Probability of Hurricane/Tropical Storm Conditions: A User's Guide For Local Decision Makers

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On Saturday, September 8, 1900, a major hurricane struck Galveston, Texas, resulting in the deaths of approximately 6,000 persons. These deaths occurred despite the fact that the hurricane had been tracked from the Windward Islands into the Gulf of Mexico. According to a report by Dr. H. C. Frankenfeld of the U.S. Weather Bureau, the hurricane was first detected ten days earlier near the Windward Islands. Its progress was monitored as it passed through the Caribbean, transversed Cuba, and moved into the Gulf of Mexico, south of Key West, Florida. On the afternoon of Tuesday, September 4, mariner storm warnings were issued for Florida ports from Cedar Keys to Jupiter. The next day these warnings were extended to cover the area from Port Eads, Louisiana, to Savannah, Georgia. As the hurricane moved northwestward into the Gulf of Mexico, mariner storm warnings were shifted westward to cover the entire Texas coast on Friday, September 7.

Despite the fact that the storm had been detected ten days earlier and despite the mariner storm warnings that had been posted the previous day, the residents of Galveston were completely unprepared for the hurricane. In 1900, of course, we did not have many of the modern tools available to us today to track and predict the movement and landfall location of major hurricanes. Organized aircraft reconnaissance of detected storms was not instituted until the 1940's. The network of coastal radar stations to monitor hurricanes near landfall was not in place until the 1950's. And, the first satellites were not available until the 1960's.

During the period when these technological tools were being developed and implemented, the tropical meteorologists were also improving their ability to forecast the movement of hurricanes. During this same period, however, there was a rapid increase in the concentration of both population and industry along the Atlantic and Gulf Coasts. In a number of areas, this concentration has become so great that the total time required for evacuation of threatened residents has now exceeded the confident warning time which can be given by hurricane forecasters.

For example, a recent study in the Galveston area has estimated that it will take at least 26 hours to completely evacuate the island, a task that would be required if a repeat of the 1900 storm occurred. In order for such an evacuation to be completed before the onset of dangerous conditions, the decision to order an evacuation must be made approximately 36 to 38 hours before the anticipated time of landfall. Hurricane Warnings, however, are generally not issued by the National Weather Service's National Hurricane Center in Miami, Florida, until about 24 hours before anticipated landfall. Similar situations have been documented in a number of major metropolitan coastal areas and are suspected in others.

At the present time, then, there is growing recognition that a critical need exists for forecast information on hurricane movement prior to 24 hours before anticipated landfall. To address this need, the National Weather Service will begin routinely disseminating such information during the 1983 hurricane season. These long range forecasts will be in the form of probabilities that selected coastal communities will experience hurricane or tropical storm conditions. These probabilities will be issued for selected coastal and island locations beginning approximately 72 hours before expected landfall or when the first forecast is issued if that occurs less than 72 hours before expected landfall. These probabilities will continue to be issued approximately until hurricane conditions threaten the coast; they will be dropped at the discretion of the National Hurricane Center.

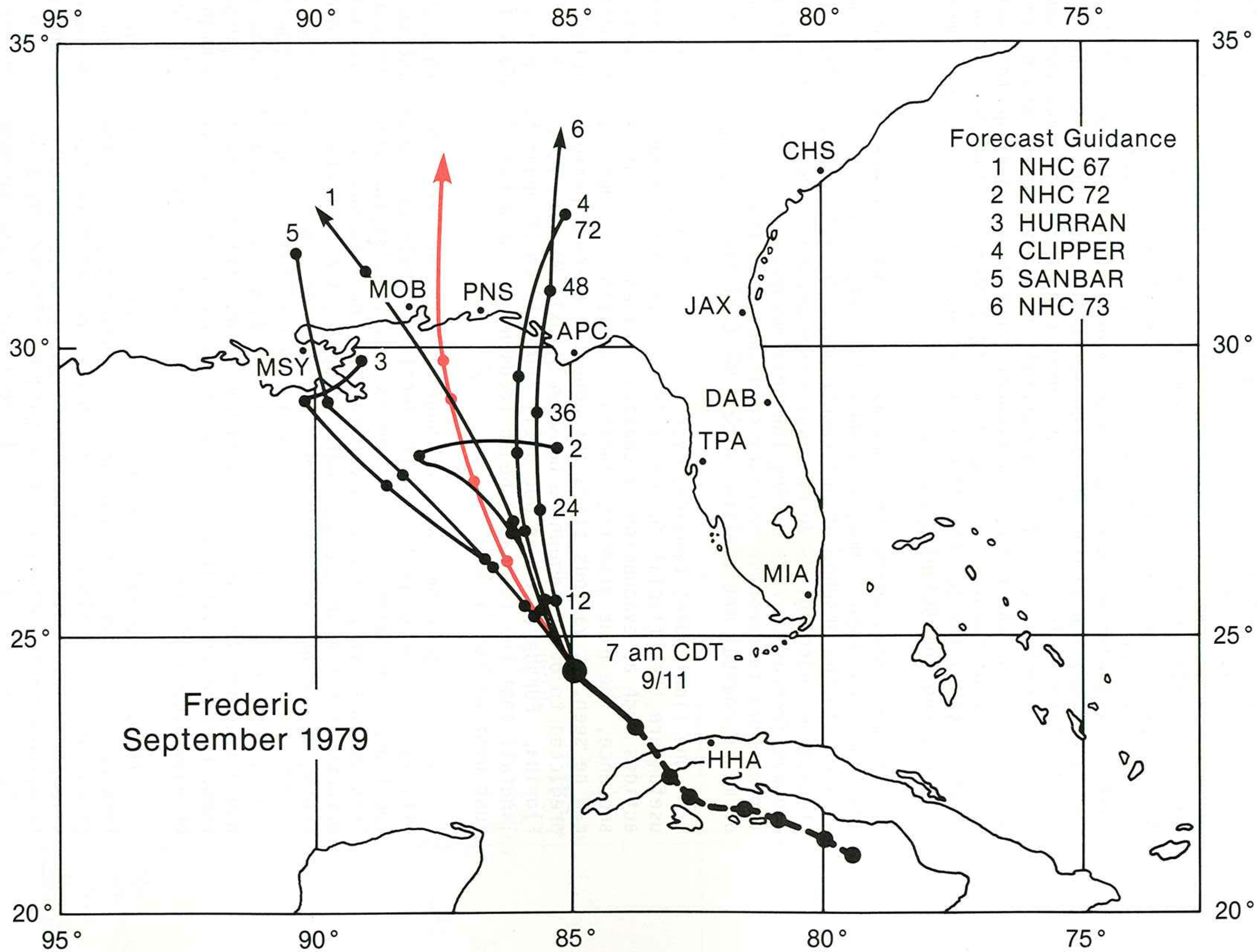
The purpose of this manual is to explain in detail what these probabilities represent, how they are computed, how they should be interpreted, and how they can be most effectively utilized in decision making for such preparatory actions as evacuation, setting up shelters, or industrial plant shutdowns.

I. Forecast Problem

Before discussing directly the basis of the probabilities which will be issued, it will be helpful to review briefly both how the National Hurricane Center develops its forecasts of hurricane movement and how accurate these forecasts have proven to be during the past decade. Since the operational use of large computers became commonplace during the early 1960's, tropical meteorologists have spent considerable effort developing various computer models to predict the movement of tropical storms out to 72 hours in the future. These models represent a variety of techniques ranging from simple climatology through rather complex mathematical equations. As one would expect from such a variety of techniques, the computer models often predict quite different tracks for a given storm. Given these different predictions, the hurricane forecaster must use his experience and knowledge of the characteristics of each of the models as well as his own analysis of current, past, and expected storm and environmental conditions to arrive at his estimate of where the tropical storm will move during the next 72 hours. This estimate constitutes the "official" forecast storm track produced by the National Hurricane Center and forms the basis of the National Weather Service's Hurricane Watches and Warnings.

As an example of this process, Figure 1 presents the forecast tracks produced by each of the computer models and the official forecast which was issued for Hurricane Frederic at 11 AM CDT on September 11, 1979. A new set of these forecasts is produced by the National Hurricane Center at least every 6 hours after an identified weather system develops tropical storm strength. Forecast positions are given for 12, 24, 36, 48, and 72 hours beyond the time the forecast was made.

Figure 1. Forecast Positions Generated by Six Computer Models, and the Official Forecast Track, for Hurricane Frederic, 7 am CDT, Tuesday, September 11, 1979.



The obvious question now arises as to how accurate are these forecasts. Figure 2 presents the official forecast discussed above and the actual location of Hurricane Frederic during each of the forecast periods. An arrow is also shown between the forecast location and the actual location which indicates both the distance and direction of the forecast error. A general pattern which is obvious in this example is that, as one moves farther into the future, the forecast errors become larger. In this respect, however, Frederic was a rather unique storm. While the forecast track was very accurate, the timing along the forecast track was very inaccurate for this particular forecast. Both of these components -- track and timing along the track -- contribute to overall forecast errors, which tend to be quite large for the typical hurricane. Indeed, the average forecast error in the Gulf of Mexico increases from about 60 miles for the 12-hour forecast to about 435 miles for the 72-hour forecast. These errors are somewhat larger along the Atlantic coast.

As mentioned above, the forecast errors were reduced somewhat during the 1950's and 1960's, but, as Figure 3 shows, have stablized in the past decade. In the absence of unforeseen major breakthroughs in the near future, tropical meteorologists do not anticipate any major reduction in these average forecast errors during the next decade. This leveling off of improvement in forecast accuracy coincides with the increasing vulnerability of major coastal metropolitan areas due to increasing population density.

