Rina was a typical October major hurricane that formed in the western Caribbean Sea and moved toward the Yucatan Peninsula. However, it weakened significantly prior to landfall on the Yucatan Peninsula as a tropical storm and it dissipated near the Yucatan Channel.

a. Synoptic History

A relatively low-latitude tropical wave left the coast of west Africa on 9 October with little convection, but interacted with an upper-level trough on 12 October in the central Atlantic Ocean, which caused a brief increase in thunderstorms. Convection then diminished until the wave moved through the Windward Islands four days later, with thunderstorms regenerating at that time due to a diffluent upper-level environment. On 19 October, the wave showed some signs of organization, but easterly shear was too strong for development. A cold front entered the northwestern Caribbean Sea on that day, and although it might have contributed some low-level vorticity to the system over the next couple of days, the wave appears to have been the main focus for genesis. Convection intensified near the wave axis on 21 October, which resulted in the formation of a nearly stationary broad low in the western Caribbean. The next day, surface observations indicated falling pressures in the area and a better-defined low-level circulation. Thunderstorms increased markedly near and to the west of the center later that day, and a tropical depression formed by 0600 UTC 23 October about 55 n mi north of Providencia Island, east of Nicaragua. The “best track” chart of the cyclone’s path is given in Fig. 1, with the wind and pressure histories shown in Figs. 2 and 3, respectively. The best track positions and intensities are listed in Table 1.\(^1\)

A broad mid-level trough over the southeastern United States caused a weakness in a ridge near Florida, and as a result the depression moved northward. The system strengthened gradually at first, becoming a tropical storm 24 h after genesis. However, easterly wind shear then diminished and Rina rapidly intensified over the deep warm waters of the western Caribbean, becoming a hurricane by 1800 UTC 24 October and a major hurricane 24 h later. During that time, mid- to upper-level ridging rebuilt over the Gulf of Mexico, and the hurricane

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\(^1\) A digital record of the complete best track, including wind radii, can be found on line at ftp://ftp.nhc.noaa.gov/atcf. Data for the current year’s storms are located in the btk directory, while previous years’ data are located in the archive directory.
slowed down, gradually turning toward the west. NOAA aircraft data indicate that Rina reached a peak intensity of 100 kt and a minimum pressure of 966 mb around 0000 UTC 26 October, when the tropical cyclone was 220 n mi east-southeast of Chetumal, Mexico. The conducive upper-level winds did not last very long, and Rina dropped below major hurricane strength 12 h later. Increasing southeasterly and southerly shear caused Rina to weaken further, although in an irregular fashion, for the next couple of days. The cyclone moved generally toward the west-northwest and northwest on 26 and 27 October as it was steered around the periphery of the ridge, becoming a tropical storm near 1200 UTC 27 October about 75 n mi south-southeast of Tulum, Mexico. A turn to the north commenced later that day, with strong southerly shear causing additional weakening. The tropical storm made landfall near Paamul, Mexico, about 10 n mi southwest of Playa del Carmen, with an intensity of 50 kt near 0200 UTC 28 October. The center of Rina remained over land for about 9 h before emerging into the Yucatan Channel. Strong southerly shear caused all convection near the center to dissipate, and Rina degenerated into a remnant low in the Yucatan Channel by 1800 UTC 28 October. The remnant low moved toward the east-northeast and east within the low-level flow ahead of a cold front, and dissipated early the next day just southeast of the western tip of Cuba.

b. Meteorological Statistics

Observations in Rina (Figs. 2 and 3) include satellite-based Dvorak technique intensity estimates from the Tropical Analysis and Forecast Branch (TAFB) and the Satellite Analysis Branch (SAB), as well as the Advanced Dvorak Technique from the University of Wisconsin-Madison/Cooperative Institute for Meteorological Satellite Studies (UW-CIMSS). Nine aircraft flights of the Air Force Reserve 53rd weather reconnaissance squadron and four flights of the NOAA WP-3 Orion provided flight-level and stepped frequency microwave radiometer (SFMR) surface wind and dropsonde data. Data and imagery from NOAA polar-orbiting satellites including the Advanced Microwave Sounding Unit (AMSU), the NASA Tropical Rainfall Measuring Mission (TRMM), Defense Meteorological Satellite Program (DMSP) satellites, among others, were also useful in constructing the best track of Rina.

