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Tropical Cyclone Forecasting

[Note: This document was prepared by Horace H.P. Burton and Selvin DeC. Burton of the Caribbean Institute for Meteorology and Hydrology for a storm surge mapping workshop held in Antigua in December 1998. It was updated in November 1999. A Powerpoint presentation of this material is also available.]

Introduction

A *tropical cyclone* is defined as an area of low pressure which develops over tropical or subtropical waters. These systems form over all tropical oceans with the exception of the South Atlantic and the eastern South Pacific east of about 140° W. In their most intense state these storms are called *hurricanes* in the Atlantic, *typhoons* in the western North Pacific and *cyclones* in the Bay of Bengal. These low-pressure systems draw their energy from the very warm sea-surface waters. As the warm, moist air spirals counterclockwise in toward the centre, the wind speeds increase, reaching their maximum values in the region surrounding the almost calm centre of the cyclone.

Over the Atlantic a tropical cyclone is classified according to its intensity as a ***tropical depression, tropical storm, or hurricane***, defined as follows:

> **Tropical depression***: A weak tropical cyclone in which the maximum surface wind is 38 mph, 62 km/h or 33 kt or less;*
>
> **Tropical storm***: A tropical cyclone in which the maximum surface wind ranges from 39 to 73 mph, 63 to 118 km/h or 34 to 64 kt;*
>
> **Hurricane***: A tropical cyclone with highest sustained winds 74 mph, 119 km/h or 65 kt or more.*

The Saffir-Simpson Hurricane Scale (Table 1) is used to give an estimate of the potential property damage along the coast from a hurricane landfall.

Table 1. Saffir-Simpson Intensity Scale

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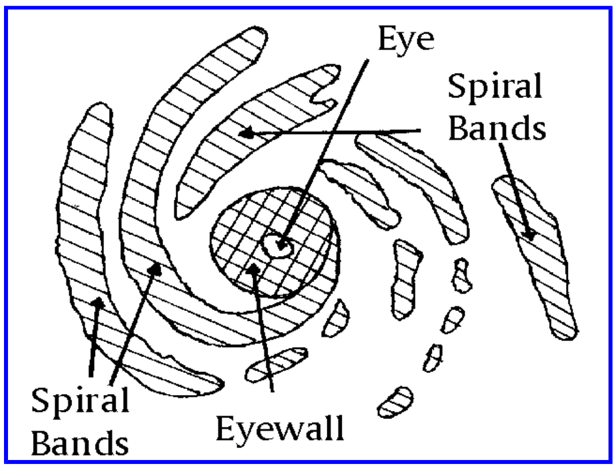
Category	**Sustained Winds**		**Pressure**	**Damage Level**
	Knots	**Km/hour**	**Millibars**	
1	65 – 82	119 – 153	> 980	Low
2	83 – 97	154 – 177	965 - 979	Moderate
3	98 – 113	179 – 209	945 - 964	Extensive
4	114 – 135	211 – 249	920 - 944	Extreme

5	> 135	> 249	< 920	Catastrophic

In the North Atlantic Ocean, including the Caribbean Sea and the Gulf of Mexico, the official hurricane season is June through November. On average, nine tropical cyclones of at least tropical storm strength form in this region each year, of which six reach hurricane intensity. Although tropical cyclones occasionally form as early as May, the most active months are August and September. Tropical cyclones which develop in the deep tropics initially move towards the west or west-northwest before recurving and moving towards the east. Recurvature generally occurs in the western and northern parts of the Atlantic Basin.

Figure 1. Schematic representation of the cloud pattern and horizontal structure of a mature hurricane.



Hurricanes vary in size from 300 to 1500 km (180 miles to 900 miles) in diameter. The mature system is characterised by a central portion called the '*eye*' which is usually enclosed by a circular mass of cloud referred to as the *eye wall* or *wall cloud*. The outer portion of the hurricane is comprised of a number of bands of clouds which spiral into the centre and are referred to as *spiral bands* or *rainbands.*

Hurricane force winds generally extend out about 100 km (60 miles) from the centre and storm force winds may extend out as much as 500 km (300 miles). The maximum wind speeds are usually found between 20 and 50 km (12 and 30 miles) from the centre, depending upon the intensity of the system. The eye of the hurricane is characterised by clear skies, calm winds and the lowest pressure. On average the eye is about 20 km (12 miles) in diameter while the eyewall is between 30 and 50 km (20 to 30 miles) in width. The spiral bands also contain regions of intense thunderstorms and strong gusty winds away from the core of the system.