One final point remains, even given the observed forecast errors, how useful are the official forecasts in deciding whether to take preparatory actions such as evacuation of coastal residents? Figure 4 presents, in sequence, the nine predicted landfall locations of Hurricane Frederic. As can be seen, at various times throughout a 48-hour period, landfall was predicted to occur somewhere between Biloxi, Mississippi, and Panama City, Florida. Further, it was not until about 12 to 18 hours before actual landfall that the forecasts began focusing on the actual landfall location -- just west of Mobile Bay.

It is only in the last few hours before landfall, then, that the official forecasts are both sufficiently accurate and consistent to allow local decision makers to use them as a sure guide for preparatory actions. This is especially true when considering the area subject to the destructive effects of the storm surge. With Frederic, a relatively well-predicted storm, it was not until about 4 or 5 hours before the onset of hurricane conditions that the official forecasts consistently pinpointed the Gulf Shores and Dauphin Island segment of the Alabama coast as the area that would receive the brunt of the storm surge. For all practical purposes, then, the individual forecasts generally cannot be used with a high degree of assurance as guides for local action beyond 24 hours prior to landfall.

If so much uncertainty exists in the official forecasts, what types of long-range forecast information can be given beyond 24 hours prior to anticipated landfall? Since the early 1960's, research has been undertaken by several meteorologists and statisticians to develop methods which assess the likelihood that a given location will be affected by a given storm. The probabilities that initially will be issued by the National Weather Service are based primarily on a technique developed by the Naval Environmental Research and Prediction Facility and modified by the National Hurricane Center.

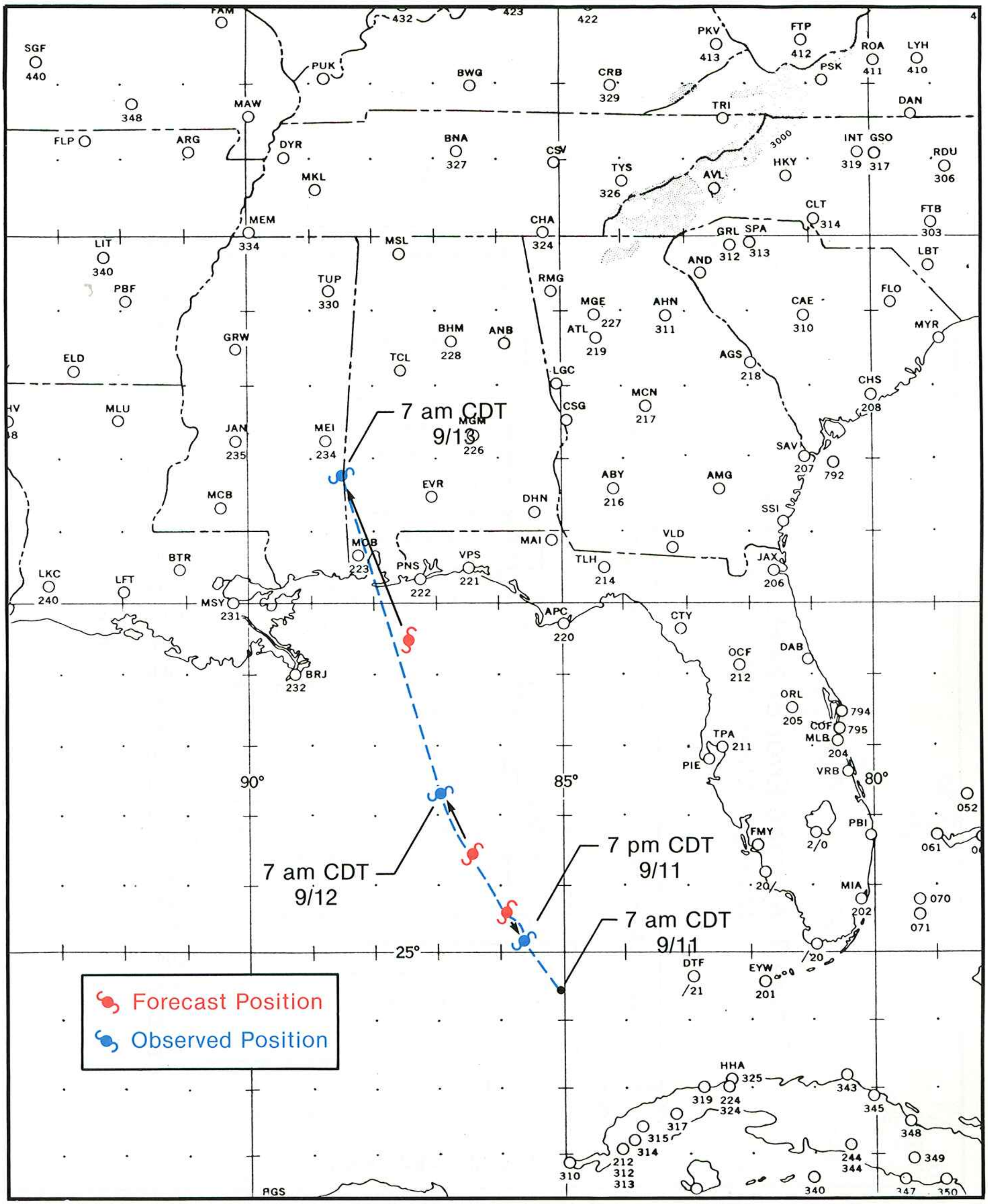
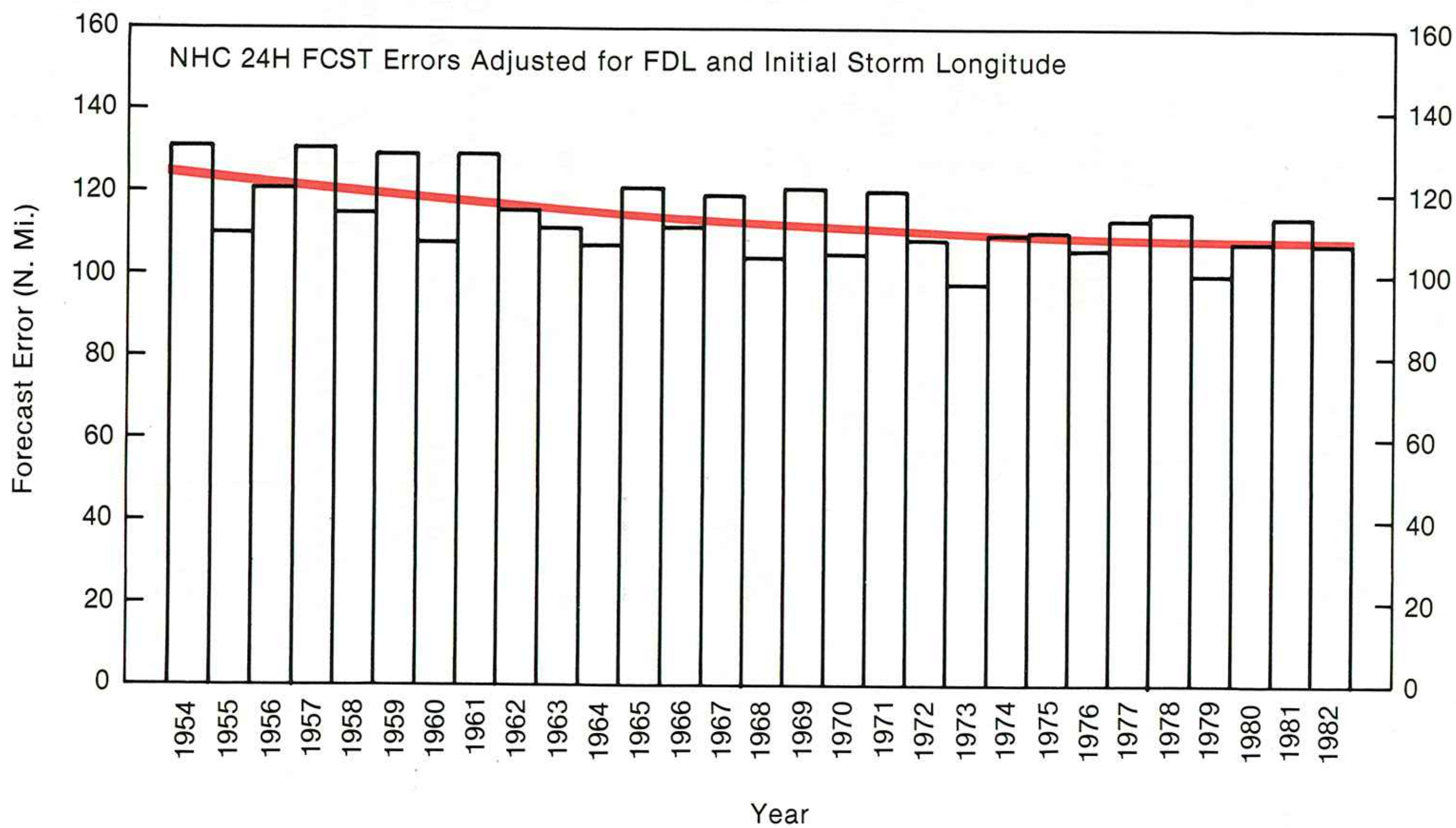


Figure 2. Observed Forecast Errors for the 7 am CDT, Tuesday, September 11, 1979, Official Forecast Track for Hurricane Frederic.

