storm is less than 10 kt, use speed of existing storm ± 5 kt. If speed of existing storm is from 10 through 20 kt, use 50 to 150 % of existing storm speed. If speed of existing storm is greater than 20 kt, use speed of existing storm ± 10 kt.

use of the persistence factor will be illustrated in the discussion of hurricane Francelia. When all the analog storms have been displaced as described above, their mean latitude and longitude (centroid) is computed for each hour and probability ellipses computed and drawn for 12, 24, 36, 48, and 72 hr. If desired, the probability that a storm will be located within a given radius of a specified point at any of these times can be computed.

Finally, a map is produced showing the eventual disposition of each adjusted analog storm by a 2½° latitude-longitude box. The numbers of these storms eventually passing through each 2½° box is shown. A complete climatology of Atlantic tropical cyclones by 2½° latitude-longitude boxes is given in Hope and Neumann (1969).

4. OPERATIONAL EXAMPLE, FRANCELIA

A complete illustration of the HURRAN technique may be seen by considering Francelia at 1200 GMT on Aug. 30, 1969. At that time, Francelia was located at 14.3° N., 72.2° W., moving on a heading of 291° at 16 kt.

Figure 3 is a computer printout of information pertinent to the 12-hr ellipse. Similar sheets are printed for the 24-, 36-, 48-, and 72-hr ellipses. First, on figure 3, there is a complete listing of all the storms selected as analogs, the 12-hr position, heading and displacement speed, distance from the current storm, and day number of each. (January 1 is day 1, etc.) Next, the semi-lengths of the major and minor axes and the area contained within each ellipse, beginning with the 0.05 ellipse and continuing at 0.05 intervals through 0.95 plus the 0.99 ellipse, are shown. Finally, the parameters from which the distribution was computed are listed along with other bits of supplementary information.

Figure 4 shows the x, y plot of the set of ellipses generated from Francelia based on the position, date, heading, and speed of movement. The actual track of Francelia has been superimposed. Only the 0.25 and 0.50 ellipses are drawn. It is seen that the path of Francelia coincided, in general, with the path of the ellipse centroids for the first 48 hr, but then Francelia turned southwestward, while the analog track continued toward the northwest.

A further illustration of the mechanics of analog selection applied to Francelia is seen in figures 5 and 6. Figure 5 shows the position of Francelia at 1200 GMT on

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LIST OF CASES INCLUDED IN 12 HR ELLIPSE.
STORM NUMBER  5. YEAR 1886. POSITION AFTER 12HRS 15.7N    75.1W .INITIAL DRCN/SPEED/DISTANCE/DAY NUMBER IS 292.4/ 11.2/ 2.1/227
STORM NUMBER  6. YEAR 1886. POSITION AFTER 12HRS 15.4N    75.1W .INITIAL DRCN/SPEED/DISTANCE/DAY NUMBER IS 292.4/  9.2/  .8/230
STORM NUMBER  7. YEAR 1887. POSITION AFTER 12HRS 15.2N    75.4W .INITIAL DRCN/SPEED/DISTANCE/DAY NUMBER IS 278.2/ 15.9/  .9/257
STORM NUMBER  6. YEAR 1889. POSITION AFTER 12HRS 15.2N    75.2W .INITIAL DRCN/SPEED/DISTANCE/DAY NUMBER IS 274.6/ 12.5/ 1.8/256
STORM NUMBER  2. YEAR 1895. POSITION AFTER 12HRS 15.2N    75.1W .INITIAL DRCN/SPEED/DISTANCE/DAY NUMBER IS 280.0/ 14.4/ 1.8/236
STORM NUMBER  3. YEAR 1911. POSITION AFTER 12HRS 14.7N    75.4W .INITIAL DRCN/SPEED/DISTANCE/DAY NUMBER IS 276.5/  8.8/  .3/250
STORM NUMBER  6. YEAR 1916. POSITION AFTER 12HRS 15.7N    76.2W .INITIAL DRCN/SPEED/DISTANCE/DAY NUMBER IS 274.9/ 17.5/ 2.4/242
STORM NUMBER  2. YEAR 1918. POSITION AFTER 12HRS 15.3N    75.4W .INITIAL DRCN/SPEED/DISTANCE/DAY NUMBER IS 283.2/ 21.9/  .3/236
STORM NUMBER  5. YEAR 1931. POSITION AFTER 12HRS 15.4N    76.4W .INITIAL DRCN/SPEED/DISTANCE/DAY NUMBER IS 292.0/  9.3/ 1.5/251
STORM NUMBER  7. YEAR 1933. POSITION AFTER 12HRS 15.1N    75.0W .INITIAL DRCN/SPEED/DISTANCE/DAY NUMBER IS 272.5/ 11.6/  .2/231
STORM NUMBER  3. YEAR 1938. POSITION AFTER 12HRS 15.5N    75.2W .INITIAL DRCN/SPEED/DISTANCE/DAY NUMBER IS 294.7/ 14.4/ 1.4/235
STORM NUMBER  2. YEAR 1942. POSITION AFTER 12HRS 15.4N    76.0W .INITIAL DRCN/SPEED/DISTANCE/DAY NUMBER IS 281.7/  9.9/  .9/235
STORM NUMBER  4. YEAR 1944. POSITION AFTER 12HRS 15.4N    75.2W .INITIAL DRCN/SPEED/DISTANCE/DAY NUMBER IS 290.7/ 11.3/ 2.1/231
STORM NUMBER  3. YEAR 1951. POSITION AFTER 12HRS 15.4N    75.5W .INITIAL DRCN/SPEED/DISTANCE/DAY NUMBER IS 279.9/ 14.6/ 2.2/229
STORM NUMBER  4. YEAR 1951. POSITION AFTER 12HRS 15.2N    75.2W .INITIAL DRCN/SPEED/DISTANCE/DAY NUMBER IS 277.1/ 12.2/  .6/246

