ANNUAL WEATHER SUMMARY

Eastern North Pacific Hurricane Season of 2011

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ABSTRACT

Overall activity during the 2011 eastern North Pacific hurricane season was near average. Of the 11 tropical storms that formed, 10 became hurricanes and 6 reached major hurricane strength (category 3 or stronger on the Saffir–Simpson hurricane wind scale). For comparison, the 1981–2010 averages are about 15 tropical storms, 8 hurricanes, and 4 major hurricanes. Interestingly, although the number of named storms was below average, the numbers of hurricanes and major hurricanes were above average. The 2011 season had the most hurricanes since 2006 and the most major hurricanes since 1998. Two hurricanes affected the southwestern coast of Mexico (Beatriz as a category 1 hurricane and Jova as a category 2 hurricane), and the season’s tropical cyclones caused about 49 deaths. On average, the National Hurricane Center track forecasts in the eastern North Pacific for 2011 were very skillful.

1. Introduction

Although the 2011 eastern North Pacific hurricane season was more active than most of the hurricane seasons since 1995, overall activity was near the long-term average. Of the 11 tropical storms that formed in 2011, 10 became hurricanes and 6 reached major hurricane strength [maximum 1-min 10-m winds greater than 96 kt (1 kt = 0.5144 m s\(^{-1}\))—corresponding to category 3 or greater on the Saffir–Simpson hurricane wind scale; Saffir (1973); Simpson (1974); Schott et al. (2010)]. In addition, there were two tropical depressions that did not strengthen into tropical storms. Although the number of named storms was below average, the numbers of hurricanes and major hurricanes were above average. In fact, 2011 had the most hurricanes since 2006 and the most major hurricanes since 1998. In terms of the accumulated cyclone energy (ACE) index (Bell et al. 2000), which accounts for the intensity and duration of the season’s storms, the value for the 2011 season was 119.6 \(\times 10^4\) kt\(^2\), or about 113% of the long-term (1981–2010) median value of 106 \(\times 10^4\) kt\(^2\). Like most years in the basin, the bulk of the cyclone activity remained offshore of the coasts of Mexico and Central America.

However, Beatriz affected the southwestern coast of Mexico as a category 1 hurricane in June (Fig. 1), and Jova made landfall in the same region in mid-October as a category 2 hurricane (Fig. 2). A total of 49 deaths in Mexico can be directly attributed to the tropical cyclone activity from this hurricane season.

Some aspects of the tropical cyclone activity observed in 2011 appear to be related to the effects of a weak La Niña, which developed during the summer. While the tropical cyclone genesis points were farther east than average, which is common in a La Niña season (Chu and Zhao 2007), the above average numbers of hurricanes and major hurricanes were unusual, especially considering the enhanced vertical wind shear that was in place during much of the season (Fig. 3). However, this type of seasonal distribution (stronger storms but fewer of them) has occurred before in a La Niña (1998), although the distribution was not as pronounced as in 2011.

The 2011 season began a few days after the median date for the first named storm, with Adrian developing on 7 June. Although the strongest activity was spread out during the season, with each month from June to November seeing one major hurricane formation, Fernanda and Greg developed within a day of each another in August, and Irwin and Jova formed on the same day in October. The climatological peak of the season was rather quiet, with a 30-day hiatus in named storms from 21 August to 21 September. Somewhat unusually

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for a La Niña event, the end of the season was quite active with three hurricanes in October and November. The season ended much later than average when Kenneth dissipated on 25 November—over a month after the median ending date of 23 October and the latest end of the season since 1983. Kenneth was also the latest major hurricane ever noted in the basin since reliable major hurricane records began around 1971, forming about three weeks after the previous record holder, Xina of 1985.

2. Data

The individual cyclone summaries that follow are based on the National Hurricane Center (NHC) post-storm meteorological analyses of a wide variety of data as described below. These analyses result in the creation of a “best track” database for each cyclone, consisting of 6-hourly representative estimates of the cyclone’s center position, maximum sustained (1-min average) surface...
Observations of eastern North Pacific tropical cyclones are almost exclusively obtained from satellites, with the National Oceanic and Atmospheric Administration (NOAA) Geostationary Operational Environmental Satellites (GOES) serving as the primary platform. GOES-East and GOES-West provide the visible and infrared imagery that serves as input for intensity estimates based on the Dvorak classification technique (Dvorak 1984; Velden et al. 2006). Subjective Dvorak intensity estimates used by NHC are performed by NHC’s Tropical Analysis and Forecast Branch (TAFB) and the Satellite Analysis Branch (SAB) in Camp Springs, Maryland. The Advanced Dvorak Technique (ADT; Olander and Velden 2007) is an objective method from University of Wisconsin–Cooperative Institute for Meteorological Satellite Studies (UW-CIMSS) that also provides geostationary satellite intensity estimates of tropical cyclones.

Geostationary imagery is supplemented by passive microwave imagery from NOAA polar-orbiting satellites, Defense Meteorological Satellite Program (DMSP) satellites, the U.S. Navy’s WindSat, and National Aeronautics and Space Administration (NASA) satellites that include the Tropical Rainfall Measuring Mission (TRMM) and Aqua2 instruments. Such imagery is useful for tracking tropical cyclones and assessing their structure (e.g., Hawkins et al. 2001). Ocean surface vector wind retrievals from the European Space Agency’s Advanced Scatterometer (ASCAT) are useful for analysis. Careful examination of scatterometer data provides estimates of the location, intensity, and outer wind radii (e.g., Brennan et al. 2009). In addition, these data can be helpful in resolving whether a disturbance has acquired a closed surface circulation. Information about the thermal structure of cyclone cores is provided by the Advanced Microwave Sounder Unit (AMSU; Demuth et al. 2006; Brueske and Velden 2003). Intensity estimates derived from these AMSU data can sometimes be superior to Dvorak classifications (Herndon and Velden 2004).

