Eastern North Pacific Hurricane Season of 2005

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ABSTRACT

The 2005 eastern North Pacific hurricane season is summarized, the individual tropical cyclones are described, and official track and intensity forecasts are verified and evaluated. The season’s overall activity was, by most measures, below average. While a near-average 15 tropical storms formed, many of them were relatively weak and short-lived. Seven of these storms became hurricanes, but only one reached major hurricane status (an intensity of 100 kt or greater on the Saffir–Simpson hurricane scale) in the eastern North Pacific basin. One of the hurricanes, Adrian, approached Central America in May but weakened to a tropical depression prior to landfall. Adrian was the only eastern North Pacific tropical cyclone to make landfall during 2005, and it was directly responsible for one fatality.

1. Overview

Similar to the preceding two years, tropical cyclone activity in the eastern North Pacific basin (the area north of the equator between the American continents and 140°W longitude) was below average during 2005, especially in terms of hurricanes and major hurricanes [category 3 or stronger on the Saffir–Simpson hurricane scale (Saffir 1973; Simpson 1974)]. Sixteen tropical cyclones formed during the season, and all but one of these cyclones reached tropical storm strength. Seven of the fifteen tropical storms eventually became hurricanes (Table 1, Fig. 1). The corresponding averages during the period 1971–2004 are 15 tropical storms and 9 hurricanes, while the previous 10-yr averages are 13 and 7. Kenneth was the only major hurricane, although Jova reached category 3 intensity in the central Pacific basin (west of 140°W) after having reached category 2 in the eastern Pacific. The occurrence of only one major hurricane is well below the 1971–2004 average of four and the 10-yr (1995–2004) average of three.

A useful measure of the season’s overall activity is the accumulated cyclone energy (ACE) index, which reflects the combined intensity and duration of the entire season’s storms. It is calculated by summing the squares of the 6-hourly intensities (maximum sustained surface winds in knots) of all tropical cyclones while at tropical storm or hurricane strength. The ACE index during 2005 in the eastern North Pacific was 75 (units are 10^4 kt^2) or about 66% of the long-term (1971–2004) mean value of 114. The 2005 ACE value is the ninth-lowest since 1971 (when reliable tropical storm and hurricane data began in the basin), although the values for 2003 and 2004 are even lower. The relatively low ACE value shows that, while the total numbers of tropical storms and hurricanes were not drastically different from their corresponding long-term averages, many of the storms were relatively weak and short lived. The 2005 season extended the period of mostly below-average activity that began in the eastern North Pacific basin in about 1995. In general, cooler-than-average sea surface temperatures (Fig. 2) across much of the basin during the peak months of the 2005 season appear to have contributed to the below-average activity.

The season began early, with the first tropical cyclone forming on 17 May, which is the fourth-earliest tropical cyclone in the basin since 1971. The median date during 1971–2004 for the first tropical cyclone was 29 May. The first cyclone of 2005 became Hurricane Adrian, which was also the only cyclone to make landfall during the season, although it did so as a tropical depression. Despite weakening prior to landfall, Adrian was directly responsible for one fatality in Nicaragua. Following Adrian, a full month passed before the next
The tropical waves, with their focused source of low-level vorticity, propagated into the eastern North Pacific throughout the hurricane season as usual. However, they led to the development of more tropical cyclones during the upper-level divergence phases of the MJO, which provided an environment more conducive for convection. A summary of the life cycle of each of the 2005 season’s tropical cyclones is provided in section 2. Section 3 provides verification statistics on official National Hurricane Center (NHC) forecasts of these cyclones.

2. Tropical cyclone summaries

The individual cyclone summaries in this section are based on NHC’s poststorm meteorological analyses. 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 location, maximum sustained (1-min average) surface wind (10 m) and, minimum sea level pressure. The best track identifies a system as a tropical cyclone at a particular time if NHC determines that it satisfies the following definition: “A warm-core, non-frontal synoptic-scale cyclone, originating over tropical or subtropical waters with organized deep convection and a closed surface wind circulation about a well-defined center” (NWS 2006). The life cycle of each cyclone (corresponding to the dates given in Table 1 for the season’s tropical storms and hurricanes) is defined to include the tropical depression stage, but it does not include the remnant low stage. The tracks for the season’s tropical storms and hurricanes, including their tropical depression and remnant low stages (if applicable), are shown in Fig. 1. Other than for Hurricane Adrian, no damages or casualties were reported in association with any of the tropical cyclones described in this section.

Observations of eastern North Pacific tropical cyclones are mostly limited to satellite data, primarily from the Geostationary Operational Environmental Satellites (GOES). GOES-East and GOES-West provide the visible and infrared imagery that serves as input for intensity estimates via the Dvorak (1984) technique. This imagery is supplemented by occasional microwave satellite data and imagery from National Oceanic and Atmospheric Administration (NOAA) polar-orbiting satellites, Defense Meteorological Satellite Program (DMSP) satellites, the National Aeronautics and Space Administration (NASA) Tropical Rainfall Measuring Mission (TRMM), and the NASA Quick Scatterometer (QuikSCAT). While passive microwave imagery is useful for tracking tropical cyclones and assessing their structure, QuikSCAT retrieves estimates...
FIG. 1. Tropical storms and hurricanes of 2005 in the eastern North Pacific basin.
of ocean surface vector winds across a fairly wide swath, and with careful interpretation it can provide occasional estimates of the location, intensity, and outer wind radii of a tropical cyclone. While aircraft reconnaissance missions into eastern North Pacific tropical cyclones are infrequent, one mission by the 53rd Weather Reconnaissance Squadron of the United States Air Force Reserve Command was conducted during Hurricane Adrian, because of the storm’s proximity to Central America.

