NATIONAL HURRICANE CENTER TROPICAL CYCLONE REPORT

HURRICANE PATRICIA

(EP202015)

20 – 24 October 2015

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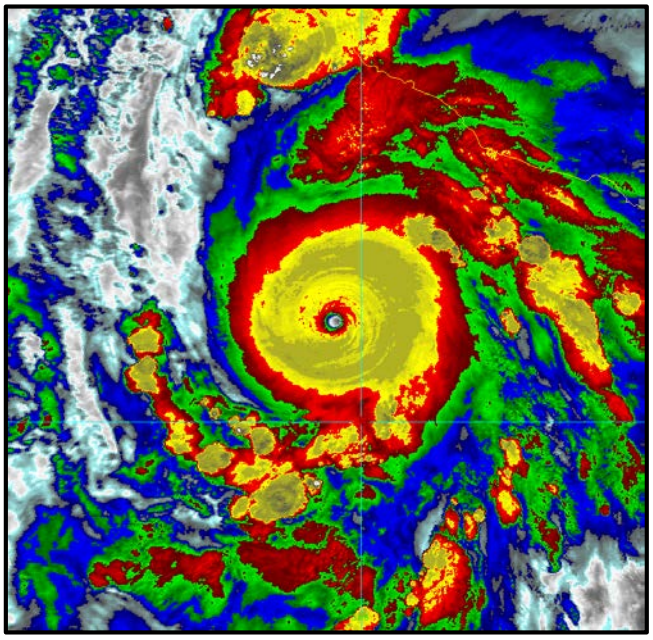

METOP-B ENHANCED INFRARED SATELLITE IMAGE AT 0323 UTC 23 OCTOBER. IMAGE COURTESY CIRA.

Patricia was a late-season major hurricane that intensified at a rate rarely observed in a tropical cyclone. It became a category 5 hurricane (on the Saffir-Simpson Hurricane Wind Scale) over anomalously warm waters to the south of Mexico, and the strongest hurricane on record in the eastern North Pacific and North Atlantic basins. The hurricane turned north-northeastward and weakened substantially before making landfall along a sparsely populated part of the coast of southwestern Mexico as a category 4 hurricane. Patricia produced a narrow swath of severe damage and two direct deaths.

[1] Original report date 1 February 2016. Updated 4 February to correct storm chaser report, peak 24-h pressure fall, Hurricane Linda's peak intensity in Fig. 6, and the date of Hurricane Lane.

Hurricane Patricia

20 – 24 OCTOBER 2015

SYNOPTIC HISTORY

Patricia's development into a tropical cyclone was slow and complicated, involving the interaction of multiple weather systems. A tropical disturbance crossed the southern part of Central America on 11 October, and entered the eastern Pacific the following day several hundred nautical miles south of El Salvador. While this system moved little, a tropical wave was moving westward over the Caribbean Sea, and reached Central America on 15 October. The wave moved into the eastern Pacific the next day and merged with the first disturbance while a Gulf of Tehuantepec gap wind event was occurring. The gap wind event provided an injection of cyclonic vorticity to the merged disturbance (Levine 2012, Holbach and Bourassa 2014), and an elongated area of low pressure formed later that day, extending from the Yucatan Peninsula southward for several hundred miles into the eastern Pacific. Deep convection associated with the large cyclonic gyre increased substantially on 17 October, possibly due to more favorable large-scale conditions associated with the passage of the rising branch of a strong Madden-Julian Oscillation moving eastward across the eastern Pacific.

The system's cloud pattern was gradually becoming better organized while it moved slowly northwestward to a position a few hundred nautical miles south of the Gulf of Tehuantepec on 18 October, where it developed a smaller and better defined circulation. However, a second gap wind event, stronger than the first, began later that day. Although this gap wind event initially had a disruptive effect on the formative tropical cyclone, the low reformed to the northeast later on 19 October on the cyclonic shear side of the strengthening gap wind event. Deep convection associated with the low increased and became well organized by early on 20 October. An ASCAT pass around 0400 UTC 20 October suggested that a small, well-defined circulation had developed underneath the convection within a larger cyclonic envelope elongated from north to south, and it is estimated that a tropical depression finally formed around 0600 UTC that day centered about 180 n mi south-southeast of Salina Cruz, Mexico. The "best track" chart of the tropical cyclone's path is given in Fig. 1, with the wind and pressure histories shown in Figs. 2 and 3, respectively. The best track positions and intensities are listed in Table 1[2].

The depression was located to the south of a mid-level ridge centered over the Gulf of Mexico, extending west-southwestward into the eastern Pacific. The steering provided by this feature and the gap wind event caused the depression to drift west-southwestward while the cyclone gradually strengthened, and the system became a tropical storm 18 h after genesis. By early on 21 October Patricia encountered relatively drier and more stable lower- to middle-tropospheric air, and sea surface temperatures that were at least 2º C lower than the surrounding

[2] A digital record of the complete best track, including wind radii, can be found on line at ftp://ftp.nhc.noaa.gov/atcf. Data for the current year's storms are located in the *btk* directory, while previous years' data are located in the *archive* directory.

region, the result of strong gap winds over a large area extending well to the south of the Isthmus of Tehuantepec. The less favorable thermodynamic environment slowed development, with deep convection temporarily diminishing and cloud-top temperatures warming late on 20 October and early on 21 October. Once Patricia moved outside of the affected region later that morning, however, a rapid increase in deep convection occurred over the low-level center, and a small central dense overcast (CDO) began to form while the storm moved at a faster forward speed toward the west and then the west-northwest. A NOAA Hurricane Hunter aircraft reached Patricia that afternoon and discovered it to already be a 50-kt tropical storm, consistent with the rapid increase in organization of the cloud pattern seen in satellite imagery. A period of rapid intensification had already begun in an environment of very light vertical wind shear, high atmospheric moisture and greater instability over anomalously warm waters, untapped since Hurricane Carlos traversed the region in June. Patricia strengthened into a hurricane shortly after 0000 UTC 22 October while centered about 200 n mi south of Acapulco, Mexico.

Over the next 24 h, Patricia's satellite presentation changed dramatically, as a large band with cloud-top temperatures of -80º to -90º C coiling cyclonically inward over the center evolved into an almost perfectly symmetric CDO around a 10 n mi wide eye. A NOAA plane arrived at the end of this 24-h period around 1800 UTC 22 October, and indicated that Patricia had already reached major hurricane strength, with estimated surface winds of 115 kt and a minimum pressure of 957 mb. The rapid intensification phase continued into the night while Patricia turned northwestward and its forward speed decreased, and satellite imagery indicated that a solid ring of cloud-top temperatures colder than -90º C surrounding a 7 n mi wide eye had formed by 0300 UTC 23 October (cover figure). By the time an Air Force Hurricane Hunter aircraft reached the cyclone around 0600 UTC, Patricia had intensified into an extremely powerful hurricane with maximum sustained winds of 180 kt and a minimum central pressure of around 879 mb. The satellite presentation continued to increase in organization over the next several hours after the plane left, and Patricia is estimated to have reached a peak intensity of 185 kt around 1200 UTC that day while centered about 130 n mi southwest of Manzanillo, Mexico.

Patricia reached the western periphery of the mid-level ridge centered over the Gulf of Mexico around this time and turned north-northwestward and then northward while essentially maintaining its intensity. By the time the last reconnaissance mission reached Patricia around 1800 UTC 23 October, the hurricane had turned north-northeastward with some increase in forward speed, in response to a shortwave trough moving across the Baja California peninsula and northwestern Mexico. Although the aircraft still found surface winds of near 180 kt on its first pass through the storm in the southeastern quadrant, a 2023 UTC Global Precipitation Mission (GPM) overpass indicated a distinct double eyewall structure (Fig. 4), suggestive of an imminent weakening trend. Upper-air analyses also indicated that southwesterly vertical wind shear was gradually increasing over the cyclone, and a final pass by the plane around 2030 UTC indicated that a rapid filling of the cyclone had begun; the peak flight-level winds had decreased nearly 50 kt in the same quadrant traversed earlier and the central pressure had risen 24 mb in the 3 h since the first fix.

Patricia continued to rapidly weaken during the next couple of hours before landfall, and is estimated to have reached the southwestern coast of Mexico in the state of Jalisco, near Playa Cuixmala, around 2300 UTC 23 October with an intensity of 130 kt and a minimum pressure of around 932 mb. The hurricane continued to weaken rapidly during the next several hours while

it moved over the high terrain of the Sierra Madre mountains, and Patricia fell below hurricane strength before passing well to the west of Guadalajara around 0300 UTC 24 October. When the mid-level center raced northeastward and separated from the low-level center overnight, Patricia weakened to a tropical depression. The cyclone dissipated later that morning over central Mexico.