Figure 3. Average Error of 24-Hour Forecast Positions, in Nautical Miles, 1956-1982.



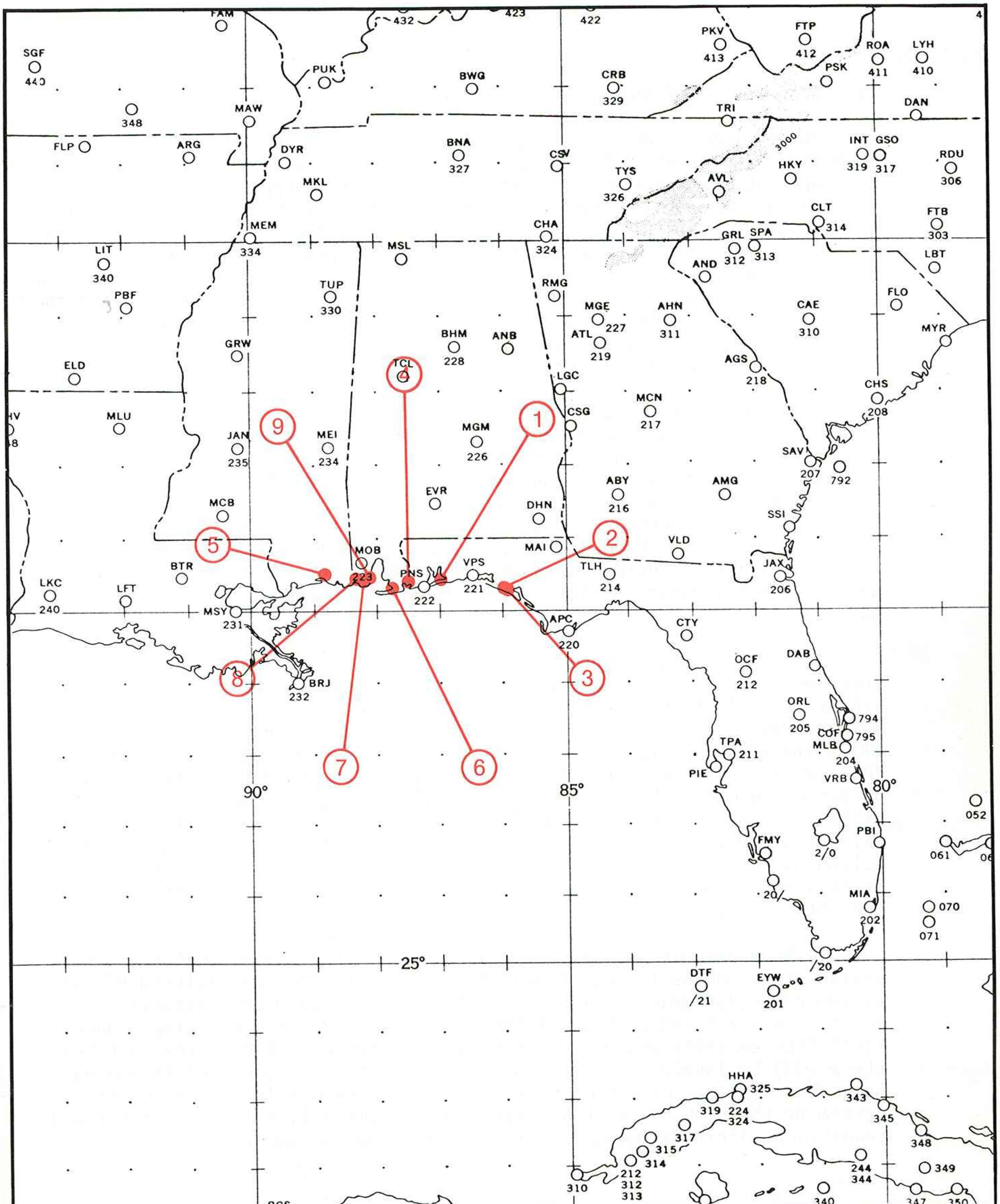


Figure 4. Successive Predicted Landfall Locations for Hurricane Frederic, for Period from 1 pm CDT, Monday, September 10, 1979, Through 1 pm CDT, Wednesday, September 12, 1979.

II. Probability of Hurricane Conditions

To develop an understanding of exactly what probabilities of hurricane conditions represent, let us begin with an example storm whose past track and forecast positions are presented in Figure 5. Suppose, for a moment, that we had data on all hurricanes for the past 100,000 years rather than the 100 or so years which we actually have. Suppose also that our forecasting ability had not changed during this 100,000 year period. During this period, it would be very likely that we could find 100 cases in which a storm was located at the position shown and also was forecasted to move along the track shown in Figure 5. We can now address the question of where each of these 100 storms were actually located during some forecast period -- for example, 48 hours after the forecast was made.

Based on all the data we do have for this region of the Gulf of Mexico, Figure 6 gives a reasonable approximation of the locations of these 100 storms. As can be readily seen, the locations are rather scattered throughout the Gulf. Indeed, while the forecast placed the storms approximately 70 miles off the Louisiana coast, some 25 percent of these storms already would have made landfall. Further, landfall locations would have ranged from the Galveston, Texas, area to the southwest Florida coast. Figure 6, then, gives graphic evidence of the implications of the forecast errors which currently exist in the official forecasts produced by the National Hurricane Center.

The distribution of actual storm locations versus forecasted storm location presented in Figure 6 can be used to address the question of how likely it is that the storm will actually be located in any portion of the Gulf of Mexico. One possible example of this is presented in Figure 7 in which the ellipse shown encloses 50 percent of the actual storm locations. Thus, using standard statistical concepts, we can state that there is a 50 percent probability that the storm will be located somewhere within this ellipse 48 hours after the forecast was made. Figure 8 shows a much larger ellipse which encloses 99 percent of the actual storm locations. Again, following standard statistics, we can be almost virtually certain that the storm will be located somewhere within this larger ellipse 48 hours after the forecast was made.

To be even more precise, Figure 9 presents this 99 percent ellipse divided into one-half percent segments. By using this partitioned ellipse, we can directly compute the probability that the storm will actually be located in any given portion of the Gulf of Mexico. For example, Figure 10 identifies an arbitrary area. There is a 24 percent probability that the storm will be located within this area since it is composed of 48 one-half percent segments. Extending this concept, we are now in a position to determine the probability that, say, New Orleans will experience hurricane conditions within 48 hours of the time the forecast was made.

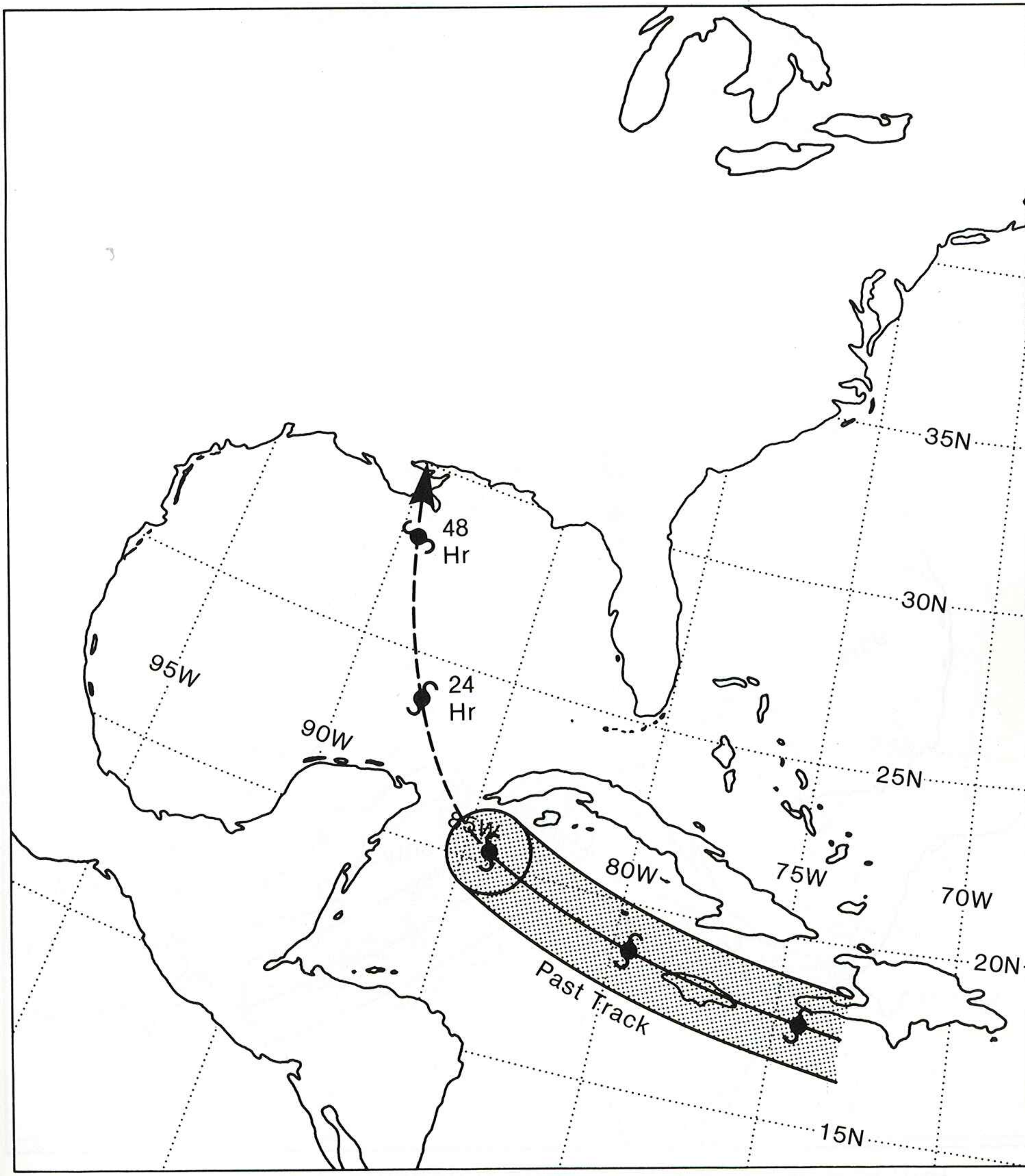


Figure 5. Example Showing the Past Track of a Hurricane, and the 24-Hour and 48-Hour Forecast Positions.