Ships and buoys occasionally provide important in situ observations. For systems posing a threat to land, direct measurements from reconnaissance aircraft are often available, from both flight-level winds and stepped-frequency microwave radiometer (SFMR) data (Uhlhorn et al. 2007). The 53rd Weather Reconnaissance Squadron of the U.S. Air Force Reserve Command (AFRC) flew four reconnaissance missions into eastern North Pacific tropical cyclones, and NOAA’s Aircraft Operations Center flew three WP-3D Orion missions in the basin during 2011. Land-based radars from the meteorological

1 The term post-tropical was adopted in 2010 and refers to a cyclone that no longer possesses sufficient tropical characteristics to be considered a tropical cyclone.

2 The AMSR-E instrument on Aqua failed on 4 October 2011.
service of Mexico were also useful for monitoring systems near land. For a more complete description of the observational platforms used at NHC, see Rappaport et al. (2009).

Historically, a description of the cyclone’s precursor disturbance or genesis mechanism has been provided in these summaries, if known. Recent research has indicated that convectively coupled Kelvin waves can be important as triggers for genesis. Schreck and Molinari (2011) show the passage of these waves enhance a number of parameters thought to be favorable for tropical cyclogenesis, including low-level potential vorticity. Kiladis et al. (2009) and Ventrice et al. (2012) also show that the convectively active phase enhances moisture and promotes the development of convection. These factors combine to produce an enhanced probability of tropical cyclogenesis relative to the background state at any given time.

3. Individual storm summaries

a. Hurricane Adrian, 7–12 June

Several factors appear to have contributed to Adrian’s genesis, including a Kelvin wave that originated over the western Pacific Ocean and increased convection south of the Gulf of Tehuantepec on 31 May (Fig. 4). After the Kelvin wave passed, a band of strong northeasterly low-level winds emanating from the mountain gap on the Isthmus of Tehuantepec induced a disturbance within the intertropical convergence zone (ITCZ) near 95°W by 2 June. Little development occurred with the nearly stationary system until a second surge of northeasterly winds began early on 6 June, and this surge likely contributed to the development of an area of low pressure early on 7 June several hundred miles south of Acapulco, Mexico. Deep convection near the low consolidated and became better organized, and a tropical depression formed around 1200 UTC that day.

The depression strengthened into a tropical storm early on 8 June while it accelerated toward the west-northwest and northwest. As Adrian moved through an environment of light vertical wind shear and over 30°C waters, the cyclone went through rapid intensification (defined as a 30 kt or greater increase in a 24-h period) during the next couple of days and became a major hurricane. Adrian reached a peak intensity of 120 kt near 0000 UTC 10 June, developing an annular structure with a 20–25 n mi (1 n mi = 1.852 km) wide eye surrounded by a wide ring of deep convection on enhanced infrared satellite imagery (Fig. 5). Although annular hurricanes tend to maintain a relatively constant intensity (Knaff et al. 2003b), Adrian soon moved almost directly across the sharp sea surface temperature gradient located to the southwest of Baja California, causing it to weaken rapidly. As the cyclone decayed, it turned toward the west under the influence of the low-level trades. The system lost nearly all of its deep convection late on 11 June and degenerated into a post-tropical low by 1200 UTC 12 June while centered about 495 n mi southwest of Cabo San Lucas, Mexico. The remnant low lasted for almost another 48 h before opening up into a trough about 600 n mi southwest of Cabo San Lucas.

Adrian was one of the strongest hurricanes observed in the eastern North Pacific basin for so early in the year. Only Adolph (2001) and Ava (1973) reached stronger intensities before 10 June.

### Table 1. 2011 eastern North Pacific hurricane season statistics.

<table>
<thead>
<tr>
<th>Name</th>
<th>Class</th>
<th>Dates</th>
<th>Max 1-min wind (kt)</th>
<th>Min sea level pressure (mb)</th>
<th>Direct deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adrian</td>
<td>MH</td>
<td>7–12 Jun</td>
<td>120</td>
<td>944</td>
<td>1</td>
</tr>
<tr>
<td>Beatriz</td>
<td>H</td>
<td>19–22 Jun</td>
<td>80</td>
<td>977</td>
<td>1</td>
</tr>
<tr>
<td>Calvin</td>
<td>H</td>
<td>7–10 Jul</td>
<td>70</td>
<td>984</td>
<td>1</td>
</tr>
<tr>
<td>Dora</td>
<td>MH</td>
<td>18–24 Jul</td>
<td>135</td>
<td>929</td>
<td>1</td>
</tr>
<tr>
<td>Eugene</td>
<td>TS</td>
<td>15–19 Aug</td>
<td>60</td>
<td>992</td>
<td>1</td>
</tr>
<tr>
<td>Greg</td>
<td>H</td>
<td>16–21 Aug</td>
<td>125</td>
<td>942</td>
<td>3</td>
</tr>
<tr>
<td>Hilary</td>
<td>H</td>
<td>21–30 Sep</td>
<td>125</td>
<td>942</td>
<td>3</td>
</tr>
<tr>
<td>Irwin</td>
<td>H</td>
<td>6–16 Oct</td>
<td>85</td>
<td>976</td>
<td>9</td>
</tr>
<tr>
<td>Jova</td>
<td>MH</td>
<td>6–12 Oct</td>
<td>110</td>
<td>955</td>
<td>9</td>
</tr>
<tr>
<td>Kenneth</td>
<td>MH</td>
<td>19–25 Nov</td>
<td>125</td>
<td>940</td>
<td>9</td>
</tr>
</tbody>
</table>

*a Tropical storm (TS), wind speed 34–63 kt (17–32 m s$^{-1}$); hurricane (H), wind speed 64 kt (33 m s$^{-1}$) or higher; major hurricane (MH), hurricane with maximum winds 96 kt (49 m s$^{-1}$) or higher.

*b Dates are based on UTC time and include the tropical depression stage but exclude the post-tropical stage.