METEOROLOGICAL STATISTICS

Observations in Patricia (Figs. 2 and 3) include subjective satellite-based Dvorak technique intensity estimates from the Tropical Analysis and Forecast Branch (TAFB) and the Satellite Analysis Branch (SAB), and objective Advanced Dvorak Technique (ADT) estimates from the Cooperative Institute for Meteorological Satellite Studies/University of Wisconsin-Madison. Observations also include flight-level, stepped frequency microwave radiometer (SFMR), and dropwindsonde observations from three flights of the 53rd Weather Reconnaissance Squadron of the U. S. Air Force Reserve Command and one NOAA Aircraft Operations Center WP-3D aircraft. A NASA WB-57 aircraft flying at high altitude provided useful dropsonde data on Patricia's intensity on 21 October. Data and imagery from NOAA polar-orbiting satellites including the Advanced Microwave Sounding Unit (AMSU), the NASA Global Precipitation Mission (GPM), the European Space Agency's Advanced Scatterometer (ASCAT), and Defense Meteorological Satellite Program (DMSP) satellites, among others, were also useful in constructing the best track of Patricia.

There were no reliable ship reports of winds of tropical storm force associated with Patricia. Selected surface observations from land stations are given in Table 2.

The highest flight-level wind obtained during Patricia, 192 kt, was measured by an Air Force Reserve Hurricane Hunter aircraft at 0647 UTC 23 October in the northeastern eyewall, and a wind of 191 kt was measured on a NOAA mission at 1734 UTC that day. The maximum SFMR-observed surface wind was 182 kt at 0600 UTC, and a value of 180 kt was measured on the later flight at 1732 UTC (Fig. 5). SFMR data from both flights were reprocessed, and confirmed to be reliable after an evaluation by NOAA Hurricane Research Division staff (Klotz 2015, personal communication). The reprocessing yielded the 180 kt peak value on the NOAA flight, up from 166 kt reported operationally. SFMR winds of comparable values have only once been previously measured in a tropical cyclone (Supertyphoon Megi in 2010). Patricia's peak intensity is estimated to be slightly higher, at 185 kt, since the satellite signature of the storm continued to increase in organization (warmest eye and coldest surrounding cloud-top temperatures) between the two aircraft flights until around 1200 UTC. The 185-kt analyzed peak intensity makes Patricia the strongest hurricane on record in the eastern North Pacific, surpassing Hurricane Linda in 1997 (Fig. 6). Patricia is also the strongest hurricane on record in either the eastern North Pacific or North Atlantic basins. It should be noted, however, that records for the most intense eastern North Pacific hurricanes are particularly uncertain prior to 1988; records for the most extreme North Atlantic hurricanes are considered reliable beginning in the early 1970s at the start of routine monitoring of the basin using satellite and aircraft data.

Patricia's explosive deepening from 22 October to 23 October was remarkable. Over the 24-h period ending at 0600 UTC 23 October, the pressure is estimated to have fallen 95 mb and

the wind to have increased from 75 kt to 180 kt. Over a 2-day period ending at the same time, the winds are estimated to have increased by nearly 150 kt. The 1-day intensification of 105 kt exceeds a 95-kt increase for Hurricane Wilma in 2005 over the western Caribbean Sea. This intensification occurred while Patricia was moving in a very light shear and moist environment while over an expansive region of anomalously warm sea surface temperatures (SSTs) of 30.5ºC to 31º C, which are the highest SSTs ever observed over this region to the south of Mexico in mid-October (Fig. 7).

A pressure of 885 mb was measured by dropsonde at 0646 UTC with splash winds of 57 kt, supporting an estimated minimum pressure of 879 mb. The central pressure was still falling on the last pass through the eye at 0646 UTC (by 7 mb between the last two fixes that were 45 min apart), and it is possible in the hours that followed that Patricia's pressure fell lower than the global record value of 870 mb observed in Supertyphoon Tip in 1979. The lowest central pressure measured by a dropsonde during Patricia was 883 mb at 1733 UTC 23 October. Given surface winds from the dropsonde of 45 kt, Patricia's minimum pressure at that time is also estimated to be 879 mb. In between these two times, a minimum pressure of 872 mb has been assigned to 1200 UTC 23 October, the time of the estimated peak winds. The value of 872 mb was determined from the Knaff-Zehr-Courtney (KZC) pressure-wind relationship (Courtney and Knaff, 2009), which very accurately reproduced the observed reconnaissance pressure-wind data near 0600 and 1800 UTC that day (Fig. 3)[3]. The 872 mb value represents the lowest pressure on record in the western Hemisphere and the second lowest globally. Also of note is the maximum 700-mb temperature of 32.2º C measured by an Air Force reconnaissance aircraft at 1733 UTC, several hours after the time of estimated peak intensity; this is the warmest 700-mb eye temperature ever measured in a tropical cyclone. A pressure gradient of up to 24 mb/n mi was computed from aircraft data on the 0600 UTC mission[4]; this is thought to be one of the steepest pressure gradients recorded in a tropical cyclone.

The remarkably rapid intensification rate was followed by a period of weakening, at an even more rapid rate, beginning around 1800 UTC 23 October. After a pressure of 879 mb was inferred from the dropsonde data at 1733 UTC, the plane made another pass through the center (after some technical difficulties) and launched a dropsonde at 2044 UTC that measured a pressure of 910 mb with 68 kt surface winds; these data support a minimum pressure of around 903 mb at that time, corresponding to a filing rate of about 8 mb/h. There was also a dramatic reduction in the winds measured by the reconnaissance aircraft in Patricia's southeastern quadrant, following the 191-kt flight-level and 180-kt SFMR winds observed near 1733 UTC; the return trip to this quadrant at 2033 UTC found a peak flight-level wind of only 146 kt and a peak SFMR wind of 131 kt.

Patricia made landfall around 2300 UTC along the coast of the Mexican state of Jalisco near Playa Cuixmala, about 45 n mi west-northwest of Manzanillo. Operationally, Patricia was assessed to have been of category 5 intensity with a landfall pressure of 920 mb, but a post-analysis of additional data obtained later suggests that the hurricane had weakened more rapidly

[3] The following inputs were used in the KCZ pressure-wind computation: maximum sustained winds (185 kt), latitude (17.3N), mean radius of tropical-storm-force winds averaged over the four quadrants of the cyclone (110 n mi), cyclone translation speed (8 kt), and the outermost closed isobar (1007 mb).

[4] The estimated pressure change over 1.39 n mi from reconnaissance data was 33.3 mb, or approximately 24 mb per n mi.

than estimated in real time. A minimum pressure of 934.2 mb was observed around 2300 UTC by an automated weather station at Playa Cuixmala, located on the coast near Emiliano Zapata. Although the wind data from this site failed near landfall, a temperature spike to 28° C was recorded, suggesting that the eye passed close to this location. A storm chaser in Emiliano Zapata, a couple of nautical miles inland from the landfall point, measured a minimum pressure of 937.8 mb on the eastern edge of the eye at 2313 UTC with simultaneous winds of near tropical storm force. The automated weather station in Pista, located about a mile north-northeast of Playa Cuixmala, measured a station pressure of 939.4 mb at an elevation of 15 m, which converts to a sea level pressure of 941.0 mb. The wind data for this site indicate that the station never experienced a calm, and thus the winds at the time of the minimum pressure are unknown. A plot of these pressures for comparison is given in Figure 8. A minimum central pressure of 932 mb at landfall is inferred from these data, with the uncertainty of this value likely on the order of 2-3 mb. The 932 mb analyzed landfall pressure is the lowest central pressure for a landfalling Pacific hurricane in Mexico in the historical database.

There were several reports of high winds near or within Patricia's radius of maximum winds; two of these warrant additional discussion. An automated weather station in Chamela, belonging to the Mexican Weather Service (SMN) but operated by the NOAA Hydrometeorological Automated Data Systems (HADS), was located about 10 n mi northwest of Patricia's eye. Although maximum sustained winds from this site were operationally reported to be as high as 161 kt, with a gust of 183 kt, a time series of the wind data from this site indicates higher and unrealistic values. It is not known at what point the data become questionable, however. The site is at an elevation of about 85 m and is surrounded by complex terrain, which could result in local accelerations not representative of the cyclone's sustained wind. In addition, the station was probably located beyond Patricia's small radius of maximum winds, estimated at about 5 n mi from the last reconnaissance flight, on the west or weaker side of the tropical cyclone. Based on these factors, the wind data from Chamela are deemed unreliable for estimating the maximum wind speed. The automated weather station in Pista, a little more than 1 n mi inland from the coast near the point of landfall, reported peak sustained winds of 85 kt between 2230 and 2300 UTC before the anemometer failed.

With no reliable wind measurements near where Patricia made landfall, determining the landfall intensity is challenging. Since there is good confidence in the landfall pressure, however, it is possible to estimate the maximum sustained winds from the central pressure. The KZC pressure-wind relationship, which as noted above captured very precisely the reconnaissance data just a few hours prior to landfall, gives a value of 131 kt for a central pressure of 932 mb.[5] In addition, the Dvorak wind equivalent for the 54-mb filling that occurred from 1800 UTC until landfall is ~50 kt, which implies a landfall intensity of 130 kt. Finally, the modified cyclostrophic balance equation, using the methodology detailed in Willoughby (1993) produces a landfall intensity of 128 kt[6]. Based on these data, the landfall intensity of Patricia is estimated to be 130 kt; this makes Patricia a category 4 hurricane on the Saffir-Simpson Hurricane Wind Scale, the

[5] The remaining inputs for the KZC computation were: latitude (19.4N), radius of tropical-storm-force winds averaged over the four quadrants of the cyclone (110 n mi), cyclone translation speed (13 kt), and the outermost closed isobar (1007 mb).

