ABSTRACT: The objective of this work is to determine the design wind speeds produced by the hurricanes that have affected the Yucatan Peninsula, by means a numerical simulation of the wind speed field. The model developed to determine the hurricane wind speed field is presented. The HURDAT data base is used to provide tropical cyclones information. A mesh of interest points is established, for which the wind speed is calculated using numerical simulation of each tropical cyclone wind field. The extreme probabilistic distribution that best fits the distribution of maximum wind speeds is determined. Finally, design wind speeds for different return periods are calculated. It is concluded that those wind speeds are very sensitive to the maximum wind speed obtained from the numerical simulation and that the wind speeds of those hurricanes that have affected the Yucatan Peninsula over the last 22 years have produced the need to increase the design wind speeds at the Riviera Maya.

1 INTRODUCTION

The Yucatan Peninsula, located in the south-east part of Mexico, is a major hurricane prone zone; structures built in this region must be designed and evaluated using extreme wind speeds obtained from hurricanes. Many hurricanes have affected the Yucatan Peninsula, such as Gilbert in 1988, Isidore in 2002 and Wilma in 2005; the last one caused large economical loses and infrastructure damage, not only affecting the Riviera Maya, but also the whole local region (Fernández-Baqueiro et al. 2006). The objective of this research work is to determine design wind speeds for the Yucatan Peninsula based on the numerical simulation of the tropical cyclones wind speed field.

There are many works about the determination of extreme wind speeds, such as those from Vickery et al. (2000a, b), Avelar (2008) and López et al. (2008). Two different approaches are identified in those works: deterministic and probabilistic. In the first approach, the historical data base is numerically simulated, while in the second approach a population of hurricanes is generated randomly using methods such as Monte Carlo. In this work a deterministic approach is used together with a Hurricane Wind Speed Field Model (HWSFM) developed in this study.

2 METHODOLOGY

The methodology developed for this work is described as follows (Fernandez-Ojeda 2008):

a) Select the data base that has the information needed for the HWSFM and its calibration. Two data bases were used in this work:
   • HURDAT hurricane data base from the National Oceanic Organization.
   • Automatic Meteorological Stations (AMS) data base from the Mexican Meteorology Service.
The first data base has information about tropical cyclones from the Atlantic basin from 1851 to 2007. This data base has information of tropical cyclones every 6 hours during its trajectory.

The second data base has information of wind speeds every 10 minutes from different places of the country. The data base used in this research comes from those AMS located in the states of Campeche, Quintana Roo, and Yucatan. Each state has four AMS. This data base is used in the model calibration.

b) Implement numerically the HWSFM developed in this study, which is based on the previous work of Fernandez-Baqueiro et al. (2009). A general description of the model is given as follows:

STEP 1. Obtain the hurricane trajectory information needed as input data in the HWSFM for the numerical simulation: maximum wind speed, translation speed, latitude, and terrain roughness.

STEP 2. Obtain the central pressure at the surface \( (P_{os}) \) as a function of the maximum wind speed.

STEP 3. Calculate the radius to maximum winds \( (R_{max}) \).

STEP 4. Calculate the gradient wind speed \( (V_{gt}) \) from the surface wind speed (at 10m high) and the parameter \( H \) (the ratio between the surface wind speed and the gradient wind speed).

STEP 5. Calculate the gradient central pressure \( (P_{og}) \) with Equation 1.

\[
P_{og} = P_n - \frac{\rho R_n B \left[ V_{gt}^2 + (V_{gt} \cdot r \cdot f) \right]}{10.197 B e^{(-R_n^n)}}
\]

where: \( P_n \) is the pressure outside the tropical cyclone, \( \rho \) is the air density, \( r \) radial distance to the tropical cyclone center, \( R_n \) is the normalized radius \( (R_n = r / R_{max}) \), \( B \) is the Holland’s profile parameter, \( f \) is the Coriolis parameter.

STEP 6. Calculate the gradient wind speed at a given point located at a radial distance \( r \), using Equation 2.

\[
V_{gs} = -\frac{r f}{2} + \left( \frac{r f}{2} \right)^2 + \frac{10.197 (P_n - P_{og}) B}{\rho} \left( \frac{1}{R_n} \right)^B e^{(-1/R_n^n)}
\]

STEP 7. Calculate a modified gradient wind speed \( (V_g) \), which includes the effect of the tropical cyclone translation speed, using Equations (3) and (4).

\[
V_g = \sqrt{V_{gs}^2 + V_t^2 + 2 \cdot V_{gs} \cdot V_t \cdot \text{Sen}\beta, si \_R_n \leq 1}
\]

\[
V_g = \sqrt{V_{gs}^2 + \left( \frac{V_t}{R_n} \right)^2 + 2 \cdot V_{gs} \cdot \left( \frac{V_t}{R_n} \right)^2 \cdot \text{Sen}\beta, si \_R_n > 1}
\]

c) Calibrate the model by adjusting the Holland parameter \( B \) to get the best approximation of the simulated wind speed field in comparison to the data recorded by the AMS in different locations during hurricanes. This is done using information from hurricanes Isidoro, Emily and Wilma.