### a. Hurricane Adrian, 17–21 May

Hurricane Adrian was a very early season tropical cyclone that moved east-northeastward. Adrian was briefly a category 1 hurricane as it approached Central America but then weakened just offshore of El Salvador. It later made landfall as a tropical depression on the Pacific coast of Honduras via the Gulf of Fonseca. Adrian caused heavy rains, floods, and mud slides in portions of Central America. One fatality directly attributable to Adrian was reported in Nicaragua. No other eastern Pacific hurricane has come closer to El Salvador in at least 57 yr.

#### 1) SYNOPTIC HISTORY

As is often the case with early season tropical cyclones in the eastern North Pacific basin, the incipient weather systems leading to the formation of Adrian were relatively weak and difficult to track until just before reaching the area of genesis. Disorganized areas of disturbed weather moved westward from Central America during 10–14 May, perhaps aiding in the development of a broad and nearly stationary area of low pressure centered about 450 n mi south-southeast of Acapulco, Mexico. While convection within this broad low gradually consolidated on 15–16 May, another disturbance crossed Central America on 15 May. Analysis of satellite imagery indicates the latter disturbance can be traced back to a poorly defined tropical wave that crossed northern South America during 11–13 May. As this wave moved westward over the eastern Pacific into the area of the nearly stationary low on 16 May, convective organization within the low increased further. Dvorak classifications began late on 16 May as the low began drifting east-northeastward. A tropical depression is estimated to have formed from these systems at 1800 UTC 17 May about 400 n mi west-southwest of El Salvador.

Adrian did not follow the typical westward-to-northwestward track of most eastern North Pacific tropical cyclones. Rather, it moved generally toward the east-northeast throughout its lifetime in advance of an unusually strong mid- to upper-level trough that extended over Mexico and the extreme eastern Pacific Ocean. Following genesis, the depression initially moved very slowly, about 4 kt, while strengthening to a tropical storm by 0000 UTC 18 May. Adrian gradually...
gained additional strength on 18–19 May while moving at 7–8 kt in an environment of moderate southwesterly vertical wind shear. During this period, convective bands away from the center dissipated, while convection became more concentrated in a small area near the center. Adrian was briefly a hurricane with an estimated intensity of 70 kt near 1800 UTC 19 May about 75 n mi southwest of the coast of El Salvador. Operationally, Adrian was assessed to have made landfall on the coast of El Salvador near 0600 UTC 20 May as a category 1 hurricane. Poststorm analysis reveals, however, that shortly after Adrian reached hurricane status offshore, increasing southwesterly vertical wind shear led to its abrupt weakening, and that the low-level center turned toward the east and never made landfall in El Salvador. The nearly perpendicular approach of Adrian toward the mountain ranges of Central America might have enhanced the effects of the vertical wind shear by limiting the northeastward motion of the low-level portion of the tropical cyclone. While it appears that a midlevel circulation center accompanied the strong convection that continued north-northeastward and passed over El Salvador early on 20 May, the low-level center moved eastward and roughly parallel to the El Salvador coast. Adrian weakened to a tropical storm with maximum sustained winds of 35 kt by 1200 UTC 20 May when it was centered about 30 n mi offshore from eastern El Salvador. Further weakening ensued and the center of the tropical depression entered the Gulf of Fonseca at about 1800 UTC 20 May and moved inland over Honduras around 2100 UTC. The circulation dissipated within a few hours after moving inland.

As a hurricane, the center of Adrian made the closest approach to El Salvador (approximately 75 n mi) of any eastern North Pacific hurricane in the available records since 1949. The next closest were an unnamed hurricane in 1954 and Hurricane Olivia (1971), both of which became hurricanes about 100 n mi west-southwest of El Salvador and were moving westward. Since the center of Adrian did not make landfall on the coast of El Salvador, Andres (1997) remains the only landfall in that country since 1949, and it did so as a tropical depression (Lawrence 1999). Adrian was only the third eastern Pacific tropical cyclone since 1949 to make landfall in Central America; all were depressions at landfall including Paul (1982) in Guatemala.

2) METEOROLOGICAL STATISTICS

The significant changes in Adrian on 19 and 20 May were challenging to diagnose both operationally and in poststorm analysis even given more data than usual, including aircraft reconnaissance, for an eastern North Pacific hurricane. Passive microwave imagery at 1238 UTC 19 May from the Special Sensor Microwave Imager (SSM/I) (not shown) depicted inner-core convective banding, suggesting, along with Dvorak classifications, that Adrian was nearing hurricane intensity. Later, the one U.S. Air Force Reserve reconnaissance flight into Adrian during the early afternoon of 19 May indicated that it had become a hurricane. At 1830 UTC
that day the aircraft measured maximum 850-mb flight-level winds of 92 kt. The standard 80% reduction of this observation would yield about 75 kt at the surface. This peak measurement was somewhat isolated, however, and 75 kt might not be representative of the maximum sustained surface wind, so the peak best-track intensity is 70 kt at 1800 UTC 19 May. A slight rise in central pressure measurements between the two aircraft fixes that day (from 982 mb at 1655 UTC to 984 mb at 1830 UTC) might have been an early sign of the subsequent weakening of Adrian. Also, the second aircraft fix was due east of the first by about 7 n mi, which was possibly an initial indication of the turn of the low-level center toward the east that has been analyzed based on several other sources of data from the following 24 h. The aircraft fixes and subsequent microwave and GOES imagery (Fig. 4) strongly suggest that the low-level circulation of the weakening tropical cyclone remained offshore early on 20 May and made landfall east of El Salvador later that day.