*c Tropical Depression Twelve-E caused an additional 36 direct deaths, but is not specifically listed here because the cyclone never reached tropical-storm strength.
b. Hurricane Beatriz, 19–22 June

The genesis of Beatriz, the first June hurricane to strike the coast of Mexico since Boris of 1996, was complex. A tropical wave emerged from the west coast of Africa on 4 June and reached the western Caribbean Sea near 14 June. A Kelvin wave was enhancing low-level vorticity and large-scale ascent east of 110°W at the time the tropical wave reached the eastern Pacific on 15 June (Fig. 4). The tropical wave entered this favorable environment, and satellite pictures revealed that a slow-moving low- to midlevel cyclonic circulation formed along the wave axis several hundred miles south of El Salvador by 16 June. A faster-moving easterly wave entering the region reached the eastern portion of the cyclonic circulation around this time, resulting in the formation of an elongated surface low with multiple centers several hundred miles southeast of Acapulco on 17 June.

Convection gradually increased during the next 24 h, and a loosely organized curved band developed near the westernmost circulation center by early on 18 June. A 1630 UTC ASCAT pass that day indicated that this circulation, closest to the convection, was becoming dominant, and a well-defined area of low pressure formed within this circulation by 1800 UTC 18 June. A concentrated burst of deep convection developed over the center around 0600 UTC the next day, and a tropical depression formed around that time about 225 n mi south-southeast of Acapulco.

The depression moved generally west-northwestward to northwestward around the southwestern periphery of a midtropospheric ridge centered over the northwestern Caribbean Sea. The cloud pattern became better organized, and the depression strengthened into a tropical storm 12 h after genesis. In a moist, low shear environment and over sea surface temperatures of 29°–30°C, Beatriz quickly intensified. Data from a U.S. Air Force Reserve Hurricane Hunter mission around 1800 UTC 20 June indicated that Beatriz reached hurricane strength around that time while located about 180 n mi south-southeast of Manzanillo, Mexico. The cyclone then turned north-northwestward and its forward speed decreased as it moved into a weakness in the subtropical ridge.

The intensification phase continued as Beatriz approached the southwestern coast of Mexico, and the hurricane is estimated to have reached a peak intensity of 80 kt around 0600 UTC 21 June (Fig. 6). The forward speed of the hurricane increased at this point in response to a rebuilding of the subtropical ridge over Mexico, and the heading gradually shifted from north-northwest to northwest. The eye passed within 15 n mi of the coast between 0600 and 0900 UTC, with the northern eyewall brushing coastal areas to the southeast of Manzanillo. It is likely that sustained hurricane-force winds were experienced over a small portion of the southwestern coast of Mexico. The interaction of the circulation with the high terrain of the Sierra Madre del Sur contributed to the rapid weakening of Beatriz observed after this time, with Beatriz becoming a tropical storm by 1200 UTC that day. The cloud pattern of the storm continued to rapidly lose organization during the day while the storm turned westward and slowed. Beatriz dissipated about 75 n mi west of Manzanillo by 0600 UTC 22 June, only 24 h after its peak intensity.

The maximum flight-level (700 mb) wind measured in Beatriz was 74 kt in the northeast quadrant at 1807 UTC 20 June, followed by a dropsonde measurement of a mean wind of 76 kt in the lowest available 150 m of the sounding. The maximum SFMR wind estimate was 70 kt at 1803 UTC and the aircraft reported a central pressure of 989 mb at 2001 UTC. The intensification observed by
the plane continued during the next 12 h as the center approached the coast, and the analyzed peak intensity of 80 kt around 0600 UTC 21 June represents a blend of Dvorak satellite estimates of T4.5 to T5.0 (77–90 kt) from TAFB, SAB, and ADT values.

One death is directly attributed to Beatriz. Media reports indicate that a stream, quickly rising as a result of heavy rains related to the storm, swept away a teenage boy. Heavy rains, high waves, and strong winds also affected portions of the coast of Mexico from the states of Guerrero to Jalisco, causing uprooted trees and flooded homes in Acapulco. The maximum reported rainfall amounts by state include 223 mm in Copala at Guerrero, 168 mm at Lázaro Cárdenas in Michoacán, and 159 mm at Callejones in Colima.

c. Hurricane Calvin, 7–10 July

The tropical wave that spawned Calvin emerged from Africa on 24 June. Thunderstorm activity was limited as the wave moved westward over the tropical Atlantic and northern South America and began to slowly increase after the system reached Central America on 3 July. The wave interacted with a weak ITCZ disturbance on 5 July, which caused a low to form. Over the next 24 h, the low gradually became better defined, and convection continued to increase near the low-level center, leading to the genesis of a tropical depression around 1200 UTC 7 July, about 150 n mi southwest of Acapulco.

The depression moved west-northwestward on a path parallel to the southwestern coast of Mexico. Despite moderate easterly vertical wind shear of 15–20 kt, the depression reached tropical storm status by 0000 UTC 8 July. Over the next 24 h, the vertical shear gradually decreased and Calvin rapidly strengthened, reaching its peak intensity of 70 kt around 0000 UTC 9 July.

Almost as quickly as Calvin intensified, however, the cyclone weakened during the next 24 h as it moved over cooler waters. By 0600 UTC 10 July, Calvin degenerated into a 35-kt nonconvective low when located about 130 n mi southeast of Clarion Island. The low moved slowly west-northwestward for the next two days before turning abruptly southwestward early on 13 July and dissipating the next day about 675 n mi west-southwest of Cabo San Lucas.

d. Hurricane Dora, 18–24 July

Dora formed from a tropical wave that crossed the west coast of Africa on 7 July and reached the southwestern Caribbean Sea about a week later. As the wave approached Central America, it encountered enhanced southwesterly flow and deep convection that was partially associated with an eastward-moving Kelvin wave (Fig. 4). The interaction of the tropical wave and the strong southwesterly winds caused the formation of a broad area of low pressure over the extreme southwestern Caribbean Sea on 15 July. The system moved slowly
westward across Central America during the next couple of days and gradually became better defined. Early on 18 July, the associated thunderstorm activity quickly became organized in the eastern Pacific, resulting in the development of a tropical depression at 0600 UTC about 200 n mi south-southwest of San Salvador, El Salvador.