The 100-kt estimated peak intensity of Rina is primarily based on a NOAA SFMR measurement of 103 kt at 2240 UTC 25 October, with another SFMR reading of 98 kt also taken by the Air Force Reserve several hours later. Operationally, the peak SFMR reading was flagged as questionable, so a more conservative flight-level wind adjustment factor that supported 95 kt (actual flight-level measurement 106 kt) was used at that time. A post-analysis from the NOAA Hurricane Research Division, however, concluded that the SFMR data were not contaminated and are thus used to upgrade Rina to a major hurricane for the final best track. It is also noted that the surface-based data suggest that the typical flight-level wind adjustment factors were not applicable to Rina. Examples can be seen in Figure 2, where both the SFMR measurements (white triangles) and the surface winds from the dropsonde (yellow circles) are consistently higher than the flight-level adjustments (red triangles) and the layer-based averaging from the dropsondes (yellow triangles).
The analyzed lowest minimum pressure of 966 mb was based on extrapolation from the 700-mb flight-level from a NOAA center fix.

Selected surface observations from Rina are in Table 2. A public wind report of 46 kt with a gust to 62 kt is the basis for the estimated 50-kt landfall intensity in Mexico. A storm chaser at the landfall point reported a central pressure of 996.5 mb, which was very close to the final aircraft fix before landfall.

There were no reliable ship reports of tropical-storm-force winds in association with Rina.

c. Casualty and Damage Statistics

No significant damage or casualties were reported with Rina.

d. Forecast and Warning Critique

Rina’s genesis was well forecast. The system was introduced in the Tropical Weather Outlook in the low category (10%) 60 h before genesis and reached a high chance (60%) of genesis 30 h before formation. One small critique is that 12 h before genesis, the estimated probability of formation had decreased slightly to 50%, perhaps weighing a short-term trend in convection too much. However, at the time of genesis, the probability had increased to 70%.

A verification of NHC official track forecasts for Rina is given in Table 3a. Official forecast track errors were far below the mean official errors for the previous 5-yr period. Although the OCD5 (CLIPER) errors for this system were also below their 5-yr averages, the official forecast errors were much lower than climatology alone explains. Most of the global models, as shown in Table 3b, provided excellent guidance for this hurricane and the official forecasts were generally near or somewhat better than the models. The GFDL and HWRF models, however, did not perform well due to a large track bias to the north and east.

A verification of NHC official intensity forecasts for Rina is given in Table 4a. In contrast to the track errors, the official forecast intensity errors were much worse than the average 5-yr errors through 72 h. A homogeneous comparison of the official intensity errors with selected guidance models is given in Table 4b. The official intensity forecasts were rather poor compared to much of the guidance. An inspection of the NHC errors indicate that early forecasts were too conservative in forecasting intensification, and later forecasts held onto the high wind speeds for too long after the peak intensity. The Florida State Superensemble (FSSE) had a particularly good performance for Rina, especially considering the rapid changes in intensity. The GFDL and HWRF again struggled, showing too much intensification in a sheared environment at later time periods. The northeastward track bias of those models for this system also could have placed the storm in a more conducive environment for strengthening than what actually materialized.
Watches and warnings associated with Rina are in Table 5.

Acknowledgments:

Thanks are expressed to the Mexican Navy, Weather Underground and Josh Morgerman for providing data from near the landfall point in Mexico.
Table 1. Best track for Hurricane Rina, 23–28 October 2011.