PROBABILITY   SEMI-LENGTH MAJOR AND MINOR AXES   AREA OF SPECIFIED ELLIPSE  ELLIPSE NUMBER
     .05       A=   .13DEGLAT  B=   .08DEGLAT          113 NM SQRD          12HR
     .10       A=   .19DEGLAT  B=   .11DEGLAT          232 NM SQRD          12HR
     .15       A=   .24DEGLAT  B=   .13DEGLAT          359 NM SQRD          12HR
     .20       A=   .28DEGLAT  B=   .16DEGLAT          492 NM SQRD          12HR
     .25       A=   .31DEGLAT  B=   .18DEGLAT          635 NM SQRD          12HR
     .30       A=   .35DEGLAT  B=   .20DEGLAT          787 NM SQRD          12HR
     .35       A=   .38DEGLAT  B=   .22DEGLAT          950 NM SQRD          12HR
     .40       A=   .42DEGLAT  B=   .24DEGLAT         1127 NM SQRD          12HR
     .45       A=   .45DEGLAT  B=   .26DEGLAT         1319 NM SQRD          12HR
     .50       A=   .49DEGLAT  B=   .28DEGLAT         1529 NM SQRD          12HR
     .55       A=   .52DEGLAT  B=   .30DEGLAT         1762 NM SQRD          12HR
     .60       A=   .56DEGLAT  B=   .32DEGLAT         2022 NM SQRD          12HR
     .65       A=   .60DEGLAT  B=   .34DEGLAT         2316 NM SQRD          12HR
     .70       A=   .64DEGLAT  B=   .37DEGLAT         2656 NM SQRD          12HR
     .75       A=   .69DEGLAT  B=   .39DEGLAT         3059 NM SQRD          12HR
     .80       A=   .74DEGLAT  B=   .42DEGLAT         3551 NM SQRD          12HR
     .85       A=   .80DEGLAT  B=   .46DEGLAT         4186 NM SQRD          12HR
     .90       A=   .88DEGLAT  B=   .51DEGLAT         5081 NM SQRD          12HR
     .95       A=  1.01DEGLAT  B=   .58DEGLAT         6610 NM SQRD          12HR
     .99       A=  1.25DEGLAT  B=   .72DEGLAT        10161 NM SQRD          12HR
STND DEVY(LATD)  STND DEVX(LONG)  CORR COEF     THETA(DEGS)
   .25DEGSLAT       .40DEGSLAT      -.282        -15.07
MEAN LATD= 15.329  MEAN LONG= 75.421 (CENTROID)
STD DEVN ALONG MAJOR AXIS=    .412 DEGSLAT.  STD DEVN ALONG MINOR AXES=    .237 DEGSLAT.   NUMBER OF CASES =  15


IF THETA IS POSITIVE, IT IS MEASURED FROM EAST TOWARD NORTH. IF THETA IS NEGATIVE, IT IS MEASURED FROM EAST TOWARD SOUTH.
NOTE THAT ALL DISTANCES ARE IN UNITS OF DEGREES LATITUDE.