[6] Input parameters for the modified cyclostrophic computation were central pressure (932 mb) and environmental pressure (1007 mb).

first major hurricane landfall in mainland Mexico since Hurricane Lane in 2006. It should be noted that this estimate of 130 kt is has much less certainty than the landfall pressure estimate.

Patricia is the strongest hurricane on record to affect Mexico in the historical data base extending back to 1949, eclipsing the October 1959 Manzanillo hurricane (recently reassessed to have made landfall at an intensity of 120 kt - see recent discussion at http://hurricanes.gov) and Hurricane Madeline in 1976. However, because of the sparse nature of station observations over Mexico, the reliable record for extreme landfalling Mexican hurricanes is also tied to the availability and interpretation of satellite imagery of these systems, and is thought to be reliable only back to 1988.

Patricia's central pressure is estimated to have risen 54 mb in the 5 h prior to landfall. No other over-water filling rate this large appears in either the Atlantic or eastern North Pacific historical record.

Patricia's estimated intensity after landfall is based on output from the SHIPS Inland-Decay model for higher terrain.

Heavy rains occurred in association with Patricia, especially over or near elevated terrain (Table 2). In general, two to five inches of rain occurred at sites at lower elevation, with amounts not overly heavy due to the storm's acceleration. However, rainfall accumulations of about 8 to 13 inches occurred over mountainous terrain, with Nevado Colima in Jalisco reporting a storm total rainfall of 12.50 inches (318 mm).

CASUALTY AND DAMAGE STATISTICS

Press reports indicate that there were two direct deaths[7] attributed to Patricia. Two women, one from Argentina and the other from Coahuila, Mexico, were crushed when a tree fell on them at a campsite in the Tapalpa forest in Jalisco. Apparently, the camping party of which they were a part was unaware of the hurricane. There were four indirect deaths associated with the storm, when four passengers were killed in an automobile accident on the Colima-Guadalajara highway during heavy rains and strong winds associated with the storm.

Patricia battered a sparsely populated and rural area of the southwestern coast of Mexico in Jalisco, nearly midway between Manzanillo and Puerto Vallarta. A joint survey conducted by CONAGUA and the United States National Weather Service after the storm indicated that Patricia produced a narrow swath of severe damage along and just inland from the coast near where the hurricane made landfall. The villages of Emiliano Zapata and Chamela sustained the worst damage, according to press reports and eyewitness accounts. Strong winds tore roofs off of homes and businesses, uprooted, snapped and defoliated nearly all trees (Fig. 9), and left the

[7] Deaths occurring as a direct result of the forces of the tropical cyclone are referred to as "direct" deaths. These would include those persons who drowned in storm surge, rough seas, rip currents, and freshwater floods. Direct deaths also include casualties resulting from lightning and wind-related events (e.g., collapsing structures). Deaths occurring from such factors as heart attacks, house fires, electrocutions from downed power lines, vehicle accidents on wet roads, etc., are considered "indirect" deaths.

hillsides stripped of vegetation. Concrete power poles and transmission lines were also toppled, communication towers were crumpled, and most structures in these small towns were tremendously damaged or destroyed (Fig. 10). The small fishing villages of El Melaque, El Estrecho, and La Manzanilla to the southeast of the landfall location were also badly affected. Overall, more than 10,000 homes were damaged or destroyed by Patricia, with the majority of these in Jalisco. The damage to the agricultural sector was also considerable; about 100,000 acres of farmland were severely affected, with the primary losses to the papaya, banana, and plantain crops.

Heavy rains associated with Patricia caused severe flooding in some areas, especially near or over elevated terrain. Some of the heavy rains extended well to the southeast of Patricia's track in the Mexican state of Michoacán. The Marabasco River in this area overflowed its banks in El Rebalse, resulting in water that was reported to be chest high. The high water made many roads impassable and isolated nearby communities. Flood waters damaged several hundred houses in Coahuayana, and Highway 200 was reported to be temporarily shut down.

Large swells associated with Patricia caused significant coastal flooding for several days that resulted in beach erosion and damage to some structures in the Mexican states from Jalisco to Guerrero.

According to media reports, the preliminary damage from Patricia is estimated to be 5.4 billion Mexican pesos (~325 million USD).

FORECAST AND WARNING CRITIQUE

The genesis of Patricia was well forecast, especially in the extended-range portion of the Tropical Weather Outlook (TWO) (Table 3). Patricia's precursor disturbance was introduced in the 5-day portion of the TWO 150 h prior to genesis, and the genesis probabilities reached the medium (40 – 60%) and high (greater than 60%) categories 132 h and 96 h before tropical cyclone formation, respectively. NHC's genesis forecasts benefited from the strong signal in global models five or more days in advance that tropical cyclone formation would occur over the eastern portion of the eastern Pacific basin. However, the GFS and ECMWF models generally forecast Patricia's genesis too soon. Official genesis forecasts over the short-range (48-h period) were not as good since gauging the effects of a gap wind event on the potential for genesis in the short range was difficult. As a result, the precursor disturbance was not given a high chance of tropical cyclone formation until 12 h prior to genesis.

A verification of NHC official track forecasts for Patricia is given in Table 4a. Official forecast track errors were greater than the mean official errors for the previous 5-yr period at all times through 96 h, though the sample size after 72 h is very small. Early track forecasts were considerably east of the best track, and the official forecast only converged to the actual track by 0000 UTC 22 October. A homogeneous comparison of the official track errors with selected guidance models is given in Table 4b. The FSU Superensemble was the most accurate of all the track guidance, beating the official forecast at all times. The variable multi-model and corrected consensus aids (TVCE and TCON) also outperformed the official forecast. Several other models

did well relative to the official forecast at various forecast lead times, with the GFS and GFDL models standing out from 36 to 72 h.

A verification of NHC official intensity forecasts for Patricia is given in Table 5a. Official forecast intensity errors were substantially greater than the mean official errors for the previous 5-yr period at all forecast lead times. Several forecasts had intensity errors through 48 h that were the highest on record since the National Hurricane Center took over warning responsibility in the eastern North Pacific basin in 1988 (Fig. 13). The official intensity forecasts severely underestimated the rapid intensification that occurred and failed to explicitly show rapid intensification until it was actually occurring. It should be noted, however, that the SHIPS Rapid Intensity (RI) guidance was temporarily unavailable before Patricia's rapid intensification began due to missing satellite inputs. Having these data in real time would likely have resulted in higher intensity forecasts than those that were made. A homogeneous comparison of the official intensity errors with selected guidance models is given in Table 5b. The statistical guidance generally beat the official forecast while the dynamical guidance performed poorly in predicting Patricia's intensity. The FSU Superensemble also did well against the official intensity forecast through 36 h. However, none of the guidance anticipated the degree to which Patricia would intensify, nor how quickly it would occur.

Watches and warnings issued by the government of Mexico in association with Patricia are given in Table 6.

ACKNOWLEDGEMENTS

Josh Morgerman of iCyclone provided detailed pressure observations and an eyewitness account of conditions in Emiliano Zapata during the height of the storm. Alvaro Miranda from the Cuixmala-Chamela Biosphere Reserve provided surface data, recovered from several sites near where Patricia made landfall. Brad Klotz and Eric Uhlhorn are thanked for their assistance in reprocessing and interpreting SFMR data from the reconnaissance missions into Patricia around the time of its peak intensity. Rich Henning from NOAA's Aircraft Operations Center (AOC) is recognized for providing valuable post-processed dropsonde data. Several discussions with Chris Velden from UW-CIMSS involving the interpretation of satellite data were useful in establishing Patricia's peak intensity. Special thanks are extended to John Knaff for retrieving satellite imagery of Hurricane Linda and Patricia at peak intensity (Fig. 6), and to Phil Klotzbach for producing an SST time series over the area Patricia traversed (Fig. 7). Mark DeMaria and John Kaplan produced re-runs of the SHIPS RI Index not available in real time. I also appreciate Alberto Unzón Hernández and his colleagues within Mexico's SMN for providing data and other information useful to this report. Orlando Bermúdez of the NWS San Antonio provided critical support for gathering surface data from the Biosphere Reserve.

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Table 1. Best track for Hurricane Patricia, 20-24 October 2015.

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
20 / 0600	13.4	94.0	1007	25	tropical depression
20 / 1200	13.3	94.2	1006	30	"
20 / 1800	13.2	94.6	1006	30	"
21 / 0000	13.1	95.1	1004	35	tropical storm
21 / 0600	12.9	96.2	1004	35	"
21 / 1200	12.9	97.4	1001	40	"
21 / 1800	13.1	98.7	997	50	"
22 / 0000	13.4	100.1	991	60	"
22 / 0600	14.0	101.7	981	75	hurricane
22 / 1200	14.6	103.1	969	90	"
22 / 1800	15.2	104.2	957	115	"
23 / 0000	15.8	104.9	920	150	"
23 / 0600	16.5	105.4	886	180	"
23 / 1200	17.3	105.6	872	185	"
23 / 1800	18.3	105.3	878	180	"
23 / 2300	19.4	105.0	932	130	"
24 / 0000	19.6	104.9	946	110	"
24 / 0600	21.6	103.8	985	50	tropical storm
24 / 1200	23.2	102.3	1000	25	tropical depression
24 / 1800					dissipated
23 / 1200	17.3	105.6	872	185	maximum winds and minimum pressure
23 / 2300	19.4	105.0	932	130	landfall near Playa Cuixmala, Mexico

Table 2. Selected surface observations for Hurricane Patricia, 20-24 October 2015.