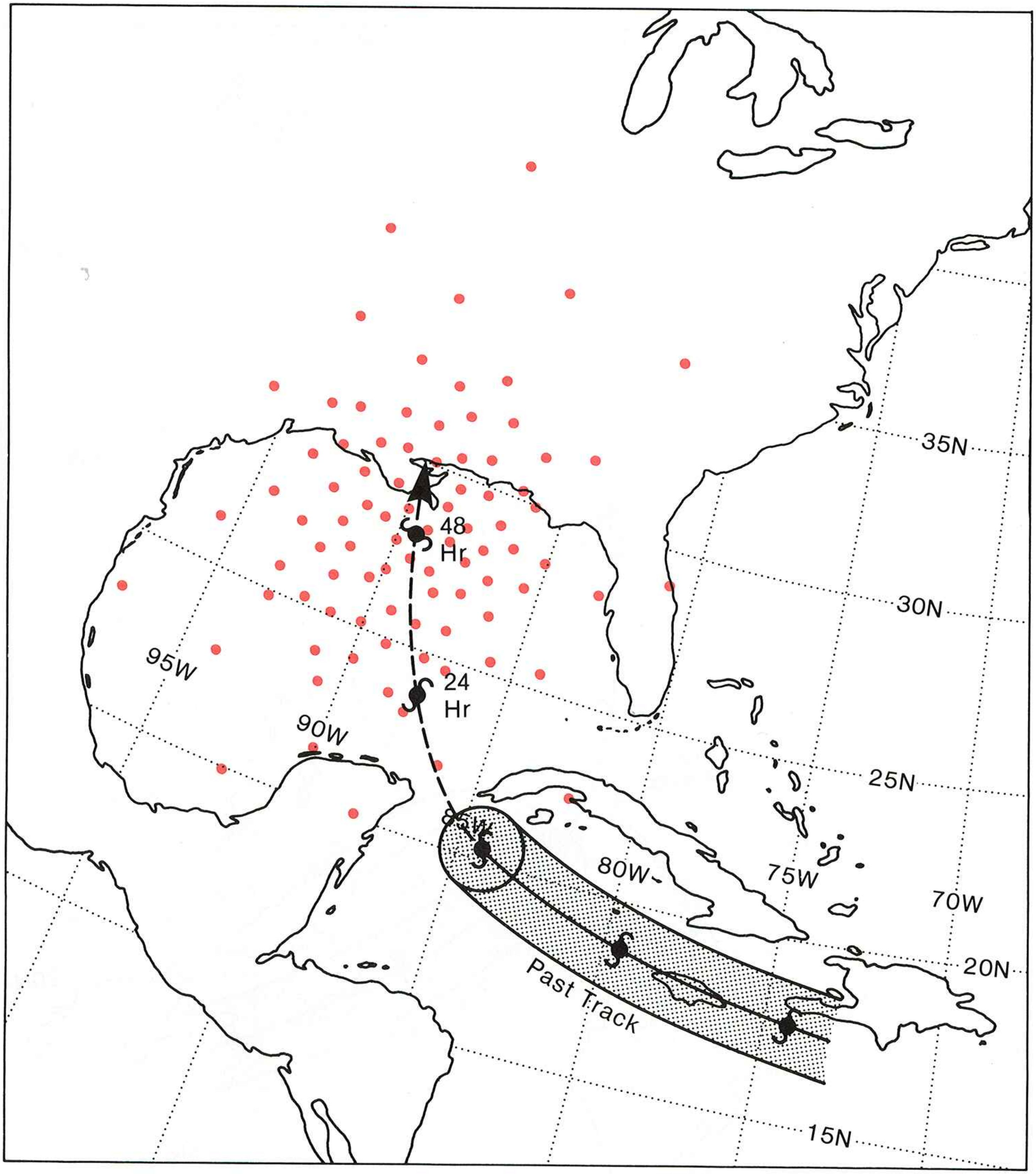


Figure 6. Expected Actual 48-Hour Locations of 100 Example Hurricanes with the Same Past Track and the Same 48-Hour Forecast Position.

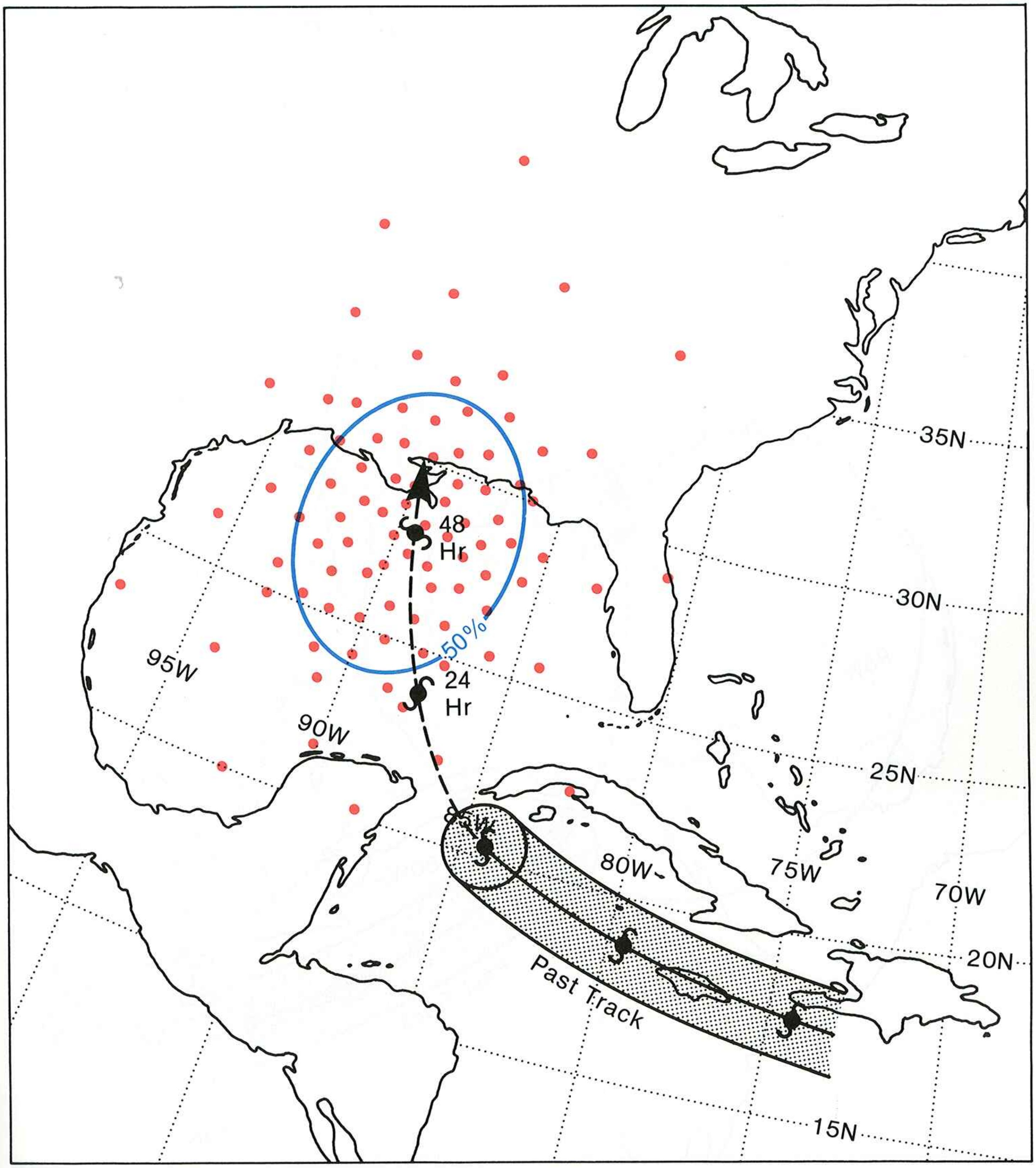


Figure 7. Ellipse Enclosing 50% of the Expected Actual 48-Hour Locations of 100 Example Hurricanes with the Same Past Track and the Same 48-Hour Forecast Position.