SPEED AND DIRECTION WHICH WILL GET STORM FROM  0 HOUR POSITION TO 12 HOUR POSITION IS 288.3 DEGS AT 16.4 KTS.
ELLIPSE CENTROID IS   15.3N  75.4W

THERE WERE NO CASES REJECTED BECAUSE OF STORM DISSIPATION BEFORE 12 HOURS.

CURRENT STORM IS MOVING  3.0 KNOTS FASTER THAN AVERAGE SPEED( 13.0KNOTS) OF ABOVE PAST STORMS.


THERE WAS A BIAS IN THE FORECAST TRACK OF -8.3 DEGS.
FOR NEGATIVE BIAS, FCST TRACK WAS ROTATED CLOCKWISE. FOR POSITIVE BIAS, TRACK WAS ROTATED COUNTERCLOCKWISE.
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FIGURE 3.—Computer printout of information pertinent to the 12-hr ellipse for Francelia analogs based on storm position at 1200 GMT on Aug. 30, 1969.

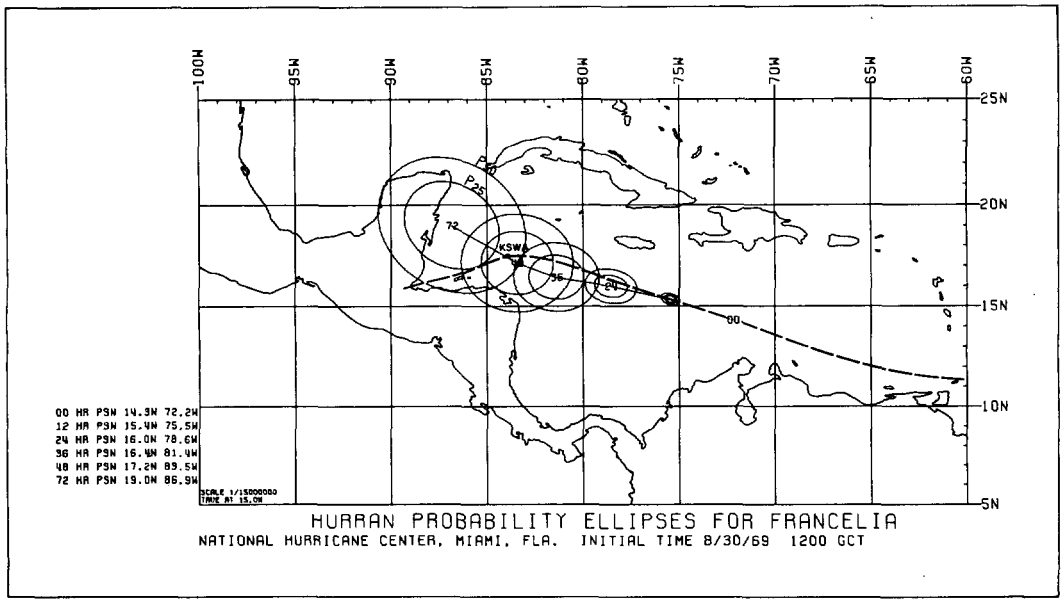

FIGURE 4.—Set of ellipses generated from Francelia analogs based on its position at 1200 GMT on Aug. 30, 1969. The actual track of Francelia is superimposed.

August 30 and the 2½° of latitude circle centered on its position together with the past track of Francelia and the tracks of the analog storms.