Forecasting the future location and intensity of tropical cyclones is considered to be the most important function of tropical cyclone warning centres. One reason for the importance is the potential damage and loss of life which can occur with the passage of an intense tropical cyclone. Early and precise warnings do not necessarily remove the risk of damage or loss or life, but the effects may be significantly reduced.

Because of the small horizontal scale of the portion of the cyclone producing major damage, the tropical cyclone forecaster is faced with the dilemma of warning too small an area and missing the landfall or over warning such a large area that great amounts of time and money are wasted in unnecessary preparations. The latter approach may be detrimental in the long run since false warnings can produce an attitude of scepticism, and future warnings are likely to be ignored. In spite of this, the present forecasting capability makes over warning a necessity.

Forecasting Methods

Over the years forecast methods have moved from simple subjective deductions based on observations of specific parameters such as cloud types and motions, sea swells, and pressure, to more sophisticated techniques which use complex computer models of the atmosphere. Until recently predictions were centred around the motion of the cyclone, but both motion and intensity are now being routinely predicted.

A tropical cyclone forecast involves the prediction of several interrelated features, including the track, winds, rainfall, storm surge and, of course, the areas threatened. In practice, the National Hurricane Center (NHC) in Miami, which is responsible for tropical cyclone forecasting in this area, will normally issues a forecast every 6 hours for period extending out to 72 hours. The official forecast is based on the guidance obtained from a variety of subjective and objective models. The forecaster assesses the output form various models and based on present and historical performance of the models, as well as personal experience, arrives at the official forecast.

Track Forecasts

The simplest method used to forecast the track of tropical cyclones is to extrapolate the motion of the tropical cyclone during some past period, say 12 to 24 hours, for the next 12 to 24 hours. Another method uses historical data to determine the average direction and speed of motion of similar tropical cyclones passing close to the given location. Another technique employs current and forecast atmospheric variables in a set of statistical equations to predict the motion. The final set of track forecast techniques make use of computer models of the atmosphere to predict the motion of the cyclone from an observed initial state of the atmosphere.

Intensity Forecasts

While numerous objective guidance models are available for predicting tropical cyclone tracks, there are only a few models in operation to predict intensity. The primary models are statistical in nature and combine several parameters into an equation to determine intensity changes for periods out to 72 hours. Improvements in regional and global computer models of the atmosphere now make it possible for these to be used to predict tropical cyclone intensity. Characteristics of the cloud patterns associated with tropical cyclones as seen in satellite imagery is also used to predict tropical cyclone intensity change.

Forecast Errors

Unfortunately, like other forecasts, tropical cyclone forecasts are not perfect. Errors arise from a lack of a full understanding of the formation and growth of tropical cyclones and from the limitations of the forecasting techniques themselves. The operational utility of the forecast is based on its performance in the operational environment and, as such, knowledge of the scope and magnitude of the errors are important in the formulation of the official forecast issued by the NHC. It is also important that all users of the forecasts, whether they are meteorologists or disaster planners, be aware of the limitations of the information provided in the various forecasts issued by the NHC.

For these reasons it is important that the tropical cyclone forecasters analyse the performance of the forecasts from the models as well as the official forecasts. One way of assessing the performance is by determining the average forecast error of the particular model. Forecast tracks are verified by comparison with a *best track* which is the track of the centre of a tropical cyclone as determined by post-analysis of all available data. The forecast track error is then defined as the distance between a forecast position and a 'best track' position for the time of the forecast.

Forecast errors increase remarkably with increasing time, but are smaller for lower latitude cyclones moving westward than for the higher latitude systems in the westerlies and for those which are recurving. There are also large year-to-year variations in the mean forecast error, depending upon the average initial latitude of storms. Errors in the initial position and motion of the tropical cyclone can have an impact on the accuracy of the forecast.

Errors in forecast, although showing a slow and steady decrease, are still substantially large. Mean forecast errors increase with time and are approximately 30 % of the cyclone movement over the same time period. The National Hurricane Center's official track average forecast errors during the 10-year period 1986 to 1995 ranged from approximately 91 km for the 12-hour forecasts to 506 km for 72-hour forecasts. The official intensity errors during the 6-year period 1990 to 1995 for similar forecast hours range from approximately 3 kt to 19 kt as shown in Table 2.

Table 2. Official Forecast Errors for Atlantic Tropical Cyclones

	Forecast Interval (hr)					
	0	**12**	**24**	**36**	**48**	**72**
Track in km (1986-1995)	26	91	173	252	335	506
Intensity in mph (1990-1995)	3	7	10	13	16	19

Fixing the current cyclone position and intensity is the first step in a making a track and intensity forecast. Since the forecast quality is dependent on the accuracy of this data, considerable care is needed in the analysis stage. Highly accurate positioning is especially important for short-range forecasts in critical situations, such as near landfall, but large position errors have resulted in major forecast failures at all times.