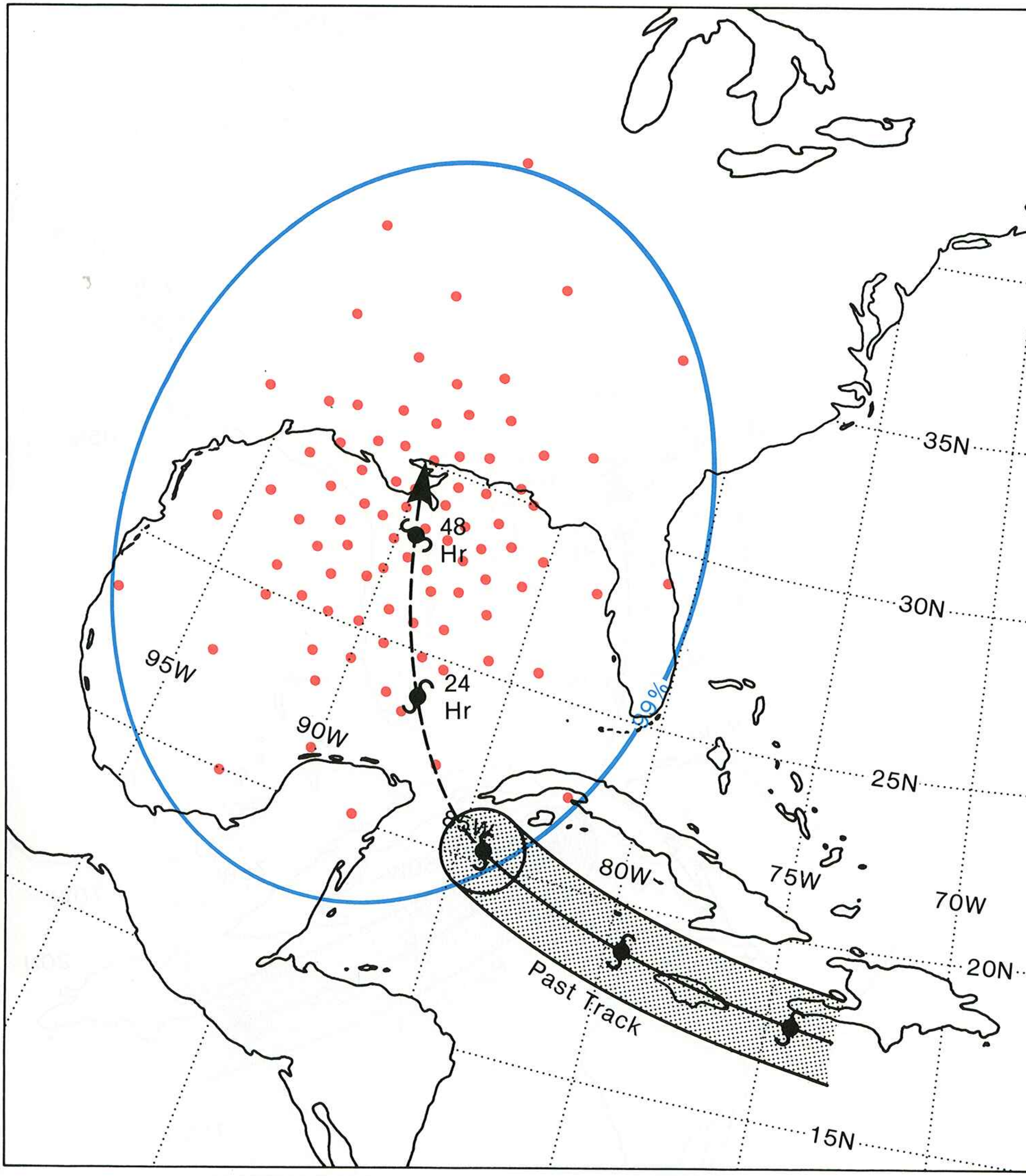


Figure 8. Ellipse Enclosing 99% of the Expected Actual 48-Hour Locations of 100 Example Hurricanes with the Same Past Track and the Same 48-Hour Forecast Position.

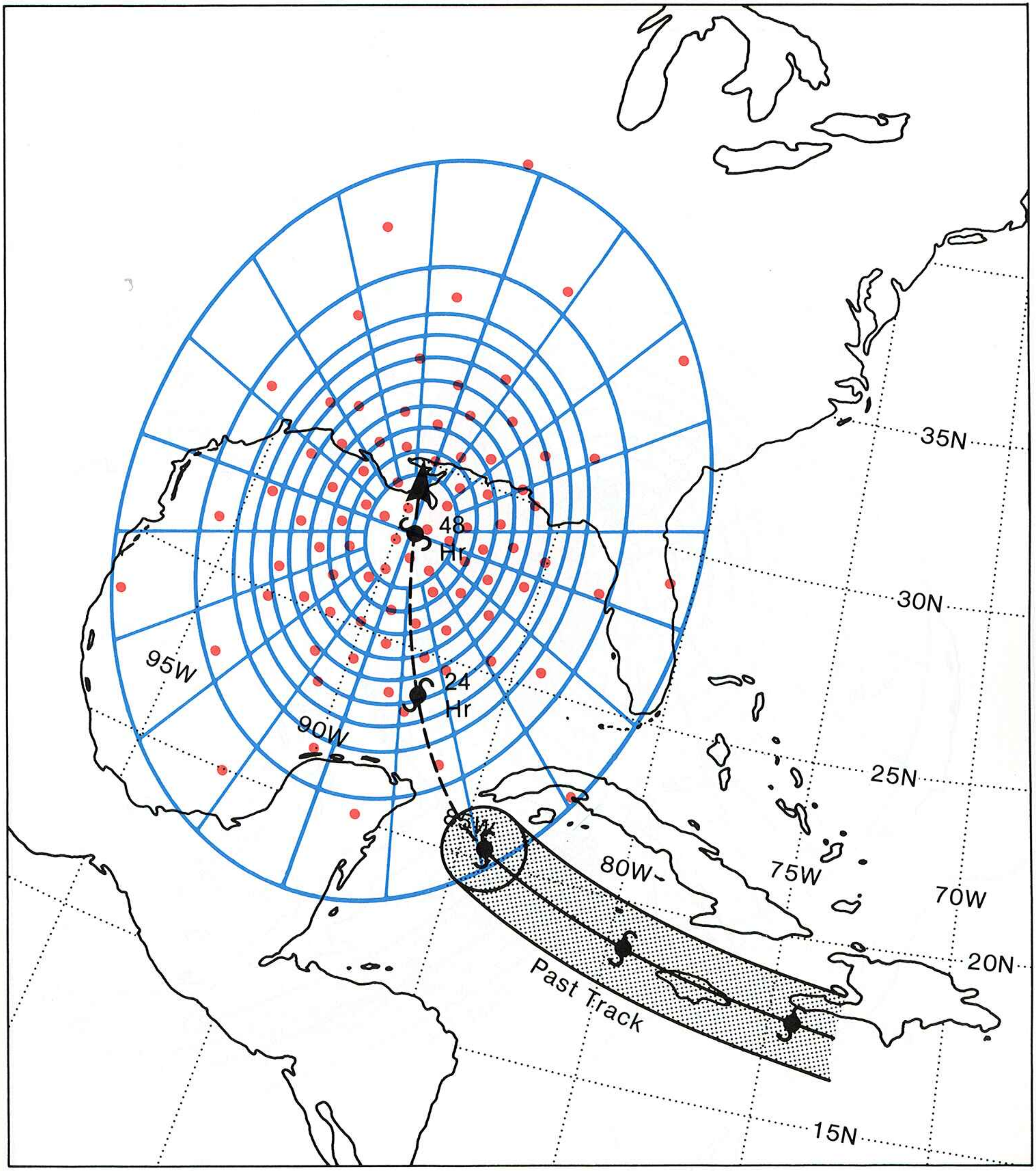


Figure 9. Partitioned Ellipse Enclosing 99% of the Expected Actual 48-Hour Locations of 100 Example Hurricanes with the Same Past Track and the Same 48-Hour Forecast Position.