Location	Minimum Sea Level Pressure[a]		Maximum Surface Wind Speed			Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)	Sustained (kt)	Gust (kt)	
Mexico						
Colima						
Manzanillo 19.067°N 104.33°W Elevation: 3 m				49		3.07
Colima 19.23°N 103.73°W Elevation: 494 m				32		9.49
Manantlán 19.463°N 103.917°W Elevation: 2490 m				85		9.54
Manzanillo 19.07°N 104.297°W Elevation: unknown				38		
Jalisco						
Emiliano Zapata 19.38973ºN 104.96391ºW	23/2312	937.8				
El Volantín 20.066°N 103.083°W Elevation: 1678 m						1.78
Tizipán 20.178°N 103.039°W Elevation: 1503 m						1.47
Chapala 20.29°N 103.202°W Elevation: 1439 m				64		2.99
Jocotopec 20.283°N 103.417°W Elevation: 1506 m						3.03
La Primavera 20.676°N 103.644°W Elevation: 1468 m						1.02
Nevado Colima 19.592°N 103.591°W Elevation: 3461 m				153		12.50
Guadalajara 20.71°N 103.39°W Elevation: 1551 m						1.85
Ciudad Guzmán 19.73°N 103.464°W Elevation: 1515 m						4.69
Tlajomulco 20.442°N 103.418°W Elevation: 1566 m						3.07

Location	Minimum Sea Level Pressure[a]		Maximum Surface Wind Speed			Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)	Sustained (kt)	Gust (kt)	
Manantlán 2 19.554°N 104.147°W Elevation: 2882 m						4.31
Chamela-Cuixmala (19.497ºN 105.045ºW) Elevation: 84 m	23/2340	946.6[a]				4.05
Rio Tomotlán 19.998ºN 105.133ºW Elevation: 141 m				58		2.36
El Corcovado				43		2.46
Cuixmala-Chamela Biosphere Reserve						
Playa Cuixmala (19.367ºN 104.99ºW) Elevation: 2 m	23/2230-2300	934.0[a]	23/2230-2300	70[b]		
Pista (19.383ºN 104.99ºW) Elevation: 15 m	23/2230-2300	941.0[a]	23/2230-2300	85[b]		
Fundación (19.833ºN 104.977ºW) Elevation: 30 m	23/2300-2330	942.7[a]				
Teopa (19.427ºN 104.99ºW) Elevation: 40 m	23/2330-24/0000	939.9[a]				
Cumbres 2 (19.425ºN 104.95ºW) Elevation: 50 m	23/2330-24/0000	951.1[a]				

[a] Pressure reduced to mean sea level using the hypsometric equation
[b] Maximum winds before anemometer failed or was blown away

Table 3. Number of hours in advance of formation associated with the first NHC Tropical Weather Outlook forecast in the indicated likelihood category. Note that the timings for the “Low” category do not include forecasts of a 0% chance of genesis.

	Hours Before Genesis	
	48-Hour Outlook	**120-Hour Outlook**
Low (<40%)	72	150
Medium (40%-60%)	36	132
High (>60%)	12	96

Table 4a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) track forecast errors (n mi) for Hurricane Patricia, 20-24 October 2015. Mean errors for the previous 5-yr period are shown for comparison. Official errors that are smaller than the 5-yr means are shown in boldface type.

	Forecast Period (h)						
	12	24	36	48	72	96	
OFCL	34.8	55.9	86.9	105.7	105.4	199.8	
OCD5	66.3	162.5	267.6	345.6	413.1	346.6	
Forecasts	15	13	11	9	5	1	
OFCL (2010-14)	23.4	36.4	47.2	59.4	89.0	123.6	
OCD5 (2010-14)	36.6	74.2	116.5	159.7	245.6	331.1	

Table 4b. Homogeneous comparison of selected track forecast guidance models (in n mi) for Hurricane Patricia, 20-24 October 2015. Errors smaller than the NHC official forecast are shown in boldface type. The number of official forecasts shown here will generally be smaller than that shown in Table 4a due to the homogeneity requirement.

Model ID	Forecast Period (h)						
	12	24	36	48	72		
OFCL	33.1	50.2	72.0	80.0	102.9		
OCD5	59.7	148.2	257.1	326.2	437.1		
GFSI	35.6	53.0	**60.3**	**74.5**	**83.8**		
GHMI	47.4	70.2	**71.6**	**60.2**	**80.3**		
HWFI	35.8	52.8	76.1	112.0	191.5		
UKMI	**28.9**	57.6	**60.8**	**56.6**	106.0		
EMXI	**27.8**	52.4	85.3	99.1	**65.0**		
NVGI	35.9	**46.9**	**69.5**	99.5	**100.5**		
GFNI	37.8	65.0	102.4	111.4	140.2		
CMCI	41.4	75.5	100.6	118.8	166.2		
TCON	35.4	**49.7**	**52.4**	**66.3**	**97.0**		
TVCE	**32.6**	**46.1**	**54.0**	**70.7**	**79.0**		
FSSE	**28.4**	**40.6**	**55.2**	**74.4**	**65.8**		
AEMI	**32.7**	50.6	**68.1**	86.3	181.9		
LBAR	44.7	84.0	121.6	145.4	289.0		
BAMS	48.8	96.0	148.3	148.1	126.4		
BAMM	41.3	67.5	107.4	108.3	148.0		
BAMD	46.7	80.0	130.7	127.1	**99.3**		
Forecasts	10	9	8	6	2		

Table 5a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) intensity forecast errors (kt) for Hurricane Patricia, 20-24 October 2015. Mean errors for the previous 5-yr period are shown for comparison. Official errors that are smaller than the 5-yr means are shown in boldface type.

	Forecast Period (h)						
	12	24	36	48	72	96	
OFCL	22.7	35.0	47.7	57.8	55.0	25.0	
OCD5	29.5	55.5	64.3	72.1	74.6	2.0	
Forecasts	15	13	11	9	5	1	
OFCL (2010-14)	5.9	9.8	12.5	14.0	15.5	16.3	
OCD5 (2010-14)	7.7	12.8	16.4	18.8	21.1	20.9	

Table 5b. Homogeneous comparison of selected intensity forecast guidance models (in kt) for Hurricane Patricia, 20-24 October 2015. Errors smaller than the NHC official forecast are shown in boldface type. The number of official forecasts shown here will generally be smaller than that shown in Table 5a due to the homogeneity requirement.

Model ID	Forecast Period (h)						
	12	24	36	48	72		
OFCL	26.5	41.5	56.1	64.3	25.0		
OCD5	34.2	59.4	74.4	79.4	29.7		
HWFI	33.6	46.4	60.4	72.1	**14.0**		
GHMI	35.8	50.3	58.2	67.0	35.0		
DSHP	**26.2**	46.4	**54.9**	68.0	**16.3**		
LGEM	**26.1**	**39.8**	**52.7**	67.7	**12.3**		
ICON	29.8	43.7	**55.7**	67.9	**19.3**		
GFSI	38.1	52.4	66.9	72.6	**21.3**		
EMXI	45.5	64.8	82.8	85.6	40.7		
FSSE	**26.3**	**33.7**	**47.4**	66.0	31.0		
Forecasts	13	10	9	7	3		

Table 6. Watch and warning summary for Hurricane Patricia, 20-24 October 2015.

Date/Time (UTC)	Action	Location
21 / 0900	Tropical Storm Warning issued	Tecpán de Galeana to Lázaro Cardenas
21 / 0900	Hurricane Watch issued	Lázaro Cardenas to Playa Perula
21 / 2100	Tropical Storm Warning changed to Tropical Storm Watch	Lázaro Cardenas to Tecpán de Galeana
21 / 2100	Tropical Storm Warning issued	Punta San Telmo to Lázaro Cardenas
21 / 2100	Hurricane Watch modified to	Punta San Telmo to Lázaro Cardenas
21 / 2100	Hurricane Warning issued	Cabo Corrientes to Punta San Telmo
22 / 1500	Tropical Storm Warning issued	San Blas to Cabo Corrientes
22 / 1500	Hurricane Watch issued	San Blas to Cabo Corrientes
22 / 2100	Tropical Storm Watch discontinued	All
22 / 2100	Tropical Storm Warning discontinued	San Blas to Cabo Corrientes
22 / 2100	Hurricane Watch discontinued	San Blas to Cabo Corrientes
22 / 2100	Hurricane Warning modified to	San Blas to Punta San Telmo

23 / 1500	Tropical Storm Warning issued	San Blas to El Roblito
24 / 0300	Hurricane Watch changed to Tropical Storm Warning	Punta San Telmo to Lázaro Cardenas
24 / 0600	Tropical Storm Warning modified to	Playa Perula to Lázaro Cardenas
24 / 0600	Tropical Storm Warning discontinued	San Blas to El Roblito
24 / 0600	Hurricane Warning discontinued	All
24 / 0900	Tropical Storm Warning modified to	Manzanillo to Lázaro Cardenas
24 / 1200	Tropical Storm Warning discontinued	All