<table>
<thead>
<tr>
<th>Date/Time (UTC)</th>
<th>Latitude (°N)</th>
<th>Longitude (°W)</th>
<th>Pressure (mb)</th>
<th>Wind Speed (kt)</th>
<th>Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>22 / 0000</td>
<td>12.7</td>
<td>81.0</td>
<td>1007</td>
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<td>low</td>
</tr>
<tr>
<td>22 / 0600</td>
<td>12.7</td>
<td>81.2</td>
<td>1007</td>
<td>25</td>
<td>&quot;</td>
</tr>
<tr>
<td>22 / 1200</td>
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<td>81.4</td>
<td>1006</td>
<td>25</td>
<td>&quot;</td>
</tr>
<tr>
<td>22 / 1800</td>
<td>13.2</td>
<td>81.4</td>
<td>1006</td>
<td>25</td>
<td>&quot;</td>
</tr>
<tr>
<td>23 / 0000</td>
<td>13.6</td>
<td>81.4</td>
<td>1006</td>
<td>25</td>
<td>&quot;</td>
</tr>
<tr>
<td>23 / 0600</td>
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<td>81.4</td>
<td>1006</td>
<td>25</td>
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</tr>
<tr>
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<td>25</td>
<td>&quot;</td>
</tr>
<tr>
<td>23 / 1800</td>
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<td>81.7</td>
<td>1005</td>
<td>30</td>
<td>&quot;</td>
</tr>
<tr>
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<td>1004</td>
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</tr>
<tr>
<td>24 / 0600</td>
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<td>1003</td>
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<td>16.9</td>
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<td>1001</td>
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<tr>
<td>24 / 1800</td>
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<td>991</td>
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<td>83.2</td>
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<td>75</td>
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</tr>
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<td>25 / 0600</td>
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<td>976</td>
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<td>95</td>
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</tr>
<tr>
<td>25 / 1800</td>
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<td>84.2</td>
<td>971</td>
<td>100</td>
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</tr>
<tr>
<td>26 / 0000</td>
<td>17.4</td>
<td>84.6</td>
<td>966</td>
<td>100</td>
<td>&quot;</td>
</tr>
<tr>
<td>26 / 0600</td>
<td>17.5</td>
<td>85.0</td>
<td>969</td>
<td>100</td>
<td>&quot;</td>
</tr>
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<td>26 / 1200</td>
<td>17.7</td>
<td>85.4</td>
<td>973</td>
<td>85</td>
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<tr>
<td>26 / 1800</td>
<td>18.0</td>
<td>85.8</td>
<td>976</td>
<td>80</td>
<td>&quot;</td>
</tr>
<tr>
<td>27 / 0000</td>
<td>18.3</td>
<td>86.3</td>
<td>978</td>
<td>80</td>
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<td>18.6</td>
<td>86.7</td>
<td>987</td>
<td>65</td>
<td>&quot;</td>
</tr>
<tr>
<td>27 / 1200</td>
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<td>988</td>
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<td>87.1</td>
<td>991</td>
<td>60</td>
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<td>996</td>
<td>55</td>
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<tr>
<td>28 / 0200</td>
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<td>87.2</td>
<td>996</td>
<td>50</td>
<td>&quot;</td>
</tr>
<tr>
<td>28 / 0600</td>
<td>20.9</td>
<td>87.1</td>
<td>998</td>
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</tr>
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<td>1002</td>
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<tr>
<td>28 / 1800</td>
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<td>1007</td>
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<td>1008</td>
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<tr>
<td>29 / 0600</td>
<td>21.5</td>
<td>84.2</td>
<td>1008</td>
<td>20</td>
<td>&quot;</td>
</tr>
<tr>
<td>29 / 1200</td>
<td></td>
<td></td>
<td></td>
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<td>dissipated</td>
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<tr>
<td>26 / 0000</td>
<td>17.4</td>
<td>84.6</td>
<td>966</td>
<td>100</td>
<td>minimum pressure and maximum winds</td>
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<tr>
<td>28 / 0200</td>
<td>20.5</td>
<td>87.2</td>
<td>996</td>
<td>50</td>
<td>landfall near Paamul Mexico</td>
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Table 2. Selected surface observations for Rina, 23-28 October 2011.

<table>
<thead>
<tr>
<th>Location</th>
<th>Minimum Sea Level Pressure</th>
<th>Maximum Surface Wind Speed</th>
<th>Storm surge (ft)</th>
<th>Storm tide (ft)</th>
<th>Total rain (in)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Date/time (UTC)</td>
<td>Press. (mb)</td>
<td>Date/time (UTC)</td>
<td>Sustained (kt)</td>
<td>Gust (kt)</td>
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<tr>
<td>Mexico</td>
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<td>International Civil Aviation Organization (ICAO) Sites</td>
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<td>Cancun Airport (MMUN)</td>
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<td>36</td>
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<td>Navy Station</td>
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<td></td>
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<td>Banco Chinchorro, Quintana Roo</td>
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<td>48</td>
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<td></td>
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<tr>
<td>Public/Other</td>
<td></td>
<td></td>
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<td>38</td>
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---

a Date/time is for sustained wind when both sustained and gust are listed.
b Except as noted, sustained wind averaging periods for C-MAN and land-based ASOS reports are 2 min; buoy averaging periods are 8 min.
c Storm surge is water height above normal astronomical tide level.
d Storm tide is water height above National Geodetic Vertical Datum (1929 mean sea level).
Table 3a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) track forecast errors (n mi) for Rina. Mean errors for the 5-yr period 2006-10 are shown for comparison. Official errors that are smaller than the 5-yr means are shown in boldface type.

<table>
<thead>
<tr>
<th></th>
<th>Forecast Period (h)</th>
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<tbody>
<tr>
<td></td>
<td>12</td>
</tr>
<tr>
<td>OFCL (Rina)</td>
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<td>OCD5 (Rina)</td>
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<td>Forecasts</td>
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</tr>
<tr>
<td>OFCL (2006-10)</td>
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<tr>
<td>OCD5 (2006-10)</td>
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</table>
Table 3b. Homogeneous comparison of selected track forecast guidance models (in n mi) for Rina. Errors smaller than the NHC official forecast are shown in boldface type. The number of official forecasts shown here will generally be smaller than that shown in Table 3a due to the homogeneity requirement.