Surface observations, some of which were received after the event, also show that the low-level circulation center passed south of the El Salvador coast, and no direct evidence could be found for a landfalling circulation center in El Salvador. The only reports of winds of tropical storm force from land stations were in gusts very early on 20 May, when the center of Adrian was about 40 n mi south of the coast. The meteorological service of El Salvador, Servicio Nacional de Estudios Territoriales (SNET), indicated a gust to 38 kt was reported at 0500 UTC 20 May at the El Salvador International Airport (just inland from the central coast), and that a gust to 42 kt was reported at 0600 UTC at San Miguel (well inland in eastern El Salvador at an elevation of 80 m). Sustained winds of tropical storm force, as strong as 43 kt, were observed near 0400 UTC 20 May by the cruising yacht SV Carina that was anchored along the central coast of El Salvador near Bahia del Sol. Additionally, the wind directions from SV Carina were consistent with the conclusion that the center of Adrian remained offshore from El Salvador.

The hydrological service of SNET in El Salvador reported that Adrian produced storm total rainfall of at least 4 in. throughout most of the eastern two-thirds of that country, with isolated maxima to 16 in. in the mountainous terrain.
3) Casualty and Damage Statistics

Media reports indicate as many as 23,000 people in El Salvador were evacuated from the coast and from inland flood-prone areas. Smaller-scale evacuations were reported in Guatemala and Nicaragua. Widespread floods, many washed-out roads, and some mudslides were reported in El Salvador and Honduras. Floods were also reported in portions of Nicaragua and Guatemala. One fatality directly attributable to Adrian, due to flooding, was reported in Nicaragua. Reports from SNET indicate that wind damage in El Salvador was not substantial and was limited to some downed trees and power outages. Media reports reveal that widely scattered and mostly minor damage to homes was caused by Adrian in El Salvador and Honduras.

4) Warnings

Even though it has been determined in poststorm analysis that Adrian did not make landfall as a hurricane in El Salvador as assessed operationally, the hurricane and tropical storm watches and warnings issued on 18 and 19 May were justifiable, given the data and forecast guidance available at the time they were issued. These watches and warnings invoked prudent preparations to protect lives and property in many areas including El Salvador, which was affected by heavy rains, flooding, and mudslides and by winds of tropical storm force (at least in gusts).

b. Tropical Storm Beatriz, 21–24 June

The origin of Beatriz can be traced in part to a tropical wave that crossed the coast of Africa on 8 June and entered the eastern North Pacific basin on 17 June. Ahead of the wave, a persistent broad area of low pressure, with a number of embedded convective disturbances, had been centered over extreme southeastern Mexico. One such disturbance moved southward across Mexico and entered the Gulf of Tehuantepec on 17 June. Convection associated with this area increased south of the Gulf of Tehuantepec the following day and the disturbance began to move slowly westward and weaken. Meanwhile, the tropical wave was continuing westward and by 20 June it was not possible to distinguish between the two systems. Convective organization of the combined system increased late on 20 June, and it is estimated that a tropical depression had formed by 1800 UTC the next day, about 240 n mi south of Zihuatanejo, Mexico.

The depression moved toward the west-northwest along the southern extent of a midlevel anticyclone over the southwestern United States. The depression’s elongated convective pattern slowly consolidated, and the system reached tropical storm strength by 1200 UTC 22 June, about 250 n mi south of Manzanillo, Mexico. There was little additional development, with easterly vertical wind shear largely keeping the circulation center and convection apart. The thermodynamic environment may not have been particularly favorable either, as evidenced by the modest amounts of convection generated by the cyclone during its lifetime. The storm’s peak intensity of 45 kt was reached by 0000 UTC 23 June. Late on 23 June the cyclone crossed the 26°C sea surface temperature isotherm, and it weakened to a depression by 0000 UTC 24 June. Six hours later the system had lost all deep convection and had become a remnant low about 250 n mi south-southwest of Cabo San Lucas, Mexico. Decoupled from the mid- and upper-level easterly flow, the remnant circulation slowed and turned southward before dissipating two days later.

c. Tropical Storm Calvin, 26–29 June

Calvin formed from a tropical wave that emerged from the west coast of Africa on 11 June. The wave moved westward with little associated shower activity until it reached the southwestern Caribbean Sea on 19 June. The associated convection increased during 20–21 June while the wave crossed Central America into the eastern Pacific. By 24–25 June, the wave was passing south of the Gulf of Tehuantepec and the convection was showing increasing organization. It is estimated that a tropical depression formed around 0600 UTC 26 June about 285 n mi south-southeast of Acapulco.

The depression initially moved north-northwestward, and it intensified into a tropical storm later that day. Calvin turned west-northwestward on 27 June while reaching an estimated peak intensity of 45 kt. On 28 June, the cyclone made a gradual turn toward the west-southwest and weakened as easterly vertical wind shear separated the convection from the low-level center. Calvin became a depression that day, and it degenerated to a remnant low on 29 June as it turned westward. The low turned west-northwestward on 30 June as a transient redevelopment of convection occurred—one that lacked sufficient organization or longevity to again designate Calvin a tropical cyclone. The low moved northwestward with some acceleration on 1 July and then turned westward on the south side of a strong low-level ridge on 2 July. The low dissipated on 3 July about 680 n mi west-southwest of Cabo San Lucas.

d. Tropical Storm Dora, 4–6 July

The tropical wave that ultimately spawned Dora moved off the west coast of Africa on 18 June. The
wave moved westward for the next couple of weeks and remained essentially devoid of any deep convection. On 1 July, the wave reached Central America, at which time deep convection began to develop. By 3 July, a broad surface low pressure system had developed along the wave axis over the Gulf of Tehuantepec. By 0000 UTC 4 July, the system had acquired enough convective organization to be designated a tropical depression about 125 n mi south of Acapulco.