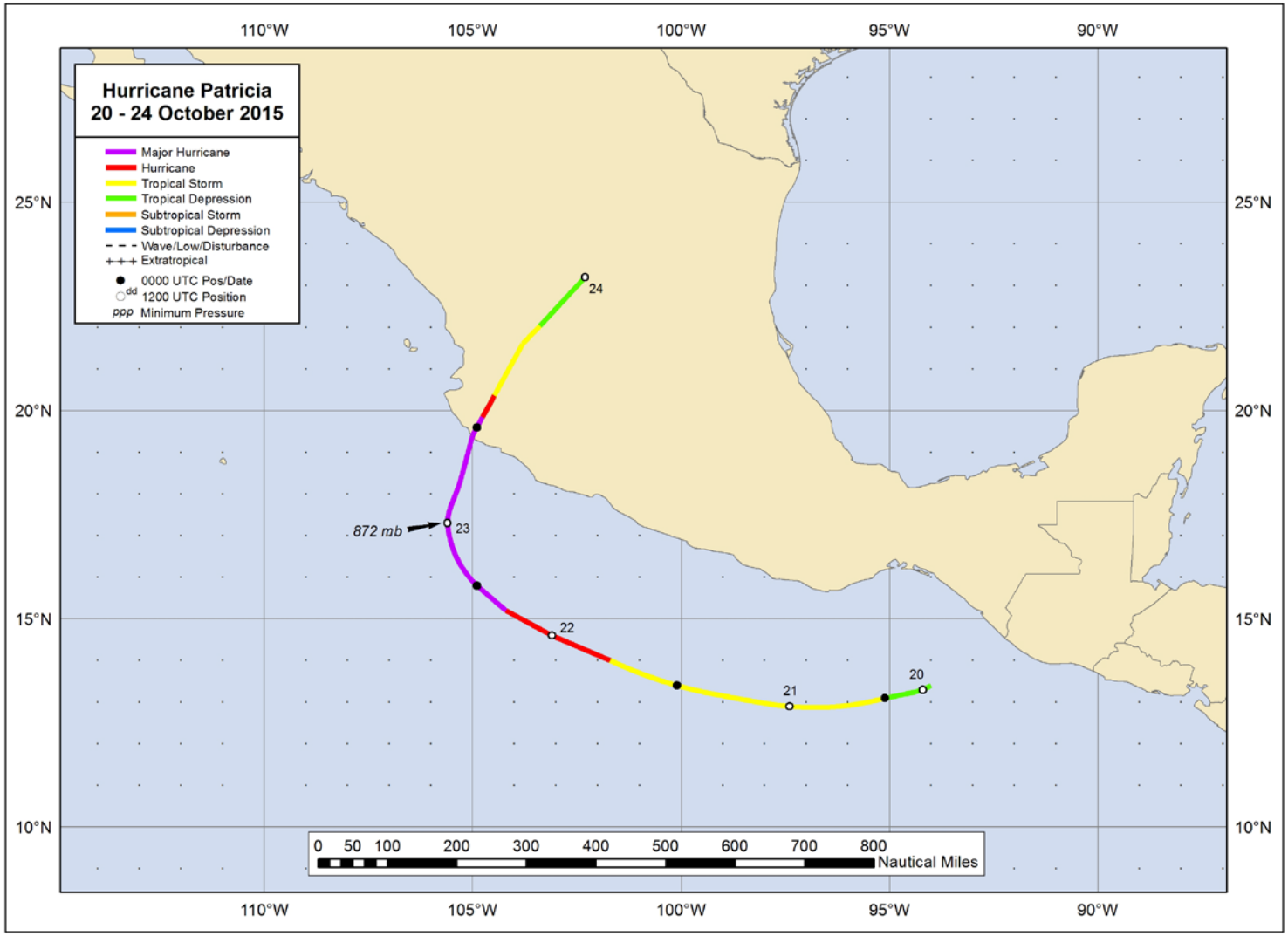

Figure 1. Best track positions for Hurricane Patricia, 20-24 October 2015.

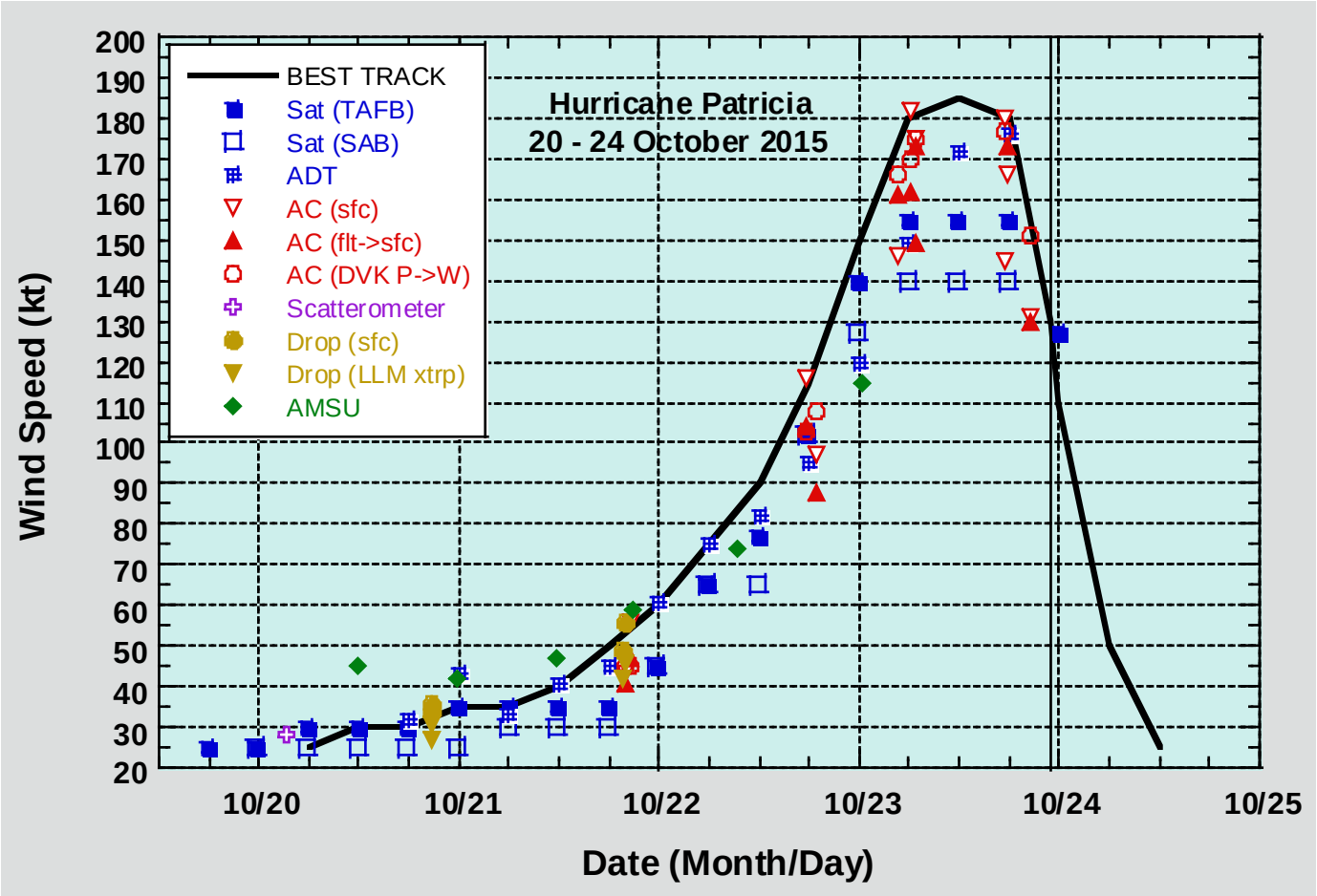

Figure 2. Selected wind observations and best track maximum sustained surface wind speed curve for Hurricane Patricia, 20-24 October 2015. Aircraft observations have been adjusted for elevation using 90%, 80%, and 80% adjustment factors for observations from 700 mb, 850 mb, and 1500 ft, respectively. Dropwindsonde observations include actual 10 m winds (sfc), as well as surface estimates derived from the mean wind over the lowest 150 m of the wind sounding (LLM). Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. There is a slight lag in the peak ADT intensity and the estimated peak best track intensity due to rules basic to the ADT algorithm. AMSU intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies technique. Dashed vertical lines correspond to 0000 UTC, and the solid vertical line corresponds to the time of landfall.