<table>
<thead>
<tr>
<th>Model ID</th>
<th>Forecast Period (h)</th>
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<tr>
<td>OFCL</td>
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<td>OCD5</td>
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<tr>
<td>GFSI</td>
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</tr>
<tr>
<td>GHMI</td>
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</tr>
<tr>
<td>HWFI</td>
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<td>GFNI</td>
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<td>NGPI</td>
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<td>EGRI</td>
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<td>EMXI</td>
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<td>CMCI</td>
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<td>FSSE</td>
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<td>TVCA</td>
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<tr>
<td>TVCN</td>
<td>15.4</td>
</tr>
<tr>
<td>TVCC</td>
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<td>LBAR</td>
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<td>BAMM</td>
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<td>BAMD</td>
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<td>Forecasts</td>
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Table 4a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) intensity forecast errors (kt) for Rina. Mean errors for the 5-yr period 2006-10 are shown for comparison. Official errors that are smaller than the 5-yr means are shown in boldface type.

<table>
<thead>
<tr>
<th>Forecast Period (h)</th>
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<th>24</th>
<th>36</th>
<th>48</th>
<th>72</th>
<th>96</th>
<th>120</th>
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<tr>
<td>OCD5 (Rina)</td>
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<td>19.1</td>
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<td>24.8</td>
<td>12.8</td>
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<td>Forecasts</td>
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<td>16</td>
<td>14</td>
<td>12</td>
<td>8</td>
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<tr>
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<td>OCD5 (2006-10)</td>
<td>8.5</td>
<td>12.3</td>
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<td>17.8</td>
<td>20.2</td>
<td>21.9</td>
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Table 4b. Homogeneous comparison of selected intensity forecast guidance models (in kt) for Rina. Errors smaller than the NHC forecast are shown in boldface type. The number of official forecasts shown here will generally be smaller than that shown in Table 4a due to the homogeneity requirement.

<table>
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<tr>
<th>Model ID</th>
<th>Forecast Period (h)</th>
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<td>OFCL</td>
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<td>OCD5</td>
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<td>DSHP</td>
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<td>ICON</td>
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<td>IVCN</td>
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<tr>
<td>FSSE</td>
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</tr>
<tr>
<td>Forecasts</td>
<td>16</td>
</tr>
</tbody>
</table>
Table 5. Watches and warnings issued for Rina, 23 – 28 October 2011.

<table>
<thead>
<tr>
<th>Date/Time (UTC)</th>
<th>Action</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>23 / 2100</td>
<td>Tropical Storm Watch issued</td>
<td>Punta Castilla, Nicaragua to Honduras/Nicaragua border</td>
</tr>
<tr>
<td>24 / 1500</td>
<td>Tropical Storm Watch discontinued</td>
<td>All</td>
</tr>
<tr>
<td>25 / 0900</td>
<td>Tropical Storm Watch issued</td>
<td>Chetumal to Punta Gruesa, Mexico</td>
</tr>
<tr>
<td>25 / 0900</td>
<td>Hurricane Watch issued</td>
<td>Punta Gruesa to Cancun</td>
</tr>
<tr>
<td>25 / 1500</td>
<td>Tropical Storm Watch changed to Tropical Storm Warning</td>
<td>Chetumal to Punta Gruesa</td>
</tr>
<tr>
<td>25 / 1500</td>
<td>Hurricane Watch changed to Hurricane Warning</td>
<td>Punta Gruesa to Cancun</td>
</tr>
<tr>
<td>25 / 1800</td>
<td>Tropical Storm Watch issued</td>
<td>Belize City to Belize/Mexico border</td>
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<tr>
<td>25 / 2100</td>
<td>Tropical Storm Watch issued</td>
<td>Roatan to Guanaja, Honduras</td>
</tr>
<tr>
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</tr>
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<td>Tropical Storm Watch discontinued</td>
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<tr>
<td>28 / 1500</td>
<td>Tropical Storm Warning discontinued</td>
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Figure 1. Best track positions for Hurricane Rina, 23 – 28 October 2011.
Figure 2. Selected wind observations and best track maximum sustained surface wind speed curve for Rina. Advanced Dvorak Technique (ADT) and AMSU estimates courtesy of UW-CIMSS. Aircraft observations have been adjusted for elevation using 90%, 80%, and 80% reduction factors for observations from 700 mb, 850 mb, and 1500 ft, respectively. Dropwindsonde observations include actual 10 m winds (sfc), as well as surface estimates derived from the mean wind over the lowest 150 m of the wind sounding (LLM), and from the sounding boundary layer mean (MBL). Solid vertical line represents when the cyclone made landfall in Mexico. Dashed vertical lines correspond to 0000 UTC.
Figure 3. Selected pressure observations and best track minimum central pressure curve for Rina. Advanced Dvorak Technique (ADT) and AMSU estimates courtesy of UW-CIMSS. Dashed vertical lines correspond to 0000 UTC. Solid vertical line represents when the cyclone made landfall. KZC P-W refers to pressure estimates derived by applying the Knaff-Zehr-Courtney pressure-wind relationship to the best track wind speeds.