The first step in analog selection for Francelia was to examine the tracks of each recorded tropical cyclone since 1886 to determine which, if any, passed through the acceptance circle. Once a storm was found to pass through the circle, it was examined further for additional selection criteria. Specifically, when approaching the closest point to the center of the circle, the tentatively acceptable

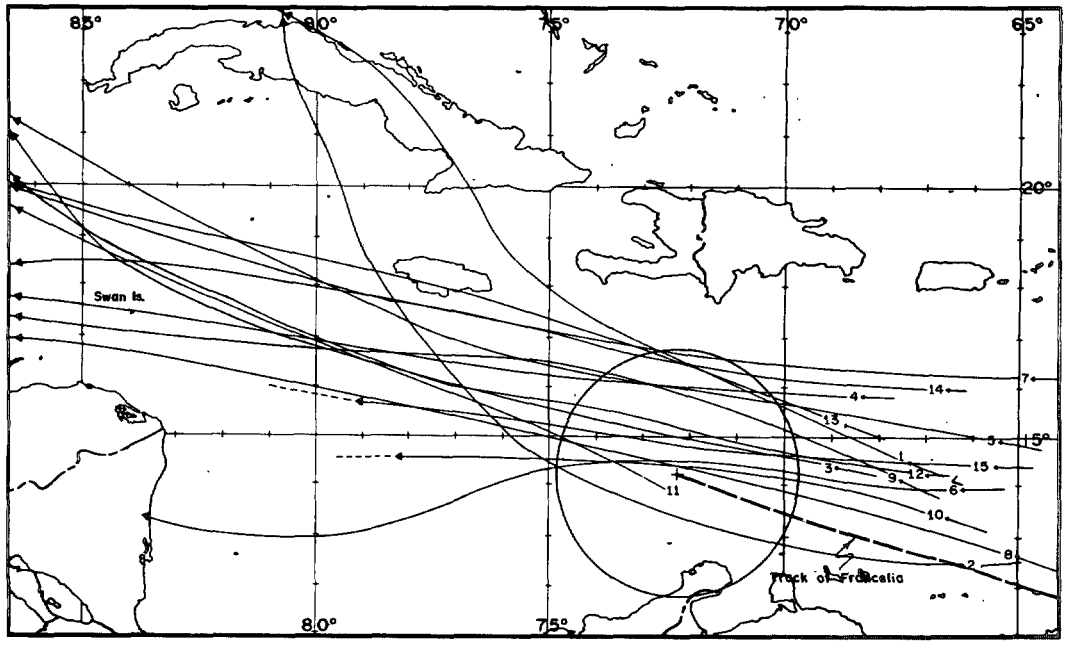

FIGURE 5.—Actual tracks of the 15 storms selected as Francelia analogs based on its position at 1200 GMT on Aug. 30, 1969. The heavier dashed line is the track of Francelia. The storms are numbered chronologically and correspond to the list shown in figure 3.