In a low-shear environment and over warm sea surface temperatures, Dora steadily strengthened as it moved west-northwestward to the south of a strong deep-layer ridge over the central United States. The storm became a hurricane by 1800 UTC 19 July and began a period of rapid intensification, with a well-defined eye apparent the next day in conventional satellite imagery. Dora attained major hurricane strength by 1800 UTC 20 July, and satellite estimates suggest it reached a peak intensity of about 135 kt at 1200 UTC the next day, while centered about 175 n mi southwest of Manzanillo (Fig. 7).

After reaching its peak intensity, Dora turned northwestward as it moved around the southwestern periphery of the strong ridge. Shortly thereafter, northeasterly vertical shear increased markedly, and the hurricane began to move over slightly cooler waters, together resulting in an episode of very rapid weakening to a tropical storm by 1800 UTC 22 July. Moving over even colder waters, Dora weakened into a tropical depression at 1200 UTC 24 July, about 220 n mi west of the southern tip of the Baja California peninsula and degenerated into a nonconvective remnant low 12 h later. The remnant low turned north-northwestward and then northward before dissipating early on 26 July off of the west-central coast of the Baja peninsula.

The NOAA P-3 aircraft flew three missions into Dora from 22 to 24 July as part of an eastern Pacific decay experiment. These data were very useful in determining how quickly the tropical cyclone weakened. Preliminary indications were that satellite estimates, as utilized by
NHC, were consistent with flight-level reduced winds and SFMR values from the NOAA aircraft.

e. Hurricane Eugene, 31 July–6 August

The high-amplitude tropical wave that eventually spawned Eugene left the coast of West Africa on 16 July. The northern end of the wave developed into Tropical Storm Don in the northwestern Caribbean Sea (Avila and Stewart 2013), while the southern portion of the wave continued westward. A combination of this wave and a Kelvin wave (Fig. 4) caused convection to increase significantly near and south of the Gulf of Panama on 25 July. The system remained disorganized until a strong burst of convection occurred on 30 July, leading to the formation and strengthening of a surface low. Convection then became more persistent, and banding features developed early the next day. This system became a tropical depression about 380 n mi south of Acapulco around 0600 UTC 31 July and strengthened into a tropical storm 6 h later.

Initially Eugene was moving toward the west-northwest at less than 10 kt in an environment of moderate northeasterly shear. The core of Eugene became better organized early on 1 August as the shear relaxed, with a small eye feature apparent in infrared and microwave images. Moving a bit faster toward the west-northwest, Eugene became a hurricane around 1800 UTC 1 August. The small eye was replaced by a larger eye on the next day, and the cyclone started to intensify more rapidly, becoming a major hurricane about 500 n mi southwest of the southern tip of Baja California. Figure 8 shows Eugene with a large and well-defined eye near its peak intensity of 120 kt at 2100 UTC 3 August. Late on 4 August, the eye rapidly lost definition due to the cyclone’s passage over waters of less than 24°C. Eugene quickly weakened to tropical storm intensity on 5 August and became a nonconvective low by 1200 UTC 6 August, when it was located about 980 n mi west of the southern tip of Baja California. The low lost gale-force winds on 7 August and turned westward and southwestward within the low-level trade winds, eventually decaying into a trough early on 10 August just after crossing 140°W.

f. Tropical Storm Fernanda, 15–19 August

A westward-moving tropical wave that spawned Atlantic Tropical Storm Emily (Avila and Stewart 2013) likely played a role in the genesis of Fernanda. The wave crossed Central America and entered the eastern Pacific on 6 August, producing disorganized convection during the following week. On 14 August a well-defined low became evident, and showers and thunderstorms gradually became more persistent in curved bands. By 1800 UTC the next day, a tropical depression formed about 1400 n mi east-southeast of the island of Hawaii, well to the west of where the other eastern Pacific tropical cyclones of 2011 formed. The system strengthened into a tropical storm by 0600 UTC 16 August, although east-northeasterly shear was displacing much of the convection to the west and southwest of the center. Later that day the shear relaxed, the cloud pattern became better organized into spiral bands, and the cyclone strengthened further.

Fernanda encountered a weakness in the subtropical ridge on 17 August and turned toward the west-northwest. The cyclone had a compact, symmetric cloud pattern near its peak intensity of 60 kt around 0600 UTC 18 August, when it became the only tropical cyclone of the year to cross into the central Pacific hurricane basin. Fernanda continued on a west-northwestward track for the next couple of days while steadily decreasing in
strength, due to both unfavorable thermodynamic conditions and increasing south-southeasterly shear. By 20 August most of the deep convection associated with the cyclone had dissipated, and the system degenerated into a nonconvective low. The low moved westward for a day or so before dissipating a couple hundred miles south of the island of Hawaii on 21 August.

g. Hurricane Greg, 16–21 August

Greg formed from a tropical wave that moved across the west coast of Africa on 3 August and crossed Central America on 14 August. Once the system was in the eastern Pacific, a low pressure center formed south of the Gulf of Tehuantepec, and the convection increased significantly. The low moved toward the west-northwest while the thunderstorm activity increased in organization, and a tropical depression formed about 150 n mi south-southeast of Acapulco at 1800 UTC 16 August. The cyclone slowly intensified within a moderate easterly shear environment and became a tropical storm 12 h later.

A strong midlevel ridge to the north of Greg helped steer the cyclone toward the west-northwest on a track parallel to the coast of Mexico. The shear relaxed somewhat late on 17 August, and Greg reached its peak intensity of 75 kt at 1200 UTC 18 August, when it had a small eye embedded within a central dense overcast. The hurricane continued to move toward the west-northwest for about another day and then westward thereafter. Greg weakened to a tropical storm on 19 August due to cooler waters and a more stable environment and degenerated into a nonconvective remnant low by 1200 UTC 21 August. The low continued to move westward and dissipated two days later.

h. Hurricane Hilary, 21–30 September

Hilary developed from a tropical wave that emerged over the eastern Atlantic Ocean on 7 September. The well-defined wave moved westward with generally limited convection as it crossed the Atlantic basin. On 17 September, the wave reached the eastern Pacific and began developing within the ITCZ, aided by a passage of a Kelvin wave. A broad low formed on the next day, and deep convection gradually increased, leading to the genesis of a tropical depression around 0600 UTC 21 September about 310 n mi southeast of Acapulco.