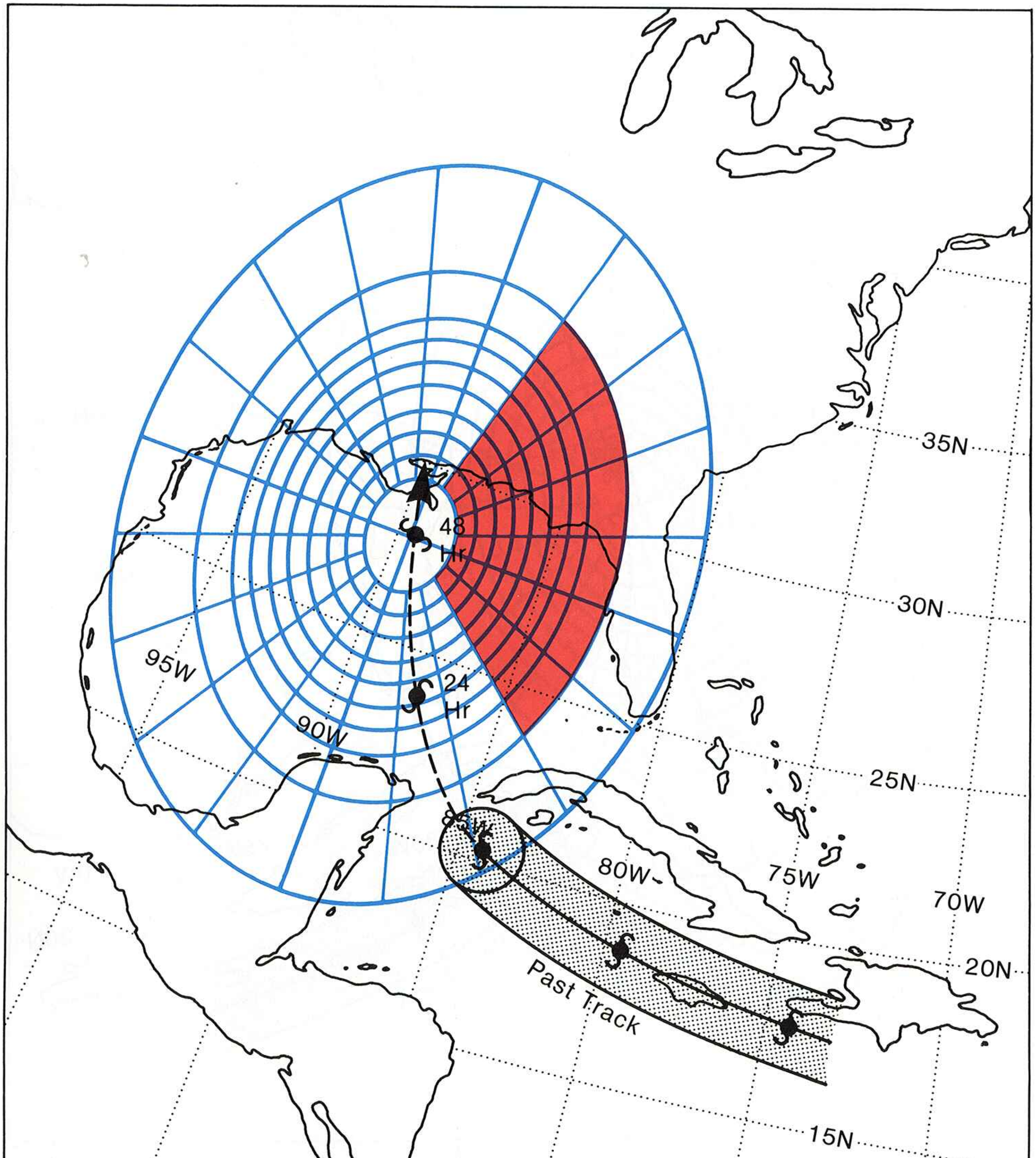


Figure 10. Example Use of the Partitioned 99% Ellipse to Define an Area for Probability Computation.

The first question to be addressed in determining this probability has to do with identifying an area around New Orleans through which the storm must pass to cause hurricane conditions in the city itself. It is important to note that this area will not be symmetrical around New Orleans since hurricanes are not, themselves, symmetrical around their centers. While there is some variation among hurricanes in the radius of hurricane winds, a useful average is around 60 to 65 miles. To account for this average and the asymmetrical nature of hurricanes, tropical meteorologists have defined the area through which a hurricane must pass as 50 miles to the right and 75 miles to the left of the location, when looking at the coast in the direction of the storm's movement.

A second concern deals with the track of the storm past the location, in this case, New Orleans. Figure 11 presents both an area surrounding New Orleans, as defined above, and a "shadow" from this area in the direction of the storm's movement. Given the direction of the storm's movement, most storms contained in this shadow generally will have passed through the area enclosing New Orleans and, thus, would have caused hurricane conditions at New Orleans.

Taking all this into account, Figure 12 shows how these probabilities would be computed for three locations -- Galveston, Texas; New Orleans, Louisiana; and Pensacola, Florida. As was the case in Figure 10, one merely counts how many one-half percent segments of the partitioned 99 percent ellipse are contained in the area of concern. In this case, of course, the area of concern is composed of the area surrounding each location and its shadow. With this example, there is approximately a 14 percent probability that New Orleans will experience hurricane conditions within the next 48 hours. The probabilities are approximately 8 percent for Pensacola and 6 percent for Galveston.

These probabilities, of course, are based on the 48-hour forecast position and the 48-hour probability ellipses. Similar probabilities can be computed for the 12-, 24-, 36-, and 72-hour forecast positions by using their respective probability ellipses. Further, by overlaying these ellipses on the forecast track, we can determine probabilities for successive time segments beyond the time the forecast was made. In particular, the probabilities issued by the National Weather Service will be for the following successive time periods: (1) less than 24 hours, (2) 24-36 hours, (3) 36-48 hours, (4) 48-72 hours, and (5) total through the next 72 hours. Because these probabilities represent discrete time periods, they may be added together to compute the total probability that the hurricane will affect a given location. The probabilities will actually be generated using computers and smoothed forecast error distributions at 3-hourly intervals summed through 72 hours. This process is more exact but similar to that illustrated in the previous examples.

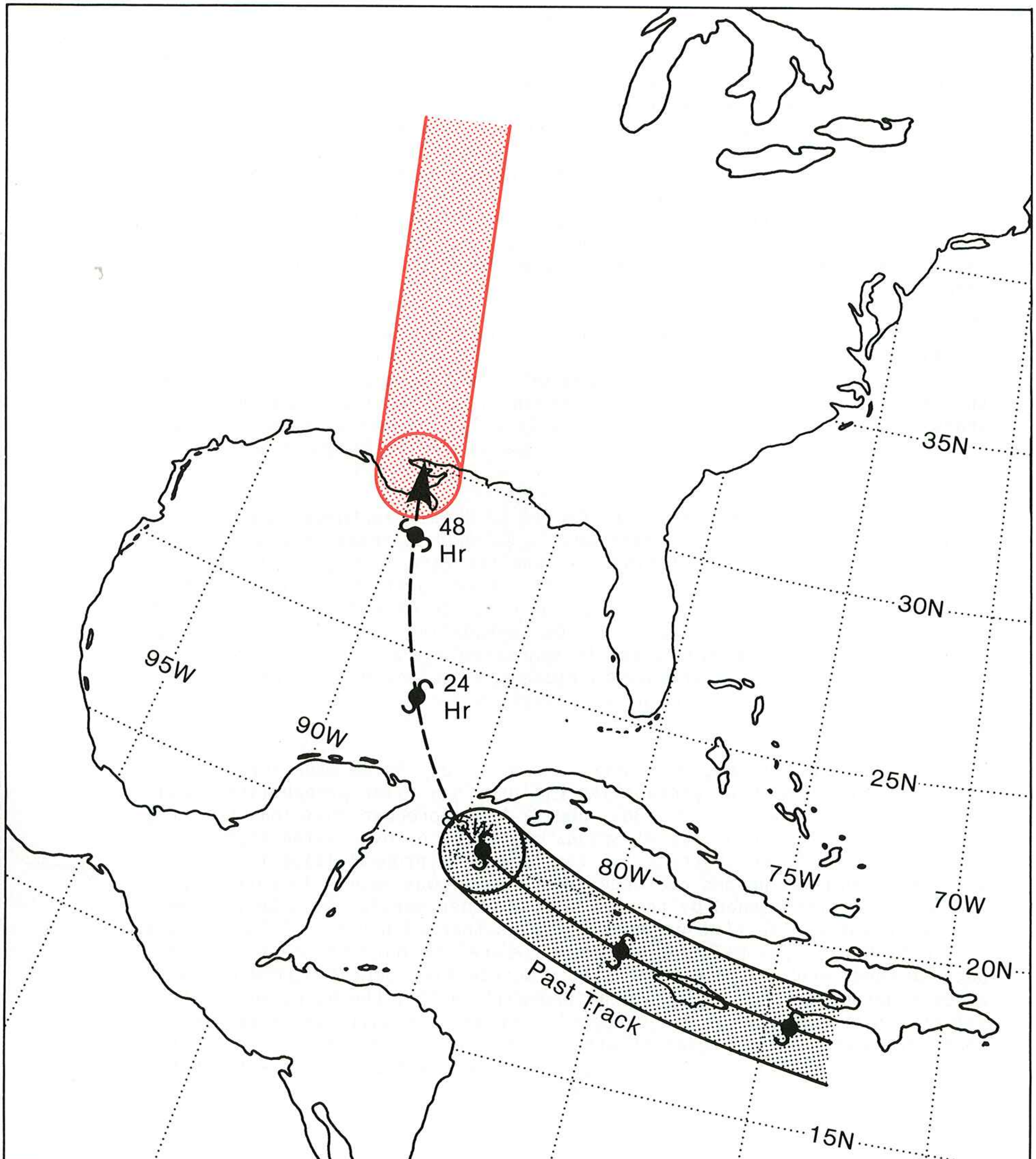


Figure 11. Area Through Which a Hurricane's Center Must Pass to Cause Hurricane Conditions at New Orleans, La.