d) Define the interest points and select from the HURDAT data base the tropical cyclone population which has affected the Yucatan Peninsula. The interest points are separated 0.125 degrees (latitude and longitude) and form a mesh that covers the whole Yucatan Peninsula; this
separation gives a dense mesh and helps for the construction of the isotach maps. From the HURDAT data base 116 tropical cyclones were identified that have affected the Yucatan Peninsula from 1851 to 2007.

e) Calculate the maximum wind speeds at each interest point generated by the numerical simulation of the trajectory of one tropical cyclone. Repeat this procedure for all the tropical cyclone population.

f) Determine the maximum wind speed distribution obtained from the numerical simulation of the whole tropical cyclone population.

g) Select an extreme probability distribution that best fits the maximum wind speed distributions.

h) Fit the extreme probability distribution selected for each interest point.

g) Determine the design wind speed for different return periods in every interest point and construct the isotach maps.

3 RESULTS

The model calibration resulted in a B parameter equal to 1.39. 116 tropical cyclones (from 1851 to 2007) were numerically simulated. The extreme probability distribution type III has the best fit to the wind speed distribution.

Isotach maps were elaborated for different return periods. These maps corresponds to a roughness terrain category 2 (open terrain) and a wind speed average time of 3 s. Isotach maps for return periods of 50 and 200 years are presented in Figures 1 and 2, respectively.

Figure 1. Isotach map of the Yucatan Peninsula for a 50 years return period (open terrain, 3 s average, Km/h)
4 DISCUSSION

Two zones of high wind speeds are shown in Figures 1 and 2. These zones are located in the east coast of the Yucatan Peninsula. Most of the tropical cyclones enter the peninsula through the east coast because they are formed in the Caribbean Sea and the Atlantic Ocean. On the other side, it is observed a zone of low wind speeds between those two zones of high wind speeds. To get more insight about these observations, bar graphs of maximum wind speeds of three interest points are presented in Figure 3; two located at the zones of high wind speeds and one located at the zone of low wind speeds. The number of maximum wind speeds recorded at each of those three interest point is also indicated in Figure 3. This number is larger for those interest points located at the north compared to that in the south; this indicates that the magnitude of the design wind speed is independent of the number of maximum wind speeds recorded at a given point. On the other hand, the design wind speed is very sensitive to the maximum wind speed recorded at an interest point, as shown in the bar graphs in Figure 3. A large value of maximum wind speed at an interest point is caused by a strong tropical cyclone which path is close to that interest point. This indicates that those high wind speeds zones are areas that have been affected by strong tropical cyclones.
Figure 3. Bar charts of maximum wind speeds for three interest points located at the east coast of the Yucatan Peninsula.

Figure 4 shows two maps with trajectory of hurricanes that affected the Yucatan Peninsula. Figure 4(a) corresponds to the isotach map for a 200 years return period, in which it has been drawn the trajectories of the last strongest hurricanes that have affected the peninsula: Gilbert (1988), Isidore (2002), Emily (2005), Wilma (2005) and Dean (2007). In this figure it is observed that the high wind speed zones correspond to the trajectory of those strong hurricanes. Figure 4(b) shows the trajectory of those hurricanes and the location of some important cities of the Yucatan Peninsula as a reference.

To evaluate the effect of the last strong hurricanes on the magnitude of the design wind speeds, a shorten tropical cyclone population was considered that includes events from 1851 to 1984. Table 1 shows the design wind speed for some important cities of the Yucatan Peninsula (Fig.
4b), calculated using the shorten (1851-1984) and complete (1951-2007) tropical cyclones population. An increment of 42% in the design wind speed is observed in Cozumel Island, where hurricanes Gilbert, Emily and Wilma crossed.

Table 1. Design wind speeds calculated from different tropical cyclones population sizes.

<table>
<thead>
<tr>
<th>City</th>
<th>Design wind speed (Km/h) (1851-1984)</th>
<th>Design wind speed (Km/h) (1851-2007)</th>
<th>Increment Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mérida</td>
<td>210</td>
<td>226</td>
<td>7.6%</td>
</tr>
<tr>
<td>Valladolid</td>
<td>253</td>
<td>270</td>
<td>6.7%</td>
</tr>
<tr>
<td>Cozumel</td>
<td>198</td>
<td>282</td>
<td>42.4%</td>
</tr>
<tr>
<td>Chetumal</td>
<td>256</td>
<td>247</td>
<td>-3.52%</td>
</tr>
<tr>
<td>Campeche</td>
<td>152</td>
<td>167</td>
<td>9.9%</td>
</tr>
</tbody>
</table>

5 CONCLUSIONS

a) The Hurricane Wind Speed Field Model was calibrated using the data base provided by the Automatic Meteorological Station. The best fit is obtained with a Holland parameter equal to 1.39.
b) The extreme probability distribution type III has the best fit to the maximum wind speed distribution.
c) The design wind speeds are very sensitive to the maximum wind speed observed in a given point.
d) The inclusion of the last 22 years of data (1985-2007) has a strong impact on the design wind speed in those areas close to the trajectory of strong hurricanes, such as Cozumel and Cancun.

REFERENCES


Vickery, P. J., Skerkj, P. F. & Twisdale, L. A. 2000b. Simulation of hurricane risk in the U.S. using em-