The cyclone initially moved slowly northward and then somewhat faster toward the west-northwest over the next couple of days, while its convective structure quickly became organized in an environment of 29°–30°C sea surface temperatures, very low wind shear, and a moist midtroposphere. Hilary underwent a prolonged period of rapid intensification and reached a peak intensity of 125 kt on 23 September (Fig. 9). Hilary then underwent an eyewall replacement cycle, which caused some weakening of the cyclone through early on 26 September. The environment remained conducive for intensification, however, and a second maximum in intensity of 115 kt occurred late that day after the eyewall cycle was completed.

By late on 27 September, Hilary encountered cooler waters and substantially stronger vertical shear, leading to a weakening of the cyclone. From 28–30 September, the hurricane moved toward the northwest around a subtropical ridge. Hilary decayed to a tropical storm around 0600 UTC 29 September, and then to a tropical depression about 24 h later about 620 n mi west of the southern tip of Baja California. Hilary became a non-convective low 6 h later and meandered generally toward the southwest over the next three days before dissipating.

Only one ship (call sign A8EH5, the Maersk Dallas) reported tropical-storm-force winds during Hilary’s lifetime. The strongest winds reported by the ship were 41 kt at 0300 UTC 22 September at 15.1°N, 97.0°W. Although there were no reports of sustained tropical-storm-force winds from any mainland stations in Mexico, it is likely that winds of that strength occurred along the sparsely monitored coast of Mexico near Acapulco. Peak gusts of 44 and 41 kt were observed at 1645 UTC 26 September at Clarion Island and at 1445 UTC 25 September at Socorro Island, respectively.

There were media reports of downed trees in Acapulco after Hilary made its closest approach to the Mexican coast on 23 September. No monetary estimate of the damage is available, but it is likely that the damage was minor. There were three fatalities directly attributed to Hilary; all fishermen who perished when their boat sank off of the town of Marguelia.

i. Hurricane Irwin, 6–16 October

Irwin is most notable for its unusually long-lasting eastward motion that brought the cyclone from several hundred miles south of Baja California to near the southwestern coast of Mexico. The hurricane appears to have developed from a breakdown of the ITCZ (e.g., Ferreira and Schubert 1997). Three distinct areas of vorticity developed along the ITCZ axis on 3 October after the passage of a strong Madden–Julian oscillation (MJO; Madden and Julian 1971) in the eastern Pacific, with the middle of the three areas initially dominant (the eastern disturbance later became Hurricane Jova). An area of low pressure formed within the middle disturbance on 4 October and produced disorganized deep convection as it moved west to west-northwestward over the next day or so on the south side of a weak midlevel
The convection consolidated into a curved band early on 6 October, and a tropical depression formed by 0600 UTC that day while centered about 735 n mi southwest of Cabo San Lucas. The depression rapidly strengthened in an environment of light vertical wind shear and over sea surface temperatures of about 28°C. Irwin became a hurricane between 0000 and 0600 UTC 7 October and reached a peak intensity of 85 kt by 1800 UTC that day. The environmental steering then changed after that time, with a midlatitude trough causing the cyclone to slow down and turn northward and northeastward on 8 October. At the same time, deep-layer easterly shear, likely enhanced by the upper-level outflow from Jova, caused the low-level center of Irwin to become exposed, and the hurricane weakened rapidly to a tropical storm by 1800 UTC 8 October. Nearly all the deep convection dissipated early on 9 October, and Irwin’s intensity decreased to 35 kt by 0600 UTC. Irwin accelerated toward the east over the next three days with little change in intensity, steered by the flow to the south of a midlatitude trough over the southwestern United States and northwestern Mexico and a developing cutoff low southwest of Baja California. As Irwin turned toward the northeast late on 12 October, shear increased to near 20 kt, causing the cyclone to weaken to a tropical depression at 0000 UTC 13 October when the cyclone was about 270 n mi west-southwest of Manzanillo.

Showers and thunderstorms redeveloped near the center, and Irwin restrengthened to a tropical storm 18 h later. The storm became nearly stationary early on 14 October, but later that day a low-to midlevel ridge built over northwestern Mexico, causing Irwin to accelerate toward the south through early on 16 October. While moving southward, Irwin again weakened as it encountered deep-layer northeasterly shear, drier air, and the cold wake from Hurricane Jova, and it became a tropical depression at 1800 UTC 15 October. Irwin degenerated into a remnant low 24 h later and moved slowly to the northwest for another two days or so. The remnant low dissipated after 1200 UTC 18 October approximately 355 n mi southwest of Manzanillo.
j. Hurricane Jova, 6–12 October

1) SYNOPTIC HISTORY

Early on 5 October a circulation developed several hundred miles south of Acapulco in association with the aforementioned ITCZ breakdown and strong MJO passage that helped to spawn Irwin. As this circulation moved westward it became better defined, and a low formed around 1200 UTC that day. Deep convection became more concentrated near the low center over the next 12 h, and it is estimated that a tropical depression formed about 475 n mi southwest of Acapulco by 0000 UTC 6 October. The cyclone moved generally west-northwestward around the southwestern periphery of the subtropical ridge and reached tropical storm intensity around 1800 UTC that day.

While Jova was moving over waters of 28°–29°C on 7–8 October, moderate northeasterly vertical wind shear allowed for only gradual strengthening. The cyclone’s forward speed decreased during that time and Jova turned northwestward and then northward around the western periphery of the ridge. By late on 8 October, the vertical shear began to decrease, and Jova became a hurricane around 1800 UTC that day while centered about 390 n mi west-southwest of Manzanillo. The hurricane strengthened steadily over the next couple of days as it moved north of the ridge and turned eastward toward Mexico. Jova reached a peak intensity of 110 kt around 1800 UTC 10 October, by which time a distinct eye was apparent in geostationary satellite imagery (Fig. 10).