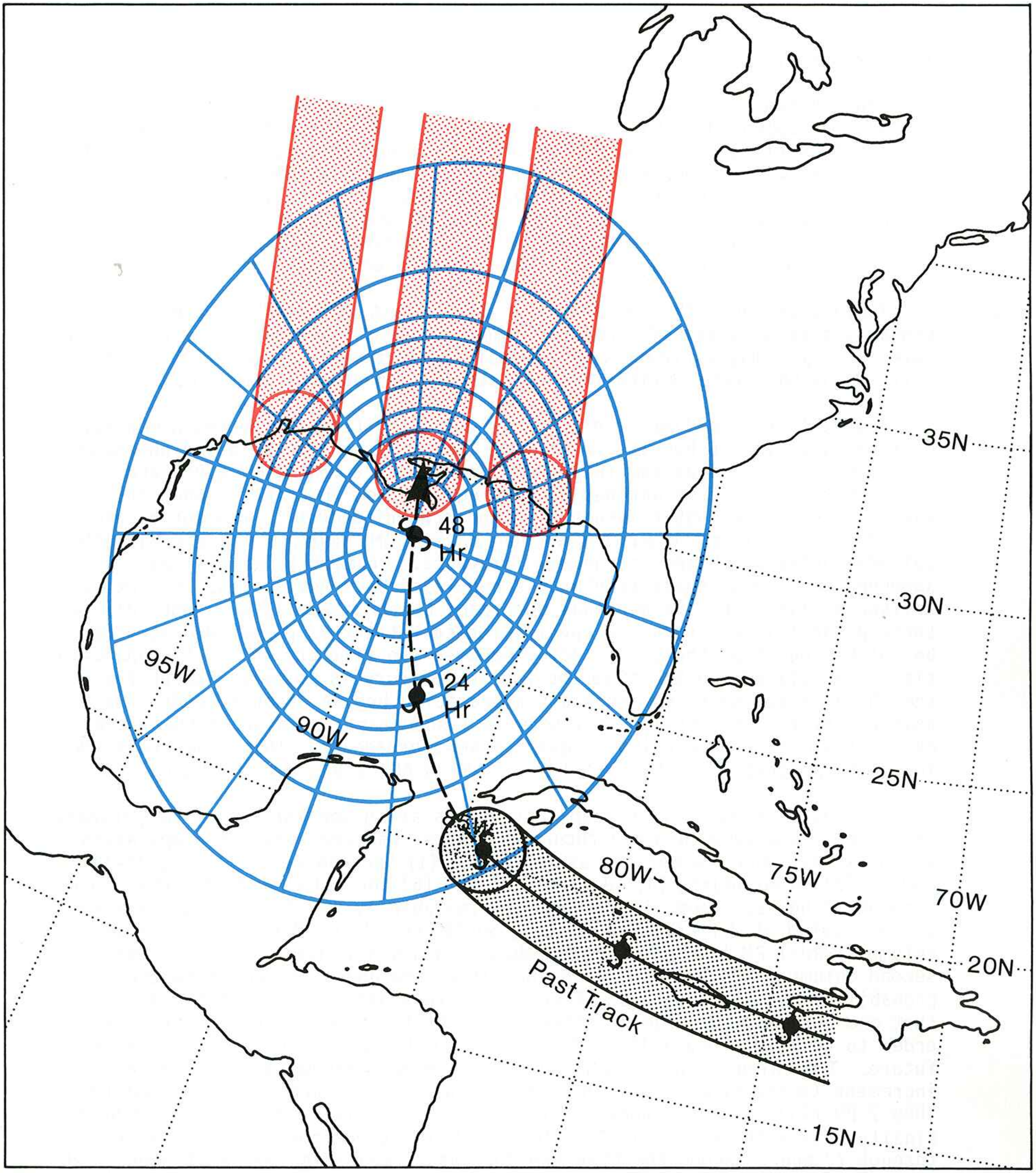


Figure 12. Example of How to Compute the Probability that Coastal Sites will Experience Hurricane Conditions Within 48-Hours.

III. PRESENTATION OF HURRICANE PROBABILITIES

The probabilities will be issued in tabular form, as shown in Table 1, and will be appended to the bottom of the numbered Public Advisories which are issued 4 times a day by the National Hurricane Center. It is important to note that the information contained in the Public Advisory will not be affected by the inclusion of the probabilities. That is, the hurricane probabilities represent an additional piece of information that is being provided by the National Hurricane Center, and, this new information will not replace or change any information currently being provided.

Table 2 presents the complete list of 44 coastal communities for which probabilities will issued. If your community or location is not included in this list, you may estimate your probability by simply averaging the probabilities of the listed communities on either side of your community.

As mentioned earlier, the National Hurricane Center produces a new set of forecasts every 6 hours. The Public Advisories which are based on these forecasts are issued at the following times EDT: 6 AM, NOON, 6 PM, and 10:30 PM when Hurricane Watches or Warnings are not in effect. When the National Hurricane Center issues a Watch or Warning, Public Advisories are issued every 3 hours. When this is done, the 6 AM, NOON, 6 PM, and MIDNIGHT EDT advisories are based on the new forecasts. Probabilities will be appended to each of these regularly scheduled Public Advisories. Any other advisories issued by the National Hurricane Center normally will not include these probabilities, unless a special forecast track is prepared. It should be pointed out that there is a delay between the time the forecast preparation is initiated and the time the Public Advisory is issued. Except for the 10:30 PM advisory, the forecast preparation begins 4 hours before the advisory time. The 10:30 PM Advisory is issued earlier in order that it may be available for the evening television news broadcast. Thus, the times the forecast preparation is initiated are 2 AM, 8 AM, 2 PM, and 8 PM EDT.

As shown in Table 1, probability values are given for five time periods. These periods extend into the future from the time the forecast preparation was initiated and are defined as follows: (1) through 24 hours, (2) 24-36 hours, (3) 36-48 hours, (4) 48-72 hours, and (5) the total probability through 72 hours. Thus, in the example in Table 1, the forecast preparation was initiated at 7 PM CDT on Tuesday, September 11 (8 PM EDT). The first column (THRU 7 PM WED) gives the probability for the next 24 hours. The second column (7 PM WED THRU 7 AM THU) gives the added increment to the probability through 36 hours. These increments are additive in the sense that one must add the probabilities of successive time periods together in order to compute probabilities for time periods longer than 24 hours in the future. The third column (7 AM THU THRU 7 PM THU) likewise gives the added increment to the probability through 48 hours. The fourth column (7 PM THU THRU 7 PM FRI) gives the added increment to the probability through 72 hours. Finally, the fifth column (TOTAL THRU 7 PM FRI) gives the total probability through 72 hours beyond the time the forecast preparation was initiated (7 PM Tuesday).

TABLE 1. HURRICANE PROBABILITY TABLE WHICH WILL BE APPENDED TO THE BOTTOM OF THE PUBLIC ADVISORY.

PUBLIC ADVISORY # 52 ISSUED AT 9:30 PM CDT TUE SEPT 11 1979

HURRICANE FREDERIC PROBABILITIES
FOR GUIDANCE IN HURRICANE PROTECTION PLANNING
BY GOVERNMENT AND DISASTER OFFICIALS

CHANCES OF CENTER OF FREDERIC PASSING WITHIN 65 MILES OF
LISTED LOCATIONS THROUGH 7 PM CDT FRIDAY SEPTEMBER 14 1979

CHANCES EXPRESSED IN PER CENT ... TIMES CDT

		ADDITIONAL INCREMENTS			
COASTAL LOCATIONS	THRU 7 PM WED	7 PM WED THRU 7 AM THU	7 AM THU THRU 7 PM THU	7 PM THU THRU 7 PM FRI	TOTAL THRU 7 PM FRI
MARCO ISLAND, FL	-	-	-	1	1
FT. MYERS, FL	-	1	-	-	1
VENICE, FL	1	-	1	-	2
TAMPA, FL	1	1	1	1	4
CEDAR KEY, FL	2	3	1	1	7
ST. MARKS, FL	7	5	2	-	14
APALACHICOLA, FL	16	3	-	1	20
PANAMA CITY, FL	19	3	-	1	23
PENSACOLA, FL	21	3	1	-	25
MOBILE, AL	16	6	1	-	23
GULFPORT, MS	14	6	1	1	22
BURAS, LA	16	4	1	-	21
NEW ORLEANS, LA	8	7	1	1	17
NEW IBERIA, LA	1	6	3	2	12
PORT ARTHUR, TX	-	1	3	3	7
GALVESTON, TX	-	1	2	2	5
PORT O'CONNOR, TX	-	-	1	2	3
CORPUS CHRISTI, TX	-	-	1	1	2
BROWNSVILLE, TX	-	-	-	1	1

- PROBABILITY LESS THAN 1 PER CENT

As an example of how to use this table to determine probabilities for different time periods, examine closely the row for Gulfport, Mississippi. First, it is important to remember that the forecast on which these probabilities are based was initiated at 7 PM on Tuesday. The first column of the table gives the probability that the center of Hurricane Frederic will pass within approximately 65 miles of Gulfport within the next 24 hours -- i.e., through 7 PM on Wednesday. This probability is 14 percent. The sum of the first two columns gives the probability that the center of Hurricane Frederic will pass within approximately 65 miles of Gulfport within the next 36 hours -- i.e., through 7 AM on Thursday. This probability is 20 percent (14 percent plus 6 percent). The sum of the first three columns gives the probability that the center of Hurricane Frederic will pass within approximately 65 miles of Gulfport within the next 48 hours -- i.e., through 7 PM on Thursday. This probability is 21 percent (14 percent plus 6 percent plus 1 percent). Finally, the sum of the first four columns gives the probability that the center of Hurricane Frederic will pass within approximately 65 miles of Gulfport within the next 72 hours -- i.e., through 7 PM on Friday. This probability is 22 percent (14 percent plus 6 percent plus 1 percent). It should be noted that this sum is the probability that is presented in the fifth column. Further, as noted in Table 1, a dash entered in place of a probability value indicates that the probability is less than one percent.

The important point to remember, then, in using this table is that the middle columns contain increments to the first column. These middle columns cannot be utilized alone. As shown above, the probability that Hurricane Frederic will affect Gulfport within 36 hours is 20 percent, not 6 percent.