The system had been moving westward prior to genesis, but the newly formed depression abruptly turned northwestward on 4 July as a shortwave trough over northern Mexico amplified southward and weakened the subtropical ridge to the north of the cyclone. This flow pattern also enhanced the upper-level outflow to the north and the cyclone intensified into a tropical storm just 6 h later. It reached its peak intensity of 40 kt by 1200 UTC that same day. By 0000 UTC 5 July, Dora began moving west-northwestward and the center passed about 40 n mi south-southeast of Zihuatanejo around 0300 UTC. By late that day, the ridge to the north of Dora restrengthened and induced a more westward track. The cyclone weakened to a depression at 1800 UTC that day about 65 n mi west-southwest of Manzanillo. Dora degenerated into a nonconvective low pressure system early on 6 July, and the low finally dissipated by 1800 UTC about 220 n mi west of Manzanillo.

e. Tropical Storm Eugene, 18–20 July

A tropical wave that entered the Caribbean Sea on 10 July probably spawned Eugene. This system continued westward and entered the eastern North Pacific basin by 14 July. Deep convection associated with the wave was disorganized as it moved generally westward to the south of Mexico. By 17 July, cloudiness became consolidated a few hundred miles to the south-southeast of Manzanillo, and Dvorak classifications were initiated around 0000 UTC 18 July. Over the next several hours, deep convection became more concentrated and some banding features formed. It is estimated that the system developed into a tropical depression around 0600 UTC 18 July while centered about 265 n mi south of Manzanillo. Organization of the cloud pattern increased, and the system strengthened into a tropical storm 6 h later. Vertical wind shear was weak and sea surface temperatures were greater than 27°C, and these factors enabled the storm to gradually strengthen over the next day or so.

A midlevel ridge over Mexico contributed to a steering current that directed the tropical storm on a northwestward heading, roughly parallel to the coast of Mexico, throughout its existence. Eugene reached its estimated peak intensity of 60 kt at 1800 UTC 19 July while centered about 180 n mi west-southwest of Cabo Corrientes, Mexico. Eugene was beginning to encounter cooler waters by this time, however, and a weakening trend was underway by 0000 UTC 20 July. As it passed about 100 n mi to the southwest of Cabo San Lucas later that day, the cyclone weakened to a tropical depression. Eugene continued to weaken and by 0000 UTC 21 July it had degenerated to a swirl of low clouds with little or no deep convection. The remnant low continued northwestward for another day and lost its identity around 0000 UTC 22 July.

f. Hurricane Fernanda, 9–16 August

Fernanda developed from a tropical wave that crossed the west coast of Africa on 25 July. The wave was well defined in upper-air data and was accompanied by a large area of thunderstorms. It was easily identified in satellite imagery as it moved westward across the tropical Atlantic, and it appeared to be developing as it crossed the Windward Islands on 31 July. The development ceased, however, when the system moved over northern South America. The westward-moving tropical wave crossed Central America and convection gradually redeveloped south of the Gulf of Tehuantepec on 5 August. The wave continued westward, and it was not until 1200 UTC 9 August that the thunderstorm activity became sufficiently organized to classify the system as a tropical depression.

The convective pattern continued to become better organized, and by 0000 UTC 10 August the system had become a tropical storm. The cyclone continued on a general westward to west-northwestward track and reached hurricane status at 0600 UTC 11 August. Slight intensification followed, and Fernanda developed a ragged eye on 12 August (Fig. 5). It reached its peak intensity of 75 kt and a minimum central pressure of 978 mb at 1200 that day. Fernanda changed little in intensity during the next day and a half, and thereafter the northern half of the circulation moved over cooler waters, resulting in gradual weakening. Fernanda began to move toward the west-southwest around a very strong subtropical ridge, toward warmer waters, and the thunderstorm activity temporarily increased. However, the cyclone was embedded within a dry and stable environment, as discerned from water vapor satellite imagery, and the deep convection did not persist. The cyclone became a depression at 1800 UTC 15 August and then weakened to a remnant low at 0600 UTC 16 August. The low continued moving toward the west-southwest, still producing intermittent convection until dissipating the next day.
The genesis of Greg appears to have been associated with a tropical wave that crossed the west coast of Africa on 27 July. While it was difficult to track in satellite imagery as it passed over the Caribbean Sea and northern South America, upper-air data suggest the wave crossed Central America and entered the eastern North Pacific basin on 6 August. Its convective organization remained minimal for the next few days as it proceeded westward. The system eventually became better organized on 10 August and was given its first Dvorak classifications at 1800 UTC. The disturbance developed quickly on the morning of 11 August, and it is estimated to have become a tropical depression by 0600 UTC that day about 600 n mi south of Cabo San Lucas.

The depression moved slowly west-northwestward on 11 August along the southern periphery of a weak midlevel ridge centered near the Baja California peninsula. Despite some modest northerly vertical wind shear associated with outflow from Hurricane Fernanda to its northwest, the depression strengthened to a tropical storm by 1200 UTC that day. It then reached its peak intensity of 45 kt at 0000 UTC 12 August while centered about 560 n mi south of Cabo San Lucas.