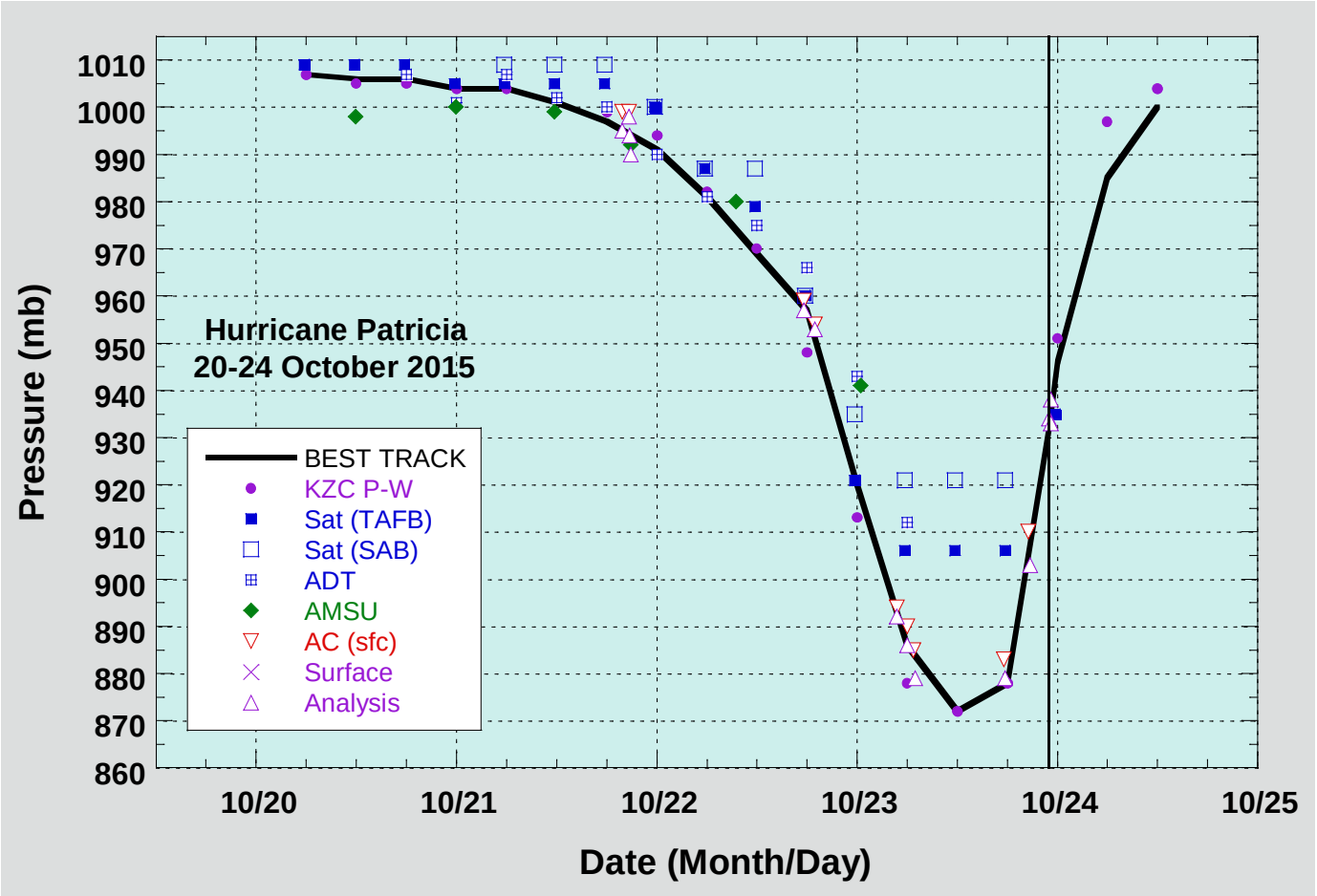

Figure 3. Selected pressure observations and best track minimum central pressure curve for Hurricane Patricia, 20-24 October 2015. Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. AMSU intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies technique. KZC P-W refers to pressure estimates derived using the Knaff-Zehr-Courtney pressure-wind relationship. Dashed vertical lines correspond to 0000 UTC, and the solid vertical line corresponds to the time of landfall.

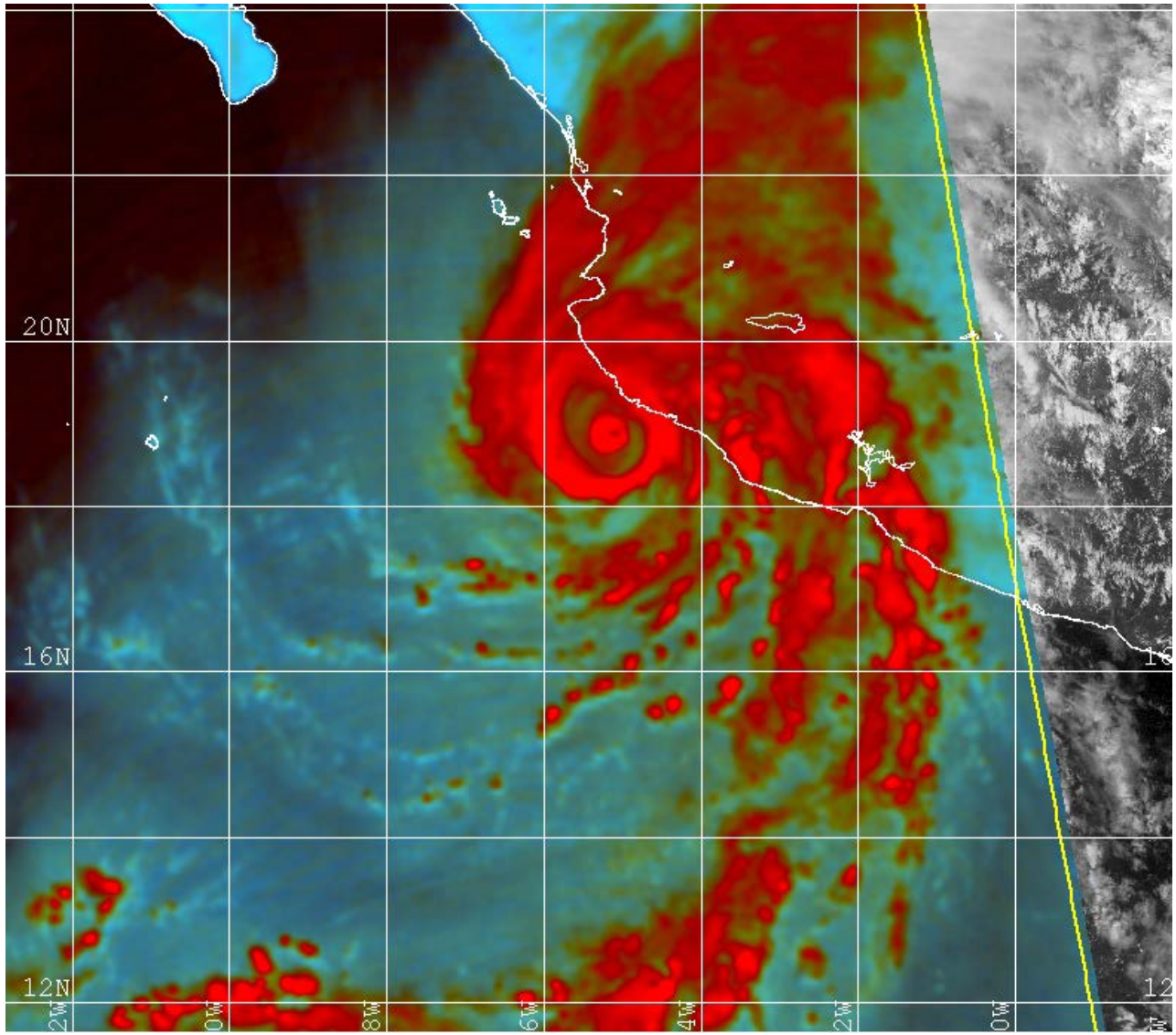

Figure 4. 91-GHz GPM 2023 UTC 23 October pass showing Patricia with a double eye wall structure prior to landfall along the southwestern coast of Mexico. Courtesy Naval Research Lab.