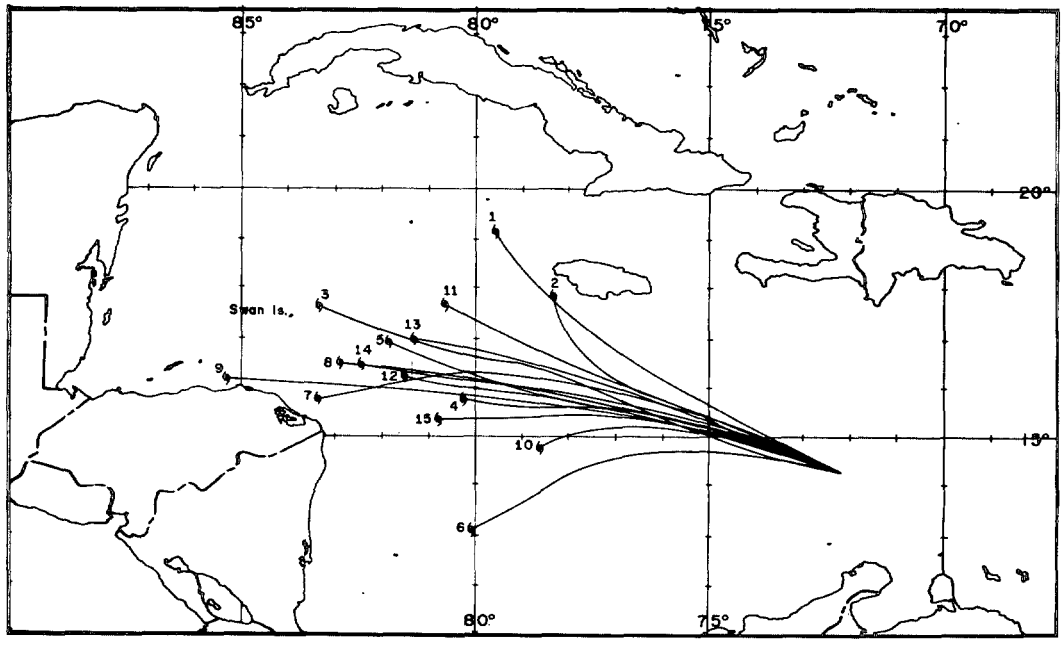

FIGURE 6.—Portions of adjusted tracks of the 15 Francelia analogs based on its 1200 GMT Aug. 30, 1969, position. The storm symbol indicated the adjusted position of each storm after 36 hr. The storms are numbered chronologically and correspond to the list shown in figure 3.

storm had to be moving on a heading ±22.5° from the 1200 GMT heading of Francelia, that is on a heading between 268.5° and 313.5°. Additionally, according to the speed criteria listed above, the speed could not depart more than 50 percent from the speed of Francelia. Storms that did not meet all of these criteria were removed from further consideration. A final screening removed any storm that passed through the acceptance circle, but more than 15 days on either side of the current date of Francelia, that is, earlier than August 15 or later than September 14.

In this example, 15 storms were found to satisfy the selection criteria and therefore were selected as analogs. Applicable portions of the 15 storm tracks are shown in figure 5. These, of course, are the same storms listed at the top of figure 3.

The initial adjustment to the track of each analog storm was to translate it from its position within the acceptance circle to the center of the circle, or to the initial position of Francelia. Each storm track was adjusted further so that its initial heading corresponded exactly with that of

Francelia. This final persistence adjustment, as pointed out above, is phased out linearly so that, after 36 hr, the position of each analog storm is adjusted according to its initial bearing and distance from the center of the acceptance circle. Figure 6 shows portions of the final translated and adjusted tracks for each of the analog storms. The position 36 hr after the initial time is shown for each storm. Comparison of figures 5 and 6 shows the reduction in scatter accomplished by adjusting the tracks of the analog storms.

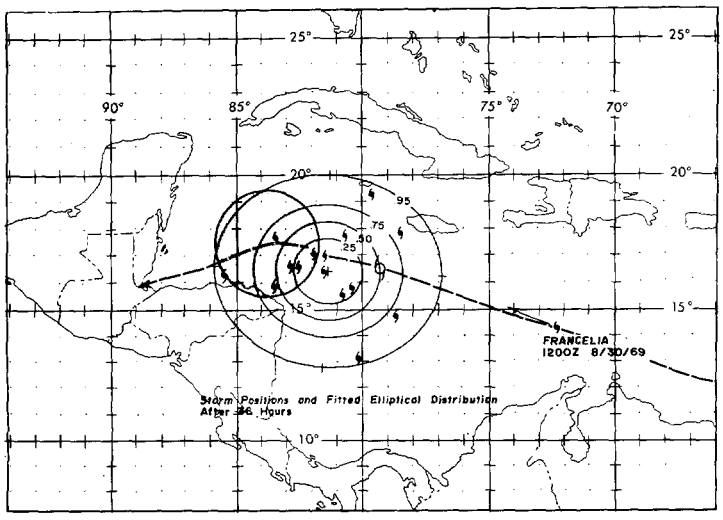

FIGURE 7.—Thirty-six hour ellipse of Francelia analogs based on its position at 1200 GMT on Aug. 30, 1969. The actual position of the analog storms and Francelia are shown. The shading includes the area within 2° of latitude of Swan Island.

Figure 7 shows an enlarged version of the 36-hr ellipse shown in figure 4, except additional elliptical rings have been added. Of the 15 storms from which the ellipse was computed, 6/15 or 40 percent were within the 0.25 ellipse, 8/15 or 53 percent were within the 0.50 ellipse, 10/15 or 67 percent inside the 0.75 ellipse, and all the analog storms were within the 0.95 ellipse. It turned out that Francelia was located 36 hr after the initial time at 16.4° N., 79.4° W., on the 0.50 elliptical ring.

In figure 7, a circle of radius 2° of latitude centered on Swan Island has been shaded. The probability that Francelia would be centered within the shaded circle was computed to be 0.24. Probabilities that Francelia would be centered within the circle 48 and 72 hr after 1200 GMT on August 30 were computed, and these values were 0.33 and 0.13, respectively. Francelia actually passed over Swan Island 54 hr after the initial time. It can be seen in figure 4 that the highest probability would have occurred between 48 and 72 hr. The total probability of Francelia passing within 2° of latitude of Swan Island during the period 48 to 72 hr would, of course, be greater than at either of those fixed times. Similar computations could have been made for offset circles of varying size.