By early the next day southwesterly shear increased over Jova ahead of a midlatitude trough digging southward over the Baja California peninsula. Jova turned northeastward ahead of the trough and weakened, falling below major hurricane status around 1200 UTC 11 October about 120 n mi south-southwest of Manzanillo. Later that day the cyclone accelerated north-northeastward, still with an intensity of 85 kt and a distinct eye in microwave imagery as it approached the coast of the Mexican state of Jalisco. The center of Jova crossed the coast at that same intensity around 0600 UTC 12 October near El Tabaco, about 35 n mi northwest of Barra de Navidad. After landfall, Jova continued moving north-northeastward and rapidly weakened to a tropical storm by 1200 UTC 12 October and then to a tropical depression 6 h later over the high terrain of western Mexico. The low-level circulation dissipated by 0000 UTC 13 October.

2) METEOROLOGICAL STATISTICS

Jova’s analyzed peak intensity of 110 kt is based on a SFMR surface wind estimate of 109 kt at 1848 UTC 10 October from an Air Force reserve aircraft. The lowest minimum pressure estimate of 955 mb is based on a dropsonde measurement of 956 mb with 17 kt of wind at the surface at 1901 UTC that day.

The 85-kt intensity estimate for Jova at landfall is based on a blend of a 90-kt Dvorak intensity estimate from TAFB and a 3-h average ADT intensity of 77 kt at 0600 UTC 12 October. The lowest pressure observed along the coast of Mexico was 985.2 mb at 0533 UTC.
12 October, as reported by storm chasers in the town of Emiliano Zapata, a few miles southeast of where Jova made landfall.

One ship report of tropical-storm-force winds was received: the Maersk Derince (call sign DDAC2) reported 39-kt winds with a pressure of 999.0 mb at 0600 UTC 11 October. There were no land-based observations of tropical-storm-force winds reported in association with Jova, although a wind gust of 40 kt was reported in Manzanillo. Selected rainfall observations from land stations are given in Table 2.

3) CASUALTY AND DAMAGE STATISTICS

According to media reports, there were nine deaths in Mexico due to Jova. In Cihuatlán, in the state of Jalisco, a woman and her son were killed in a mudslide, and the body of a man who was apparently swept away by a river was found. In Tomatlán, Jalisco, a man and a teenage boy were killed when the walls of their house collapsed because of the heavy rain. In the state of Colima a woman drowned when the car she was riding in was swept away by water. The details of the other three deaths are unknown.

The port of Manzanillo was closed because of the storm, with reports of wind damage to power lines and flooding that knocked out at least one bridge in that city. Flooding was also reported in Zihuatlán, Melaque, and Barra de Navidad. A total of 107 000 people lost power because of the storm, and 2600 people were evacuated by the Mexican Navy. No monetary damage estimates are available.

k. Hurricane Kenneth, 19–25 November

The tropical wave that helped spawn Kenneth left the west coast of Africa on 2 November. The wave moved quickly and uneventfully across the tropical Atlantic Ocean, reaching the southwestern Caribbean Sea on 13 and 14 November where a brief flare-up of deep convection occurred. A broad low pressure system formed along the wave axis prior to the system moving across Central America on 15 November. As the large disturbance moved westward over the next few days, the convective pattern slowly increased in organization, and a tropical depression formed around 1800 UTC 19 November about 400 n mi south of Acapulco. The depression became a tropical storm 24 h later when a small burst of deep convection developed near the center.

Kenneth maintained a westward motion for most of its lifetime. After it became a tropical storm, the combination of sea surface temperatures exceeding 28°C and vertical shear of less than 10 kt allowed the storm to rapidly intensify into a category 4 hurricane. Kenneth reached its peak intensity of 125 kt at 1200 UTC 22 November when it was centered about 380 n mi south-southwest of Socorro Island (Fig. 11), with the small hurricane possessing an eye with a diameter of only 10–12 n mi.

Rapid weakening began by late 22 November due to an intrusion of midlevel dry air and the cyclone’s upwelling of progressively colder water along its path, both of which caused the eyewall convection to diminish. Kenneth became a tropical storm near 1800 UTC 23 November, after which time a slower weakening trend ensued. The storm became a depression around 0600 UTC 25 November when it was located about 615 n mi west-southwest of Clarion Island. The cyclone degenerated into a nonconvective remnant low pressure system 6 h later and then continued on a faster westward track over cooler waters, decaying into a trough the next day.

Kenneth is the latest-forming major hurricane in the eastern North Pacific basin during the satellite era, and is

<table>
<thead>
<tr>
<th>Location</th>
<th>Min sea level pressure</th>
<th>Max surface wind speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mexico: International Civil Aviation Organization (ICAO) and synoptic sites</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colima (MMIA)</td>
<td>361.2</td>
<td></td>
</tr>
<tr>
<td>Manzanillo (MMZO)</td>
<td>992.9</td>
<td>2142 UTC 11 Oct 2011</td>
</tr>
<tr>
<td>Manzanillo (76654)</td>
<td></td>
<td>20 40</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cihuatlán</td>
<td>420.1</td>
<td></td>
</tr>
<tr>
<td>Coquimatlán</td>
<td>374.4</td>
<td></td>
</tr>
<tr>
<td>Penitas</td>
<td>336.6</td>
<td></td>
</tr>
<tr>
<td>Camala</td>
<td>326.9</td>
<td></td>
</tr>
<tr>
<td>Colima</td>
<td>313.7</td>
<td></td>
</tr>
<tr>
<td>El Chanal</td>
<td>289.3</td>
<td></td>
</tr>
<tr>
<td>Manzanillo</td>
<td>283.0</td>
<td></td>
</tr>
</tbody>
</table>

* Time and date are for sustained wind when both sustained and gust are listed.
** Sustained wind averaging period is 10 min.
the only major hurricane to have occurred in the month of November. The previous latest-occurring major hurricane was Xina, which reached a peak intensity of 100 kt on 29 October 1985. Kenneth is also only one of six hurricanes to have occurred during the month of November since official record keeping began in 1949 (Blake et al. 2009).