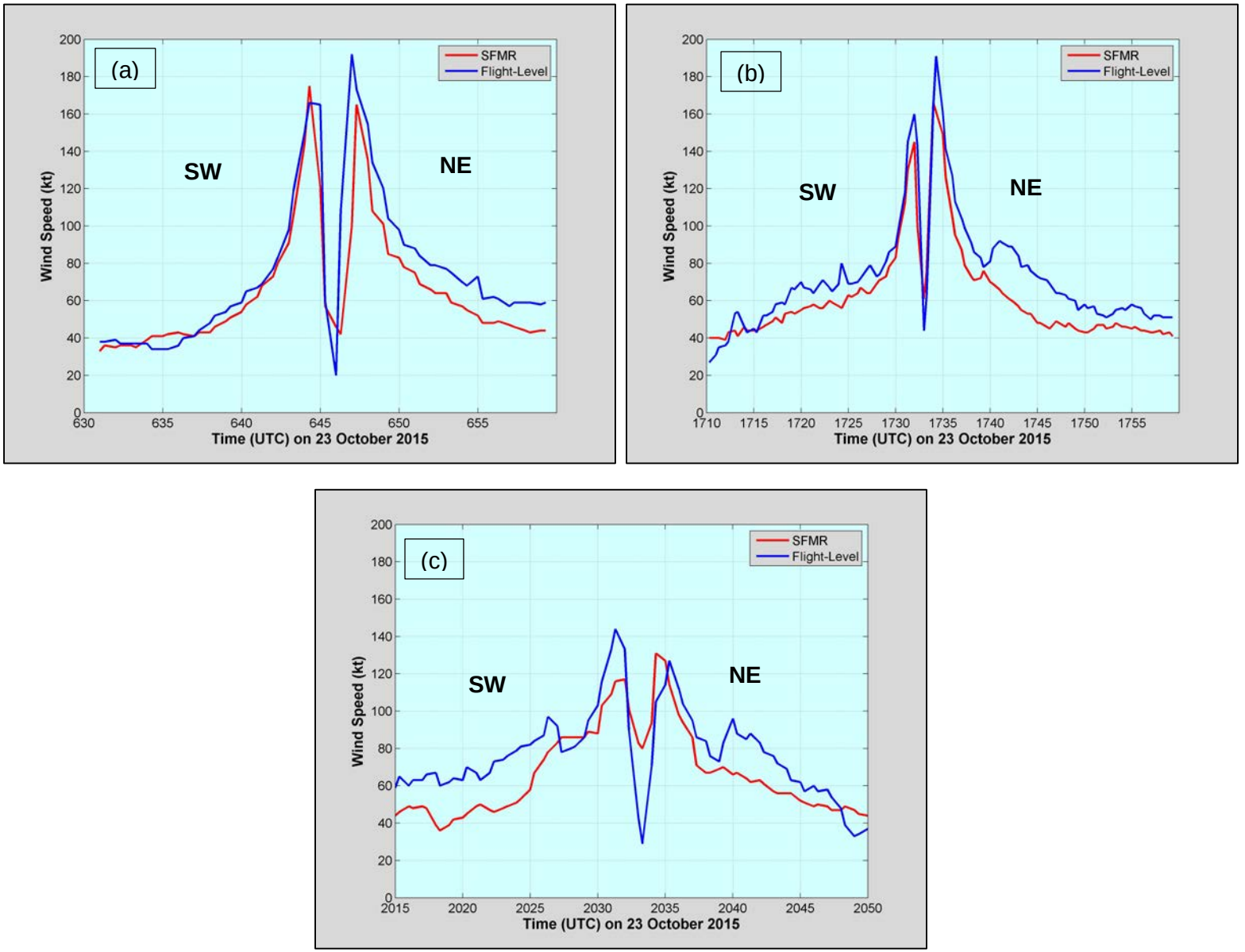

Figure 5. Radial flight legs in Hurricane Patricia showing flight-level and SFMR winds along the flight path from the (a) mission around 0600 UTC 23 October, (b) mission around 1800 UTC that same day, and (c) the last pass through the eye around 2030 UTC.

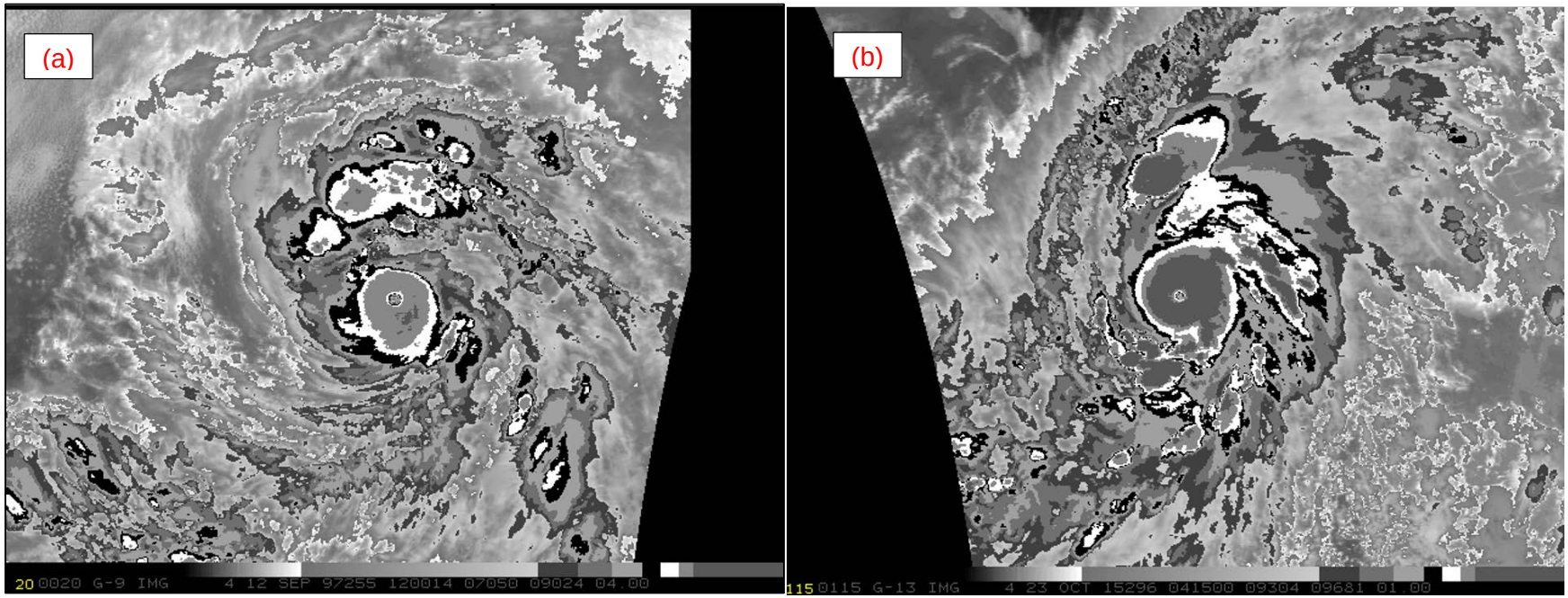

Figure 6. Comparison of infrared satellite imagery with Dvorak BD enhancement for the two strongest eastern Pacific hurricanes in the eastern North Pacific in the reliable record. (a) Hurricane Linda with a peak intensity of 160 kt on 1200 UTC 12 September 1997 (b) and Hurricane Patricia with a peak intensity of 185 kt at 0415 UTC 23 October 2015.

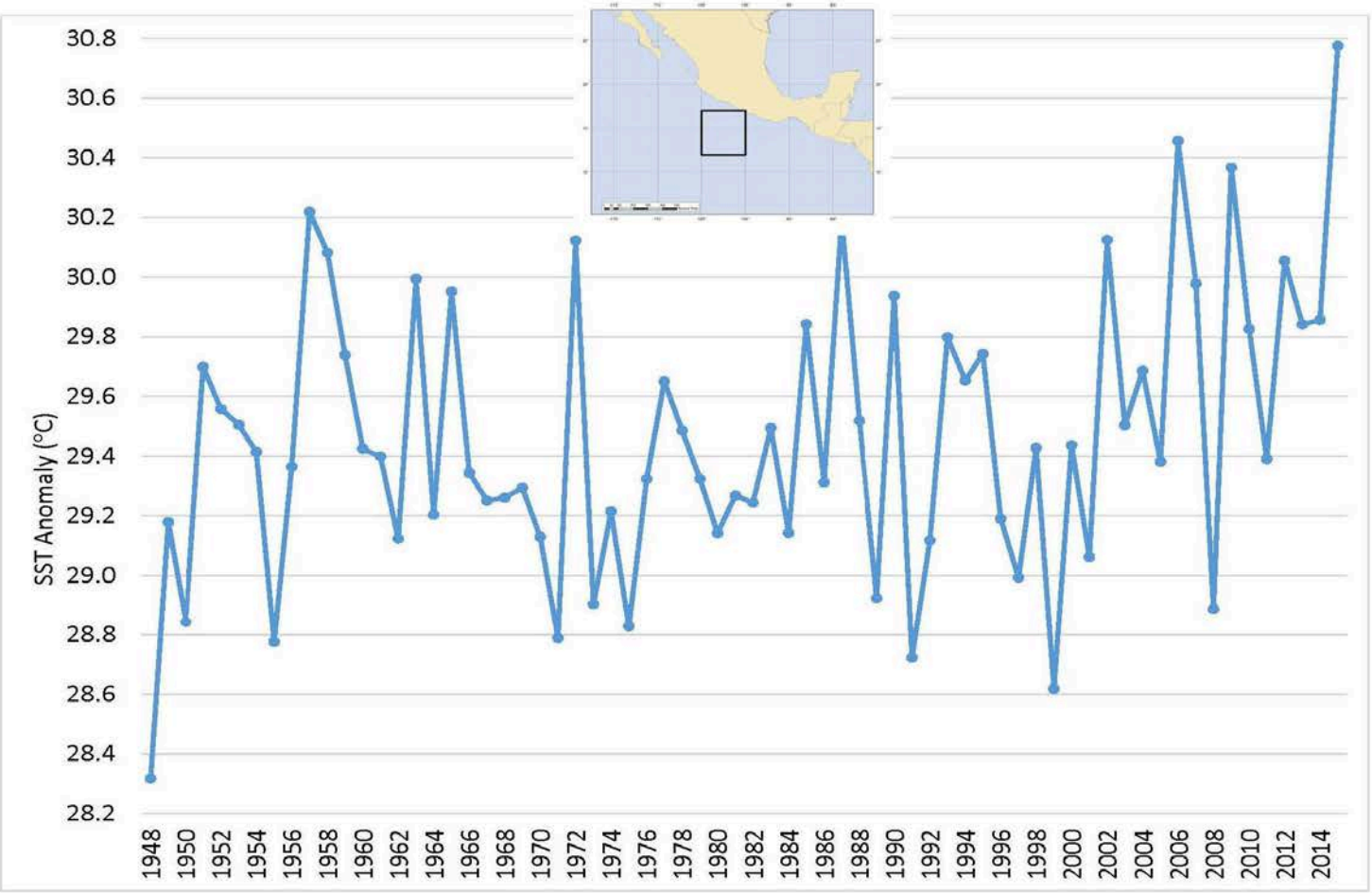

Figure 7. Sea surface temperatures from 13º-17ºN and 100º-105ºW averaged over a 10-day period prior to the passage of Patricia. Source NCEP/NCAR Reanalysis data base.