The midlevel ridge pushed Greg westward early on 12 August. Later that day, steering currents weakened and Greg began to move very slowly northwestward. Northerly vertical wind shear increased due to a combination of the upper-level anticyclone over Fernanda and an upper-level trough over Baja California, and Greg weakened to an intensity of 35 kt by 0000 UTC 13 August. Deep convection was sporadic that day, but Greg remained a tropical storm while moving slowly westward. By early on 14 August, a lower- to midtropospheric ridge had strengthened in between Fernanda and Greg, and a new surface low pressure system had developed to the east of Greg near the coast of Mexico. In response, Greg moved in a general southward direction, but the steering currents were weak, and Greg became essentially stationary late on 14 August about 600 n mi southwest of Cabo San Lucas. Meanwhile, strong upper-level easterly winds had increased the vertical wind shear over the tropical storm on 14 August, and Greg weakened to a depression by 1800 UTC that day. The depression resumed a slow motion toward the south-southwest, and degenerated to a remnant low by 0000 UTC 16 August. The remnant low was absorbed into the intertropical convergence zone (ITCZ) less than 24 h later.

h. Hurricane Hilary, 19–25 August

The tropical wave involved in the genesis of Hilary moved across the west coast of Africa on 4 August. At that time the wave was associated with a large amount of deep convection, but the convection quickly diminished over the eastern tropical Atlantic. The wave moved westward without development, crossing north-
ern South America and entering the eastern North Pacific basin on 17 August. By the following day a well-defined midlevel circulation had developed within the wave along with some banded convection south of Guatemala. The convective organization continued to increase, but the system was slow to develop a well-defined surface center of circulation. It is estimated that the system finally did so near 1800 UTC 19 August, becoming a tropical depression about 140 n mi south of Puerto Angel, Mexico.

Embedded within a deep easterly current to the south of the subtropical ridge, the depression initially moved westward at near 15 kt. It strengthened briskly, becoming a tropical storm by 0600 UTC 20 August when centered about 190 n mi south of Acapulco, and a hurricane 18 h later when it was about 290 n mi south of Manzanillo. A weakness in the subtropical ridge allowed the forward motion to slow and Hilary turned toward the northwest on 21 August. The pace of intensification also briefly relaxed during this time, but late that day Hilary turned back to the west-northwest at a faster forward speed and strengthened again, reaching its peak intensity of 90 kt near 0000 UTC 22 August (Fig. 6). This strengthening was accompanied by an expansion of the wind field that briefly brought winds of minimal tropical storm force to the Mexican coast in the Manzanillo area late on 21 August.

On 22 August, Hilary’s motion slowed abruptly and the hurricane’s deep convection began to diminish, particularly in the northern semicircle which was over cooler waters. Moving slowly to the west-northwest and northwest, Hilary gradually weakened over the next couple of days, becoming a tropical storm by 1800 UTC 24 August when it was about 435 n mi west of Cabo San Lucas, and a tropical depression 24 h later. The system had lost the requisite convection of a tropical cyclone by 0000 UTC 26 August. Hilary’s remnant low moved generally westward before dissipating early on 28 August about 1075 n mi west-northwest of Cabo San Lucas.

i. Tropical Storm Irwin, 25–28 August

Irwin likely originated from the southern portion of the tropical wave whose northern vorticity maximum helped spawn Hurricane Katrina in the Atlantic. This wave emerged from the coast of Africa on 10 August. It moved westward with little development until 19 August, when the northern portion of the wave encountered a midlevel vorticity center associated with the remnants of Atlantic tropical depression 10 north of the Leeward Islands. This interaction eventually led to the development of Katrina. The southern portion of the wave continued westward and crossed Central America into the eastern North Pacific basin on 22 August. Shower activity associated with the wave increased on 23 August and showed signs of increased organization on 24 August. It is estimated that a tropical depression
formed from the wave near 1200 UTC 25 August about 135 n mi south of Manzanillo.

The depression moved westward on the south side of a low- to midlevel ridge and intensified. It became a tropical storm early on 26 August, and the storm reached an estimated peak intensity of 45 kt later that day. Easterly vertical wind shear on the southern periphery of a deep-layer ridge extending westward from Mexico caused the cyclone to weaken thereaf er, with Irwin returning to a depression early on 28 August. The cyclone became a nonconvective remnant low later that day about 490 n mi southwest of Cabo San Lucas. The remnant low moved westward until 1 September when it turned southwestward. This motion continued until dissipation on 3 September.

j. Hurricane Jova, 12–24 September

The tropical wave that spawned Hurricane Jova moved off the west coast of Africa on 28 August. A well-defined low pressure system formed along the northern portion of the wave by 30 August about 500 n mi west-southwest of the Cape Verde Islands. That system broke away, moved northwestward, and became Hurricane Maria in the Atlantic basin. The southern portion of the wave continued westward for the next five days and emerged over the extreme eastern North Pacific Ocean on 4 September. A broad surface low pressure area developed along the wave axis by 7 September, and associated thunderstorm activity increased about 400 n mi south of Acapulco. The low moved west-northwestward at about 10 kt for the next few days, accompanied by little change in organization. Convective organization increased late on 11 September, however, and it is estimated that the system became a tropical depression at about 0000 UTC 12 September about 550 n mi south-southwest of Cabo San Lucas.