Figure 8 shows the eventual disposition by 2½° latitude-longitude boxes of the 15 Francelia analogs. The number printed in each box is the number of the 15 original storms that eventually passed through the indicated box. Note that only one of these passed east of Florida, while the remainder continued westward or northwestward.

Once a storm is located and its direction and speed determined, it requires only a few seconds of computer time to run the HURRAN program on the IBM 360

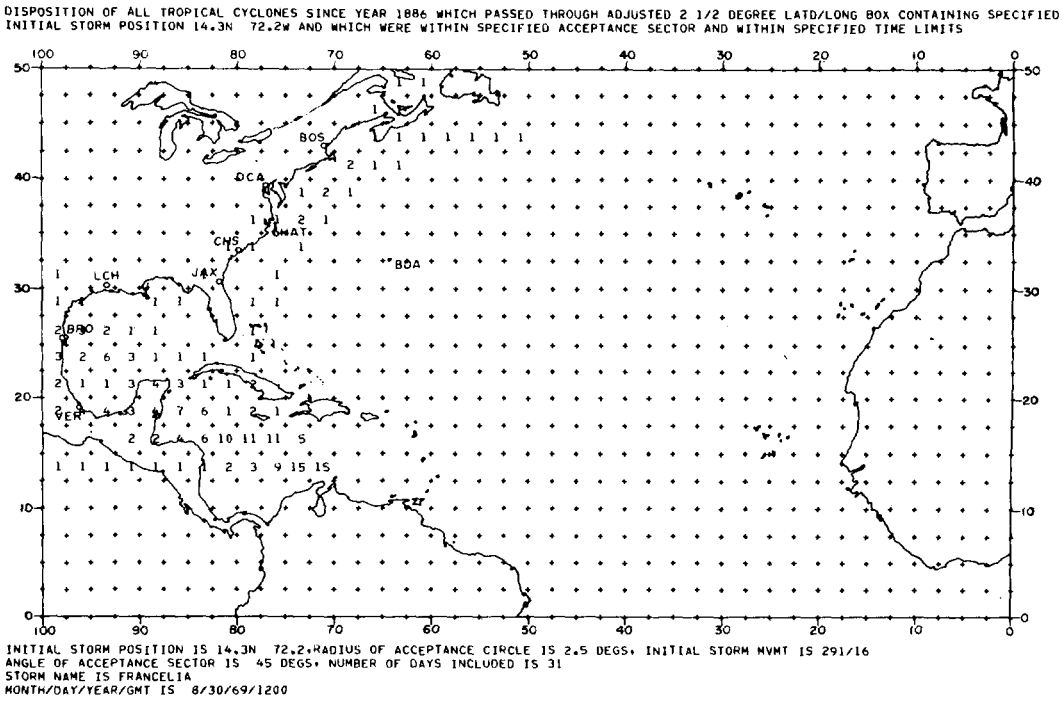

FIGURE 8.—Eventual disposition by 2½° latitude-longitude boxes of the 15 storms used as Francelia analogs.

TABLE 2.—*Mean vector errors for developmental sample*

Forecast period	Mean vector error (nautical miles)
24 hr	77
48 hr	155
72 hr	255

computer and about 5 min to plot the ellipses on the CALCOMP plotter available to the National Hurricane Center at the University of Miami.

5. VERIFICATION

Prior to the 1969 hurricane season, the HURRAN technique was tested on a number of fully developed hurricanes, all of which affected land areas. Assuming the centroid of the ellipses to be the verifying position, the actual results expressed as mean vector errors were very encouraging. In all, the sample included 41 24-hr forecasts, 36 48-hr forecasts, and 34 72-hr forecasts. The hurricanes used in the test were: the 1926 Miami hurricane, 1955 Janet, 1957 Audrey, 1960 Donna, 1961 Carla, 1964 Cleo, 1966 Faith, and 1967 Beulah. The mean vector errors obtained are shown in table 2.