4. Tropical depressions

a. Tropical Depression Eight-E, 31 August

This short-lived system originated from the interaction of a tropical wave and the ITCZ. The southern portion of the tropical wave that spawned Atlantic Hurricane Irene (Avila and Stewart 2013) entered eastern Pacific waters late on 24 August. As the wave moved westward, it merged with a disturbance in the ITCZ a few days later. This disturbance gradually became better organized, and it became a tropical depression around 0600 UTC 31 August, when it was located about 40 n mi southwest of Zihuatanejo, Mexico. After genesis, the depression moved northwestward and made landfall just west of Lázaro Cárdenas, Mexico, around 1700 UTC that day. The cyclone turned west-northwestward after landfall and degenerated into a remnant low inland about 75 n mi east-southeast of

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**TABLE 3. Homogenous comparison of official and CLIPER5 track forecast errors in the eastern North Pacific basin in 2011 for all tropical cyclones. Averages for the previous 5-yr period are shown for comparison.**

<table>
<thead>
<tr>
<th>Forecast period (h)</th>
<th>12</th>
<th>24</th>
<th>36</th>
<th>48</th>
<th>72</th>
<th>96</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011 mean OFCL error (n mi)</td>
<td>25.1</td>
<td>40.4</td>
<td>53.2</td>
<td>68.6</td>
<td>103.3</td>
<td>149.2</td>
<td>166.1</td>
</tr>
<tr>
<td>2011 mean CLIPER5 error (n mi)</td>
<td>35.7</td>
<td>71.5</td>
<td>113.7</td>
<td>167.4</td>
<td>299.7</td>
<td>457.2</td>
<td>635.6</td>
</tr>
<tr>
<td>2011 mean OFCL skill relative to CLIPER5 (%)</td>
<td>29.7</td>
<td>43.5</td>
<td>53.2</td>
<td>59.0</td>
<td>65.5</td>
<td>67.4</td>
<td>73.9</td>
</tr>
<tr>
<td>2011 mean OFCL bias vector (°/n mi)</td>
<td>101°7</td>
<td>098°20</td>
<td>098°33</td>
<td>095°47</td>
<td>088°73</td>
<td>076°106</td>
<td>067°131</td>
</tr>
<tr>
<td>2011 No. of cases</td>
<td>234</td>
<td>213</td>
<td>193</td>
<td>171</td>
<td>129</td>
<td>93</td>
<td>58</td>
</tr>
<tr>
<td>2006–10 mean OFCL error (n mi)</td>
<td>29.7</td>
<td>49.9</td>
<td>69.0</td>
<td>86.6</td>
<td>119.0</td>
<td>155.8</td>
<td>197.7</td>
</tr>
<tr>
<td>2006–10 mean CLIPER5 error (n mi)</td>
<td>38.4</td>
<td>74.8</td>
<td>115.3</td>
<td>155.9</td>
<td>226.3</td>
<td>273.7</td>
<td>310.4</td>
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<tr>
<td>2006–10 mean OFCL skill relative to CLIPER5 (%)</td>
<td>22.7</td>
<td>33.3</td>
<td>40.2</td>
<td>44.5</td>
<td>47.4</td>
<td>43.1</td>
<td>36.3</td>
</tr>
<tr>
<td>2006–10 mean OFCL bias vector (°/n mi)</td>
<td>292°13</td>
<td>291°15</td>
<td>279°7</td>
<td>273°10</td>
<td>235°11</td>
<td>183°14</td>
<td>148°22</td>
</tr>
<tr>
<td>2006–10 No. of cases</td>
<td>1198</td>
<td>1042</td>
<td>895</td>
<td>769</td>
<td>553</td>
<td>381</td>
<td>250</td>
</tr>
<tr>
<td>2011 OFCL error relative to 2006–10 mean (%)</td>
<td>−15.5</td>
<td>−19.0</td>
<td>−22.9</td>
<td>−20.8</td>
<td>−13.2</td>
<td>−4.2</td>
<td>−16.0</td>
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<tr>
<td>2011 CLIPER5 error relative to 2006–10 mean (%)</td>
<td>−7.0</td>
<td>4.4</td>
<td>−1.4</td>
<td>7.4</td>
<td>32.4</td>
<td>67.0</td>
<td>104.8</td>
</tr>
</tbody>
</table>
Manzanillo around 0000 UTC 1 September. The low emerged into the Pacific waters around 1200 UTC and degenerated into a trough early the next day.

b. Tropical Depression Twelve-E, 12 October

Analysis of satellite imagery suggests that Tropical Depression Twelve-E developed from the same tropical wave that produced Atlantic Hurricane Philippe (Avila and Stewart 2013). The wave crossed Central America on 5 October and entered an environment of enhanced low-level westerly flow related to the MJO that was propagating through the eastern Pacific. Within this favorable environment, the wave caused a well-defined surface low to form along the ITCZ by 1800 UTC 6 October, centered about 300 n mi south of the border between Guatemala and Mexico. The low moved slowly west-northwestward during the next couple of days in an environment of moderate to strong easterly wind shear, while producing intermittent bursts of deep convection. The low turned northeastward with an increase in forward speed on 10 October within the northward-migrating ITCZ and then turned northward the next day. Satellite imagery indicated that the system acquired sufficient organization to be designated as a tropical depression around 0000 UTC 12 October while centered about 160 n mi south-southeast of Salina Cruz, Mexico. The depression continued generally northward and made landfall around 1600 UTC that day along the eastern Gulf of Tehuantepec near Paredón, Mexico. Deep convection rapidly decreased after the depression moved inland, and the cyclone became a remnant low by 0000 UTC 13 October near the border of the Mexican states of Oaxaca and Chiapas, dissipating a few hours later.