The depression moved generally westward for the next three days while under the influence of moderate easterly vertical wind shear. This shear limited the strengthening process and the cyclone did not become a tropical storm until 0000 UTC 15 September. It then moved west-southwestward and intensified at a much faster rate, becoming a hurricane by 0600 UTC 16 September about 1475 n mi west-southwest of Cabo San Lucas. Jova then experienced several intensity fluctuations but generally strengthened over the next four days and became a major hurricane on 18 September after crossing 140°W longitude. After moving into the central Pacific basin, Jova (Fig. 7) made a sharp northwestward turn as it moved toward a large weakness in the subtropical ridge to its northwest. The hurricane reached its peak intensity of 110 kt at 0000 UTC 20 September about 700 n mi east-southeast of Hilo, Ha-

Fig. 7. GOES-10 visible image at 0000 UTC 19 Sep 2005. Hurricane Jova (left) had an intensity of 90 kt at this time, just after crossing 140°W longitude into the central Pacific basin. Hurricane Kenneth (center), was at its peak intensity of 115 kt (category 4 on the Saffir–Simpson hurricane scale), and Max (right) had just become a tropical storm with an intensity of 35 kt; Max reached hurricane strength about 24 h later.
waii. Gradual weakening began shortly thereafter as the cyclone moved over decreasing sea surface temperatures. The long track over cooler waters steadily took its toll on Jova, and the cyclone weakened to a tropical storm late on 22 September about 350 n mi east-northeast of Hilo. Jova became a tropical depression about 24 h later, and the remnant circulation dissipated about 260 n mi north of Hilo early on 25 September.

k. Hurricane Kenneth, 14–30 September

The origin of this long-lived tropical cyclone can possibly be traced back to a tropical wave that crossed southern Central America and entered the eastern North Pacific basin by 9 September. This system moved westward within the ITCZ for several days, and on 13 September the associated deep convection started showing signs of organization. On 14 September, the cloud pattern became sufficiently well organized to indicate the formation of a tropical depression about 780 n mi southwest of Cabo San Lucas. Kenneth’s motion was controlled largely by variations in the strength of the subtropical ridge to its north. Throughout its life cycle, the tropical cyclone moved mainly westward to west-northwestward, but steering currents weakened on a couple of occasions, leading to a slow and erratic motion.

After formation, the cyclone strengthened and it became a tropical storm around 0600 UTC 15 September. Within an environment of weak vertical wind shear and warm sea surface temperatures, Kenneth strengthened fairly rapidly and became a hurricane by about 0000 UTC 16 September. The hurricane continued to intensify while developing a well-defined eye, and Kenneth reached its peak intensity of 115 kt around 1200 UTC 18 September while located about 1500 n mi east of Hilo; Fig. 7 shows Kenneth at that same intensity about six hours later. Gradual weakening of Kenneth began early on 19 September, due to north-northeasterly vertical wind shear associated with upper-level outflow from Hurricane Jova centered to the west of Kenneth. Steering currents became weak and Kenneth drifted erratically but generally southsouthwestward on 19–20 September. Kenneth weakened to a tropical storm by 1800 UTC 20 September. Stable air evident in water vapor satellite imagery and modest northeasterly vertical wind shear caused additional slow weakening to an intensity of 45 kt around 1800 UTC 21 September. Kenneth’s intensity fluctuated between 45 and 55 kt over the next several days. The environment, however, eventually became conducive enough for the cyclone to regain hurricane strength around 0000 UTC 25 September. Steering currents again weakened, and Kenneth moved slowly south-southwestward and entered the central Pacific basin by 0600 UTC 26 September, weakening below hurricane strength shortly thereafter.

The cyclone turned toward the northwest while continuing to gradually lose strength in an environment of increasing south-southwesterly vertical wind shear. On 29 September, Kenneth turned toward the west and weakened to a depression as an intensifying upper-level trough in the vicinity of the Hawaiian Islands created a hostile vertical wind shear environment for the tropical cyclone. Kenneth dissipated as it approached Hawai’i on 30 September. The system’s remnants moved near or over the Hawaiian Islands and produced some locally heavy rains there.

l. Tropical Storm Lidia, 17–19 September

During the period from 10 to 15 September, two or three convectively active tropical waves moved into the eastern North Pacific basin from the Caribbean Sea. It is hard to precisely determine which wave triggered short-lived Tropical Storm Lidia, since the waves were close to each other and their associated convection was disorganized. However, the thunderstorm activity of one of these waves became distinct and organized enough to classify the system as a tropical depression at 1200 UTC 17 September. The depression became a tropical storm at 1800 UTC that day with maximum winds of 35 kt about 725 n mi southwest of Cabo San Lucas. Lidia moved little and never gained additional strength. Its cloud pattern became disrupted by the much larger circulation of Tropical Storm Max, which was developing to the northeast of Lidia. The tropical storm then weakened and was absorbed by Max. The cyclone was no longer identifiable by 0600 UTC 19 September.

m. Hurricane Max, 18–22 September

The system that led to the development of Max appears to have been a tropical wave that crossed the west coast of Africa on 4 September. The wave proceeded across the tropical Atlantic without development, passed through the Lesser Antilles on 10 September, and then traversed the Caribbean Sea. The southern portion of the wave crossed Central America on 13 September and entered the eastern North Pacific basin. The area of disturbed weather associated with the wave became large but was disorganized on 14 September to the south of Guatemala. The disturbance remained large during the next few days as it proceeded westward a couple hundred miles off the Pacific coast of Mexico, and convection did not consolidate until 16 September. Early on 18 September, the convective banding became
more evident as the system approached Tropical Storm Lidia, which was nearly stationary about 725 n mi southwest of Cabo San Lucas. Unhindered by the relatively small circulation of Lidia, the larger disturbance approaching from the east gained organization, and it is estimated that the disturbance became a tropical depression by 1200 UTC 18 September about 500 n mi south-southwest of Cabo San Lucas.