TABLE 2. COMMUNITIES FOR WHICH HURRICANE/TROPICAL STORM PROBABILITIES WILL BE ISSUED BY THE NATIONAL HURRICANE CENTER

BROWNSVILLE, TX	WEST PALM BEACH, FL
CORPUS CHRISTI, TX	VERO BEACH, FL
PORT O'CONNOR, TX	CAPE CANAVERAL, FL
GALVESTON, TX	DAYTONA BEACH, FL
PORT ARTHUR, TX/CAMERON, LA	JACKSONVILLE, FL
NEW IBERIA, LA	SAVANNAH, GA
NEW ORLEANS, LA	CHARLESTON, SC
BURAS, LA	MYRTLE BEACH, SC
GULFPORT, MS	WILMINGTON, NC
MOBILE, AL	MOREHEAD CITY, NC
PENSACOLA, FL	HATTERAS, NC
PANAMA CITY, FL	NORFOLK, VA
APALACHICOLA, FL	OCEAN CITY, MD
ST. MARKS, FL	ATLANTIC CITY, NJ
CEDAR KEY, FL	NEW YORK CITY, NY
TAMPA, FL	MONTAUCK, NY
VENICE, FL	PROVIDENCE, RI
FORT MYERS, FL	NANTUCKET ISLAND, MA
MARCO ISLAND, FL	HYANNIS, MA
KEY WEST, FL	BOSTON, MA
MARATHON, FL	PORTLAND, ME
MIAMI, FL	EASTPORT, ME

IV. Interpretation and Use

In this section, we will discuss in some detail how local decision makers may use hurricane probabilities as input to their decision process for hurricane protection planning. From a formal point of view, the probabilities given in Table 1 for any listed location can be interpreted as: the probability that the center of Hurricane Frederic will pass within 50 miles to the right or 75 miles to the left of the listed location within the indicated time period, when looking at the coast in the direction of the storm's movement. For simplicity, Table 1 describes this area as approximately 65 miles on either side of the location. There are, however, a number of points concerning this formal interpretation which must be made explicit.

First, the probabilities are not related to the intensity of the storm. Given the existence of a named storm and a specific forecast track for that storm, the computed probabilities will be the same whether the storm is as intense as a Hurricane Camille or is merely a weak tropical storm. This point is quite important because local decision makers must condition their interpretation and use of these probabilities upon the intensity of the storm. Obviously, one would react differently if threatened by a Camille type storm with winds nearly 200 mph and storm tides of 20 to 25 feet as opposed to a weak tropical storm with winds of only about 60 mph and storm tides of only 3 to 5 feet.

Second, the probabilities are directly dependent upon the forecast track for the storm. Again, a formal interpretation would state that the probabilities are an expression of forecast uncertainty or forecast error. As such, the probabilities tend to distribute the risk of the hurricane along the coast. If small changes occur in the forecast track, only small changes may be expected in the probabilities. On the other hand, if the National Hurricane Center makes a drastic change in the forecast track, quite large changes can be expected in the probabilities. As mentioned earlier, it should be remembered that there are two components to forecast error: (1) error resulting from the location of the track and (2) error resulting from timing along the track. The probabilities are equally sensitive to both of these components of forecast error.

Given that the probabilities are an expression of forecast uncertainty and given that there is more forecast uncertainty associated with the 72 hour forecast than there is with the 12 hour forecast, one would expect that there would be large differences between the size of the probabilities at 72 hours before forecasted landfall and the size of the probabilities at 12 hours before forecasted landfall. Indeed, this is the case. The maximum probabilities a local decision maker can expect to receive in the various time periods are given in Table 3. These probabilities are those which would be computed if the time period forecast position were directly over a listed community.

TABLE 3. MAXIMUM PROBABILITY VALUES WITHIN FORECAST PERIODS

FORECAST PERIOD	MAXIMUM PROBABILITY VALUES
72 HOURS	10 %
48 HOURS	13 - 18 %
36 HOURS	20 - 25 %
24 HOURS	35 - 45 %
12 HOURS	60 - 70 %

Given these large differences, it is obvious that a local decision maker who must initiate action 48 hours before landfall must do so with a much smaller probability than a local decision maker who can wait until 24 hours before landfall. The important point here is that local decision makers must condition their use of these probabilities on the basis of the time it will take to complete their action or actions. That is, actions which require longer lead times must be initiated on the basis of smaller probabilities than actions which require shorter lead times.

Considering these points, then, we can begin to outline a decision process which will allow local decision makers to fruitfully utilize the hurricane probabilities. The first step in this process is to determine the time window within which the action must be initiated. This time window is a function of a number of different factors. First, of course, is how much time is required to complete the action. This time is a function, in turn, not only of the action, but also of the intensity of the storm. For example, the time required to complete the evacuation of threatened residents depends both on the vulnerability of the given community and the intensity of the storm, since higher intensity storms would produce higher storm tides which would inundate larger areas. The second component of this time window is how long before eye landfall must the action be completed. It is important to remember that gale or hurricane conditions will arrive well before landfall. In the case of evacuation, this component may be up to 8 to 10 hours, since evacuation would be very risky during even gale conditions.

Once the time window has been established for a given action, the window identifies the relevant forecast period upon which local decision makers must focus their attention. For example, if it was decided that an evacuation must be initiated 22 hours before eye landfall, the relevant forecast period would be the LESS THAN 24 HOURS period. Given the information in Table 3 above, the local decision maker would know that the maximum probability which could be expected during this forecast period would be in the neighborhood of 35 to 45 percent. However, a probability value would be within this range only if the 24-hour forecast position was directly over the community. Given that the average 24-hour forecast error is about 120 miles, the local decision maker probably would have to initiate an evacuation with a probability value somewhat lower than 35 percent. Just how much lower the probability threshold would be depends on the risk the local decision maker is willing to take. A key factor in this risk taking, of course, would be some determination of the cost of not taking action and then being hit by the storm. For a major storm, the cost of not initiating an evacuation in time to complete it before being hit by gale or hurricane conditions may be quite large.

The point needs to be emphasized that all actions which require long lead times will have to be initiated with relatively low probability thresholds. This means, of course, that such actions generally will have to be initiated a number of times for each time they ultimately were necessary. A useful way to estimate the number of times actions will have to be taken when they were not ultimately necessary is to compute a MISS/HIT RATIO from the probability thresholds. Mathematically, the MISS/HIT RATIO is defined as follows:

$$\text{MISS/HIT RATIO} = \frac{100.0 - \text{PROBABILITY (IN PERCENT)}}{\text{PROBABILITY (IN PERCENT)}}$$

As an example, one can compute an expected MISS/HIT RATIO for actions which must be initiated approximately 36 hours before anticipated landfall. As shown in Table 3, one can expect a maximum probability of about 20 percent approximately 36 hours before anticipated landfall. Using this value, the required computations would be:

$$\text{MISS/HIT RATIO} = \frac{100.0 - 20}{20} = \frac{80}{20} = \frac{4}{1}$$

This MISS/HIT RATIO of 4 to 1 means that one can expect 4 storms to miss for each storm that hits. That is, when the 36-hour forecast position is directly over a community (giving a probability of about 20 percent), the community can ultimately expect 4 misses for every time it is hit. Stated another way, if an action must be initiated 36 hours before anticipated landfall, it will have to be initiated an average of 4 times for each time it ultimately turned out to be necessary. It is important to remember, however, that the probability value of 20 percent is close to the maximum which can be expected. As mentioned earlier, given the average 36-hour forecast error, it is likely that actions which require 36 hours will have to be initiated with probability values somewhat lower than 20 percent. This means, of course, that the expected MISS/HIT RATIO will be larger than 4 to 1.

Table 4 gives MISS/HIT RATIOS that are computed from the maximum probabilities that can be expected during each of the five forecast periods given in Table 3.

TABLE 4. MISS/HIT RATIOS FOR MAXIMUM FORECAST PERIOD PROBABILITY VALUES.

FORECAST PERIOD	MISS/HIT RATIO
72 HOURS	9 TO 1
48 HOURS	7 TO 1
36 HOURS	5 TO 1
24 HOURS	2 TO 1
12 HOURS	2/3 TO 1

It must be stressed that these are the best MISS/HIT RATIOS that local decision makers can expect. As stated above, most actions will have to be initiated with lower probability values than those used to compute these ratios.

One final point must be considered in developing a decision process which makes fruitful use of these probabilities. It must be recognized that the National Hurricane Center cannot tell a local community when it has, say, 36 hours before landfall. As shown in Figure 2, the major source of forecast error for Hurricane Frederic was timing along the forecast track, not the position of the forecast track. It is important, therefore, that local decision makers establish probability thresholds for various actions. These probability values take into account errors in the timing of the storm along the forecast track.

This point can be seen dramatically by examining Hurricane Frederic. Between 5 PM and 9:30 PM on Tuesday, September 11, the National Hurricane Center changed drastically the timing of Frederic along the forecast track. At 5 PM, Frederic was forecast to make landfall in a bit more than 48 hours. Less than 6 hours later, however, at 9:30 PM, Frederic was forecast to make landfall in a bit more than 24 hours. Thus, the official forecast tracks issued by the National Hurricane Center never included one which predicted landfall in 36 hours. This means that if local decision makers needing 36 hours to complete an action had relied solely on the forecast tracks, they would not have been able to initiate the action in time to complete it before landfall. Had they used probability thresholds, however, the probabilities would have been high enough at 5 PM to initiate the action.

V. Summary

In a growing number of communities along the Atlantic and Gulf coasts, local decision makers must begin initiating protective actions before the National Hurricane Center can confidently issue a Hurricane Warning for their community. In an attempt to provide these decision makers with useful long range forecasts of a hurricane's movement, the National Hurricane Center will issue probabilities that the hurricane will affect any of 44 communities from Brownsville, Texas, to Eastport, Maine.

This manual was written to acquaint local decision makers with some of the characteristics of these probabilities and outline some of the ways that they may be used to guide decision making when facing a hurricane threat. While it is hoped that local decision makers find this manual useful in effectively utilizing this new forecast information, it should be remembered that National Weather Service field personnel are available, as always, to answer any questions and to provide specific interpretations of both the probabilities and the forecast tracks that are issued for any given storm.

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