Torrential rains associated with the depression and the associated moist southwesterly flow in which it was embedded contributed to severe flooding in portions of southeastern Mexico and Guatemala. Press accounts indicate up to 305 mm of rain fell in portions of Guatemala, and the Guatemalan government indicates that 36 deaths can be directly attributed to the depression.

5. Forecast verification and warnings

For all operationally designated tropical cyclones in its area of responsibility, the NHC issues an official tropical cyclone track (latitude and longitude of the circulation center) and intensity (maximum 1-min wind speed at 10 m above the surface) forecast every 6 h. These forecasts are made for the 12-, 24-, 36-, 48-, 72-, 96-, and 120-h periods from the initial synoptic time of the forecast (0000, 0600, 1200, or 1800 UTC). The forecasts are evaluated

<table>
<thead>
<tr>
<th>Forecast period (h)</th>
<th>12</th>
<th>24</th>
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<th>48</th>
<th>72</th>
<th>96</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011 mean OFCL error (kt)</td>
<td>7.2</td>
<td>12.2</td>
<td>15.0</td>
<td>16.4</td>
<td>17.9</td>
<td>18.8</td>
<td>17.5</td>
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<td>2011 mean Decay-SHIFOR5 error (kt)</td>
<td>9.0</td>
<td>15.2</td>
<td>19.5</td>
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<td>24.6</td>
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<td>23.3</td>
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<tr>
<td>2011 mean OFCL skill relative to Decay-SHIFOR5 (%)</td>
<td>20.0</td>
<td>19.7</td>
<td>23.1</td>
<td>24.8</td>
<td>27.2</td>
<td>19.0</td>
<td>24.9</td>
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<tr>
<td>2011 OFCL bias (kt)</td>
<td>−0.3</td>
<td>−0.4</td>
<td>−0.4</td>
<td>−0.4</td>
<td>2.9</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td>2011 No. of cases</td>
<td>234</td>
<td>213</td>
<td>193</td>
<td>171</td>
<td>129</td>
<td>93</td>
<td>58</td>
</tr>
<tr>
<td>2006–10 mean OFCL error (kt)</td>
<td>6.3</td>
<td>10.5</td>
<td>13.7</td>
<td>15.1</td>
<td>17.1</td>
<td>18.6</td>
<td>18.0</td>
</tr>
<tr>
<td>2006–10 mean Decay-SHIFOR5 error (kt)</td>
<td>7.5</td>
<td>11.9</td>
<td>15.3</td>
<td>17.6</td>
<td>19.0</td>
<td>20.3</td>
<td>21.1</td>
</tr>
<tr>
<td>2006–10 mean OFCL skill relative to Decay-SHIFOR5 (%)</td>
<td>13.7</td>
<td>11.8</td>
<td>10.5</td>
<td>14.2</td>
<td>10.5</td>
<td>8.4</td>
<td>14.7</td>
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<tr>
<td>2006–10 OFCL bias (kt)</td>
<td>0.7</td>
<td>1.2</td>
<td>1.2</td>
<td>0.5</td>
<td>0.9</td>
<td>0.1</td>
<td>−1.1</td>
</tr>
<tr>
<td>2006–10 No. of cases</td>
<td>1198</td>
<td>1042</td>
<td>895</td>
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<td>553</td>
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<td>250</td>
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<td>2011 OFCL error relative to 2006–10 mean (%)</td>
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<td>16.2</td>
<td>9.5</td>
<td>8.6</td>
<td>4.7</td>
<td>1.1</td>
<td>−2.8</td>
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<tr>
<td>2011 Decay-SHIFOR5 error relative to 2006–10 mean (%)</td>
<td>23.3</td>
<td>27.7</td>
<td>27.5</td>
<td>23.9</td>
<td>29.5</td>
<td>14.3</td>
<td>10.4</td>
</tr>
</tbody>
</table>
using the postseason 6-h best-track database for all tropical cyclones. The track error is defined as the great-circle distance between forecast and best-track positions of the tropical cyclone center; the intensity error is the absolute value of the difference between the forecast and best-track intensities.

A comparison of the average track errors for 2011 and the previous 5-yr period for the official forecast and the 5-day version of the Climatology and Persistence (CLIPER5; Neumann 1972; Aberson 1998) model forecast are shown in Table 3 and Fig. 12, after Cangialosi and Franklin (2012). CLIPER5 serves as a benchmark of track forecast skill. Track forecast accuracy for 2011 was very good, and a new record was set at 12 h. Mean track errors ranged from 25 n mi at 12 h to 166 n mi at 120 h, and were between 4% and 23% lower than the 5-yr means. CLIPER5 errors were below their long-term means at 12–36 h but above those values beyond 36 h. After taking into account the higher CLIPER5 errors, forecast skill in 2011 set new records at those longer lead times. Although the forecast skill at 24 and 48 h was lower than in 2010 (not shown), the 2011 values are still the second best on record. An eastward track forecast bias was noted at every forecast time. This bias was considerable, accounting for more than 60% of the total error at 36 h and beyond. Greg and Jova were major contributors to these biases.

Table 4 and Fig. 13, after Cangialosi and Franklin (2012), compares official intensity forecasts for 2011 to the Decay-5-day version of the Statistical Hurricane Intensity Forecast (SHIFOR5; Jarvinen and Neumann 1979; Knaff et al. 2003a) model that serves as a benchmark of intensity forecast skill, as well as the previous 5-yr periods. Average official intensity forecast errors were 7 kt at 12 h and increased to 19 kt by 96 h. The errors were up to 16% lower than the 5-yr means at all times except at 120 h. The SHIFOR5 forecast errors were significantly larger than their 5-yr means, implying that forecast difficulty in 2011 was greater than normal. A review of error and skill trends (not shown) indicates NHC forecast skill in 2011 was slightly below that of 2010, but still quite high compared to historical values. Intensity forecast biases in 2011 were small through 48 h and modestly positive thereafter.

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REFERENCES