The newly formed depression became a tropical storm with estimated maximum sustained winds of 35 kt at about 1800 UTC 18 September. Lidia had weakened to a depression by that time and was being drawn northeastward toward Max. By 0600 UTC 19 September (Fig. 7), Lidia was no longer identifiable, having dissipated within the southern portion of the circulation of Max. Max turned northwestward on 19 September along the southwestern edge of a midlevel ridge extending from Texas westward to Baja California, and the storm steadily strengthened within an environment of weak vertical wind shear. It became a hurricane by 0000 UTC 20 September while centered about 520 n mi southwest of Cabo San Lucas. Continuing northwestward, Max maintained hurricane status for about 24 h. During that time it reached its estimated peak intensity of 75 kt at 1200 UTC 20 September, when satellite imagery depicted a well-defined eye about 25 n mi in diameter. However, by that time the hurricane was beginning to pass over cooler waters. As a result, it abruptly weakened the next day, and the intensity is estimated to have decreased to 45 kt by 1800 UTC 21 September. A weak midlevel ridge to the north of Max then forced the tropical storm westward. Max barely remained a tropical storm at 0600 UTC 22 September, and it lost all deep convection a few hours later. It degenerated to a remnant low by 1800 UTC that day about 700 n mi west of Cabo San Lucas. The remnant low drifted slowly southward for a few days and dissipated on 26 September.

n. Tropical Storm Norma, 23–27 September

Norma originated from a large tropical disturbance that developed south of Manzanillo on 19 September. An elongated area of low pressure formed within the slowly moving disturbance on 21 September, but persistent easterly vertical wind shear helped keep the disturbance from becoming better organized. A number of small, low-level vortices were observed rotating within a broader cyclonic envelope on 21 and 22 September. One particularly well-defined vortex spun out of the southeastern edge of the deep convection early on 22 September and spent most of the day executing a loop to the east of the convection. Continuing its loop, the vortex then reentered the convection near 0000 UTC 23 September. Within a couple of hours, convection in the area increased markedly and no other small vortices were discernible. It is estimated that the improved organization of the system that occurred around 0000 UTC represented the formation of a tropical depression.

A weak midlevel ridge to the north and east of the cyclone provided an initial steering current toward the west-northwest. The depression strengthened to a tropical storm about 475 n mi south of Cabo San Lucas by 1200 UTC 23 September. With its center of circulation remaining near the eastern side of the deep convection because of easterly vertical wind shear, Norma continued to slowly strengthen while it turned northwestward the following day. An increase in organization occurred near midday on 24 September when the center became more embedded within the convection and some banding features developed. Norma reached its estimated peak intensity of 50 kt at 1800 UTC, but by late in the day the circulation center became exposed and the convection weakened. A large upper-level ridge to the north of Norma maintained easterly vertical wind shear over the cyclone, from which Norma never recovered. Norma continued northwestward while gradually weakening, becoming a depression at 1800 UTC 26 September. Early the next day Norma crossed the 26°C isotherm and deep convection diminished. Norma degenerated to a remnant low near 1800 UTC 27 September about 410 n mi west of Cabo San Lucas. The remnant low survived for several more days before dissipating on 1 October about 600 n mi west-southwest of Cabo San Lucas.

o. Hurricane Otis, 28 September–3 October

Otis might have formed from the tropical wave that spawned Hurricane Philippe in the Atlantic. The wave emerged from the coast of Africa on 9 September and moved westward across the Atlantic with little development until 14 September. At that time, convection began increasing in both coverage and organization, which eventually resulted in the formation of Philippe on 14 September. The weak southern portion of the wave continued westward near the coast of South America, reaching the eastern North Pacific basin on 22 September. Convection associated with the wave increased on 23 September as it moved near the west coast of southern Mexico. The system showed signs of convective organization on 27 September, and it is estimated that a tropical depression formed around 0000 UTC 28 September about 120 n mi south of Manzanillo.

The depression initially drifted west-southwestward, and then it turned northwestward on 29 September while strengthening into a tropical storm. Otis contin-
ued moving northwestward until 2 October, becoming a hurricane on 30 September (Fig. 8) and reaching an estimated peak intensity of 90 kt on 1 October. The already-weak steering currents weakened further on 2–3 October as Otis missed a connection with a mid-to-upper-level trough passing to the north. This resulted in an erratic north-northwestward drift on 3–4 October close to the Pacific coast of the Baja California peninsula. Otis weakened over cooler sea surface temperatures during this time, becoming a tropical storm on 2 October and a depression the following day. The cyclone weakened to a nonconvective remnant low on 4 October. This low drifted southeastward until it dissipated on 5 October.

p. Tropical Depression Sixteen-E, 15–20 October

A tropical wave moved off the west coast of Africa on 28 September and emerged over the eastern North Pacific Ocean on 13 October. Satellite classifications were initiated at 0000 UTC 14 October, and it is estimated that a tropical depression formed at 0000 UTC 15 October about 360 n mi south of Acapulco (not shown in Table 1 or Fig. 1, which only show systems that reached tropical storm and hurricane status). The depression moved generally westward to west-northwestward along the southern extent of the subtropical ridge centered over Mexico. Deep convection persisted near the low-level center until increasing northeasterly vertical wind shear displaced the convection to the west of the center on 16 October. The cyclone degenerated into a remnant low pressure system late on 18 October, and the low moved westward with the low-level easterly flow for the next 24 h. On 19 October, thunderstorm activity redeveloped and again became sufficiently organized for the cyclone to be classified as a tropical depression about 675 n mi southwest of Cabo San Lucas. However, because of a combination of southeasterly vertical wind shear and dry midtropospheric air, weakening ensued and the system again degenerated into a remnant low by 1800 UTC 20 October. The low turned southwestward and was absorbed back into the ITCZ on 21 October about 800 n mi southwest of Cabo San Lucas.