Verifications were also run for the 1969 season, again assuming the centroids of the ellipses to be the forecast position. Since there were refinements of the HURRAN technique as the season progressed, it was not practicable to compare the verification with those of other forecast techniques. Subjectively, however, HURRAN did appear to give results that compared favorably with the other systems. It is planned to conduct a homogeneous comparison of HURRAN with the other forecast systems after the 1970 hurricane season.

6. DISCUSSION

During the 1969 hurricane season, an attempt was made to run the HURRAN program twice daily at 0000 and 1200 GMT on each storm, except in cases where it was certain in advance that no analogs would be found, such as in the case of hurricane Martha as it moved southward toward Panama. Table 3 shows the number of times five or more analogs were found for each storm and forecast period during 1969 and the number of official forecasts made from the same synoptic data.

It should be pointed out that HURRAN is an analogical rather than a climatological tool. The term "climatology" implies normality. HURRAN will work equally well with anomalous storms simply by rejecting all of the "normal" storm tracks. The only requirement is for a minimum of five storms with this particular anomaly to have occurred over the period of record. As the historic data file increases from year to year, additional anomalous storms will be included in the data tape, thereby increasing the effectiveness of the system.

TABLE 3.—*Number of runs of the HURRAN technique during the 1969 hurricane season for which five or more analogs were obtained. The numbers in parentheses in each column are the numbers of official forecasts made at the synoptic times for which HURRAN runs were attempted*

Storm	Forecast period		
	12 hr	24 hr	72 hr
Anna	1 (8)	0 (8)	0 (8)
Blanche	0 (2)	0 (0)	0 (0)
Camille	4 (10)	3 (10)	2 (5)
Debbie	16 (17)	16 (16)	14 (14)
Eve	0 (2)	0 (0)	0 (0)
Francelia	6 (9)	6 (6)	4 (4)
Gerda	1 (3)	0 (0)	0 (0)
Holly	3 (8)	2 (8)	1 (7)
Inga	1 (32)	1 (30)	0 (29)
Jenny	0 (0)	0 (0)	0 (0)
Kara	5 (18)	5 (16)	3 (14)
Laurie	1 (8)	1 (8)	1 (6)
Martha	0 (4)	0 (3)	0 (3)
Total	38 (121)	34 (105)	25 (90)

During the first half of the 1969 hurricane season, five or more analogs were obtained on more than half of the runs. However, the latter half of the season was disappointing in that only a small percentage of runs were successful. This was due, of course, to the anomalous character of the late season storms such as Inga, Kara, Laurie, and Martha. The HURRAN technique will not find analogs unless there have been past storms whose location, heading, and speed of movement can be compared to that of the current storm during the portion of the hurricane season in question. Impressions gained during the development of the technique lead to the belief that five or more analogs will be obtained on well over 50 percent of the attempts.

Work is continuing on ways to increase the usefulness of the HURRAN product. Avenues are being explored to find a way to combine the technique with objective forecast methods in use at the National Hurricane Center. An alternative course is to develop means of selecting and introducing synoptic parameters into the HURRAN technique.

It is evident, however, that the method of analog selection, where only those storms that had a number of features in common with an existing storm are chosen, often picks analogs from synoptic situations that have much in common with the current synoptic picture. This is considered to be a substantial contributing factor to the success of the technique thus far.

It can be argued that the storms of the earlier years, especially those of the previous century, were not sufficiently documented to use in this fashion. This shortcoming is admitted, and it is believed earlier storms eventually can be omitted from the history tape as new ones are added.

As stated above, it is believed that, in the long run, a substantially higher percentage of tries will be successful

than was the case in 1969 when many of the late-season storms exhibited highly anomalous characteristics.

7. CONCLUSION

The HURRAN technique was found to be a valuable supplement to the forecast tools available at the National Hurricane Center during the 1969 hurricane season.

In addition, for determining quickly the disposition of storms selected as analogs, their rapid identification enables the forecaster to confine any perusal of past storm tracks and their concomitant synoptic patterns to those pertinent to his problem.

Forecasters at the National Hurricane Center found, in the absence of strong indications to the contrary, that forecast positions frequently were improved if an effort was made to keep the forecast position within the 50 percent ellipse computed by the HURRAN technique.

During the 1970 hurricane season, the National Hurricane Center used the technique as an objective guide in determining areas for which hurricane watches were issued.

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