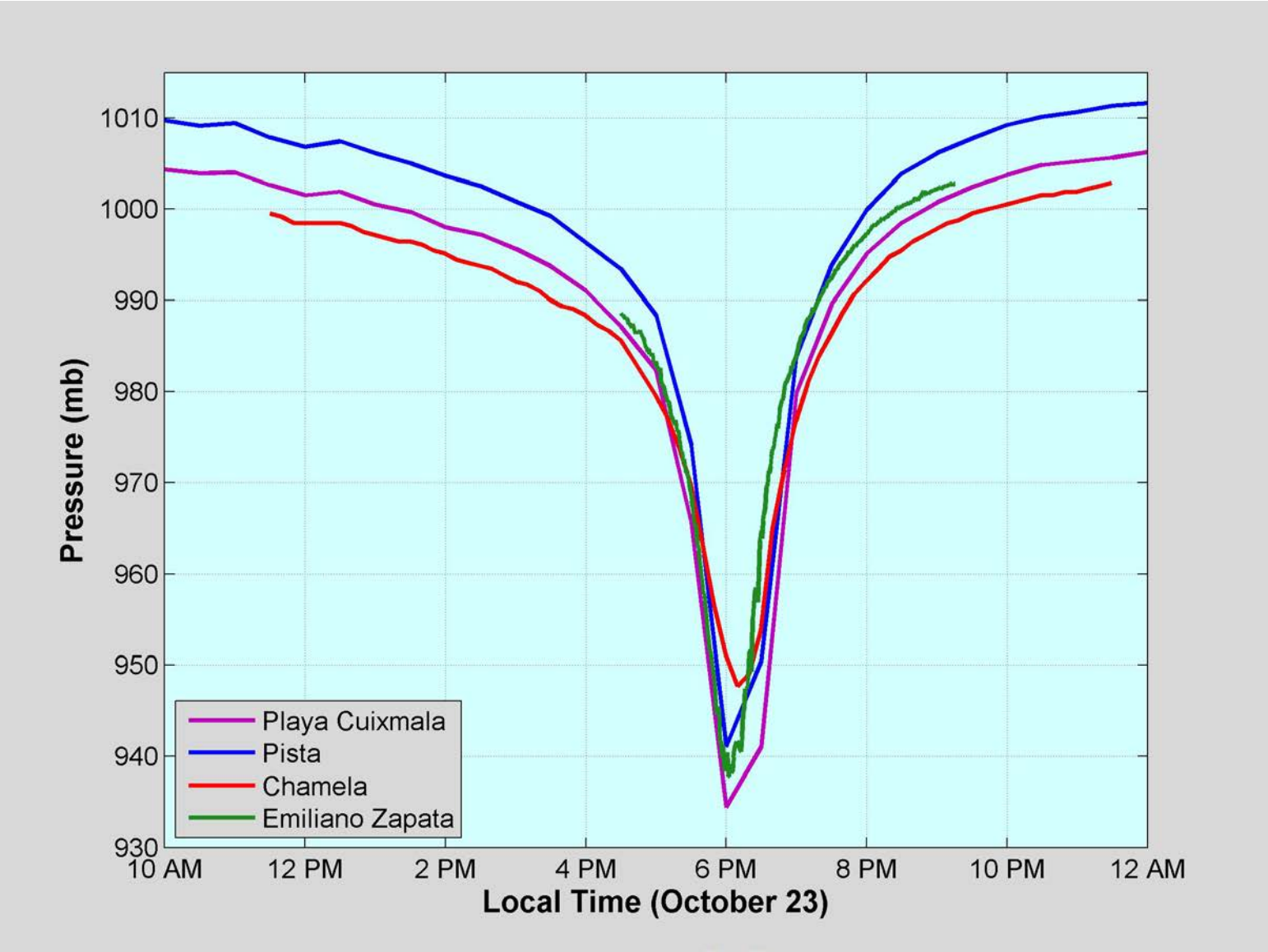

Figure 8. Pressure traces in local time from three automated weather stations and a storm chaser along the path of Hurricane Patricia at landfall: Chamela (red), Playa Cuixmala (purple), Pista (blue), and Emiliano Zapata (green). Local time is the equilvalent of Mountain Daylight Time.

Figure 9. Trees denuded and completely flattened by the strong winds in the eyewall of Hurricane Patricia as viewed from a helicopter. Image courtesy of Humberto Hernández Peralta.

Figure 10. Damage near Chamela, Mexico, near where Patricia made landfall. Image courtesy of Humberto Hernández Peralta.

Figure 11. Before and after damage photo at the Chamela Biosphere site. Courtesy John Galetzka.

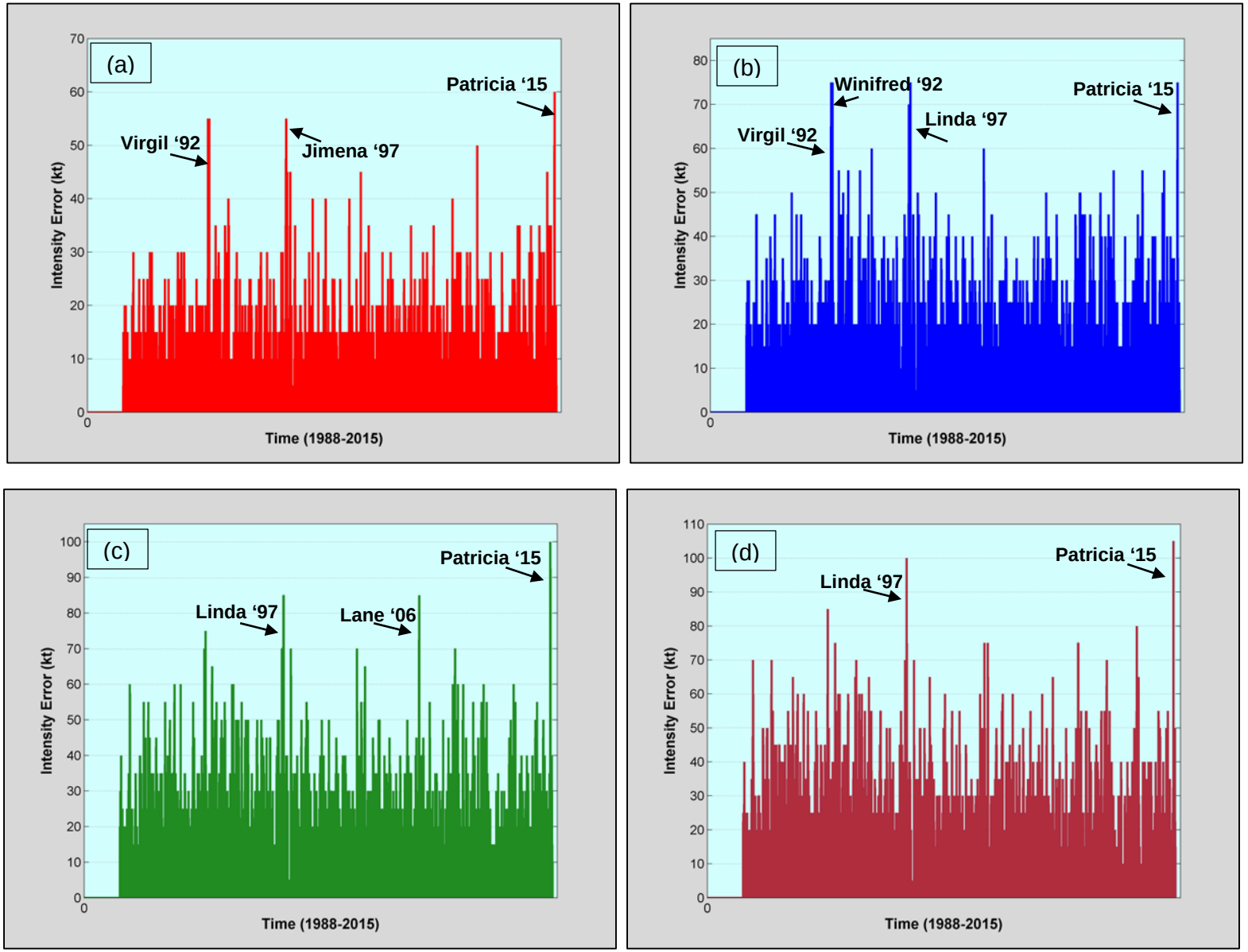

Figure 12. Distribution of all individual NHC eastern North Pacific (1988-2015) official intensity errors at a) 12 h, b) 24 h, c) 36 h, and d) 48 h.