3. Forecast verifications

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 fore-
casts are evaluated using the post-season 6-hourly best-track database for all tropical cyclones (including tropical depressions). The track error is defined as the great-circle distance between forecast and best-track positions of the tropical cyclone center, and the intensity error is the absolute value of the difference between the forecast and best-track intensities.

Table 2 (Franklin 2006) compares the 2005 and long-term mean track forecast errors for the official forecasts and the 5-day version of the original Climatology and Persistence (CLIPER) model (CLIPER5; Neumann 1972 and Aberson 1998) forecasts. CLIPER5 serves as a benchmark of track forecast skill. The long-term means for forecasts at 12–72 h are based on the 10-yr period 1995–2004, while at 96 and 120 h they are based on the period 2001–04 (these longer-range forecasts were not made prior to 2001). The official track forecast errors during 2005 set new record lows at all official forecast lead times from 36 to 120 h. The errors were 11%–36% lower than the long-term means at 12–72 h, and they were 34%–38% lower than the multiyear means at 96 and 120 h, although most of these longer-range forecasts were from just two storms (Kenneth and Jova). The 2005 CLIPER5 track errors were slightly smaller than the long-term mean CLIPER5 errors, indicating that the forecasts during 2005 were perhaps a little less difficult than usual. The official track forecast errors in 2005 were significantly lower than the CLIPER5 errors, however, so the official forecasts were quite skillful, by a margin that grew with increasing lead time. The 2005 official track forecasts were much more skillful than during 2004, and the general trend in skill in this basin

<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>
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<tr>
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<td>53.4</td>
<td>71.7</td>
<td>86.2</td>
<td>112.4</td>
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<td>160.6</td>
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<td>76.3</td>
<td>115.0</td>
<td>149.6</td>
<td>219.0</td>
<td>272.4</td>
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<td>-30</td>
<td>-38</td>
<td>-42</td>
<td>-49</td>
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<td>312/3</td>
<td>307/7</td>
<td>322/16</td>
<td>339/23</td>
<td>013/46</td>
<td>015/55</td>
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<td>263</td>
<td>233</td>
<td>203</td>
<td>177</td>
<td>138</td>
<td>110</td>
<td>89</td>
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<tr>
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<td>37.3</td>
<td>67.8</td>
<td>96.9</td>
<td>122.8</td>
<td>174.5</td>
<td>208.3</td>
<td>259.1</td>
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<td>162.5</td>
<td>236.3</td>
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<td>-21</td>
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<td>-26</td>
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<td>324/5</td>
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<tr>
<td>1995–2004 number of cases</td>
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<td>2378</td>
<td>2096</td>
<td>1829</td>
<td>1386</td>
<td>355</td>
<td>224</td>
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<tr>
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* Averages for 96 and 120 h are for the period 2001–04.

Table 3. Homogenous comparison of official and SHIFOR5 intensity forecast errors in the eastern North Pacific basin for the 2005 season for all tropical cyclones. Long-term averages 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>
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<td>11.5</td>
<td>15.2</td>
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<td>19.9</td>
<td>20.0</td>
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<td>-10</td>
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<td>1.0</td>
<td>-1.1</td>
<td>-5.6</td>
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<tr>
<td>2005 number of cases</td>
<td>263</td>
<td>233</td>
<td>203</td>
<td>177</td>
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<td>110</td>
<td>89</td>
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<td>1995–2004 mean official error (kt)*</td>
<td>6.1</td>
<td>10.8</td>
<td>14.3</td>
<td>16.5</td>
<td>18.7</td>
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<tr>
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<td>11.9</td>
<td>15.5</td>
<td>17.9</td>
<td>21.3</td>
<td>20.5</td>
<td>19.3</td>
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<tr>
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<td>-16</td>
<td>-9</td>
<td>-8</td>
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<td>-12</td>
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<tr>
<td>1995–2004 number of cases</td>
<td>2654</td>
<td>2378</td>
<td>2096</td>
<td>1829</td>
<td>1386</td>
<td>355</td>
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<td>2005 official error relative to 1995–2004 mean (%)</td>
<td>-5</td>
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<td>2005 SHIFOR5 error relative to 1995–2004 mean (%)*</td>
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<td>-3</td>
<td>-2</td>
<td>2</td>
<td>-7</td>
<td>-2</td>
<td>-3</td>
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* Averages for 96 and 120 h are for the period 2001–04.
during the past decade appears to be upward (Franklin 2006).

Table 3 (Franklin 2006) is similar to Table 2 but for intensity forecasts, and it compares official forecasts to the 5-day version of the original Statistical Hurricane Intensity Forecast (SHIFOR) model (SHIFOR5; Jarvinen and Neumann 1979) that serves as a benchmark of intensity forecast skill. Official intensity forecasts out to 96 h were somewhat skillful during 2005, based on forecast errors that averaged 4%–16% less than the corresponding 2005 SHIFOR5 errors. However, 120-h official forecast errors were on average 10% larger than the SHIFOR5 errors and were not considered skillful. The 2005 official intensity errors were smaller than the long-term means out to 72 h but were larger than the multiyear means at 96 and 120 h. The official forecasts were biased high beyond 36 h, especially at longer forecast lead times, and they were opposite in sign to the long-term mean bias. Official intensity forecast errors and forecast skill for the eastern North Pacific have not changed appreciably during the past decade (Franklin 2006).

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REFERENCES