The centre or location of a tropical cyclone is a function of both how we choose to define it and the type of observations used. Surface pressure, wind circulation centre, and the cloud system centre are parameters used to position the cyclone centre. In many cases, these positions are not coincident. Surface observations, satellites, and land-based radar are the most common method used to locate the centre and determine the intensity. Occasionally, reconnaissance aircraft are used to supplement these data.

Weak and developing systems are a particular analysis problem as they may be sheared or contain multiple centres. During this period, one centre may tend to dominate for a period, but then be displaced by a separate centre. Major forecast errors can be made by analysts following an incorrect feature or local circulation centre during satellite analysis. The average official forecast error for the initial position is 26 km, while the initial intensity error is about 3 kt. However, errors of the initial position for individual systems may range from 10 km in the case of a radar fix of a good eye to more than 180 km in the case of a satellite fix of a poorly defined centre. The initial intensity estimates may be in error by as much as 30 knots, particularly when using satellite imagery.

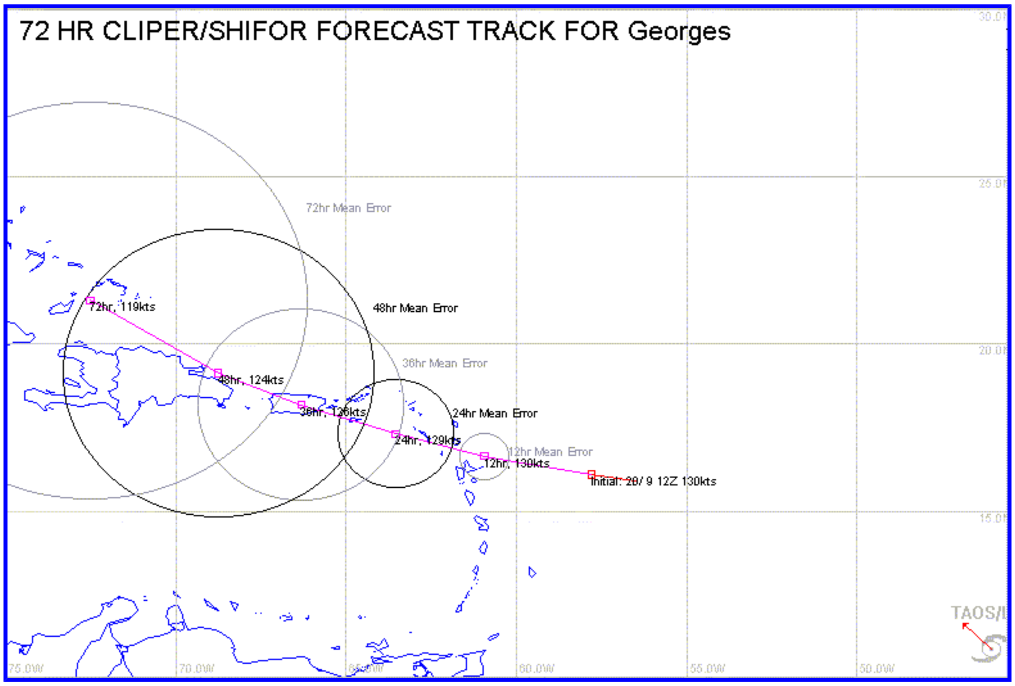
Strike Probability Forecasts

One method of objectively defining the uncertainty inherent in cyclone forecasting is to utilise strike probabilities, derived from knowledge of past cyclones and forecast errors in the region of interest. Probabilistic forecasts provide valuable early guidance in estimating the risk of tropical cyclones affecting important or vulnerable facilities.

The most common uses of forecast probability are:

i. to extend the usable length of forecasts despite their increasing uncertainty as the forecast period increases;
ii. to provide a quantitative assessment of the threat posed by a tropical cyclone approaching possible landfall;
iii. to compare the relative threat to different places at the same time, or at different times as a threat develops;
iv. to cause a consistent response to the same or similar set of circumstances; and
v. as a tool in risk analysis in respect to both long-term protective measures as well as for contemporary warning purposes.

The most common application of probability has been to express the uncertainty in forecasts of tropical cyclone motion through the construction of probability ellipses. Probability ellipses may be constructed to enclose selected percentages of all cyclone locations. In general, the dimensions of the ellipses (uncertainties) increase as the forecast interval increases and the size of the strike probability 72 hours before landfall would be less than that 12 hours before landfall. As a result, actions which require longer lead times must be made on the basis of smaller probabilities than actions which require shorter lead times.



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