CENTRAL PACIFIC HURRICANE CENTER
TROPICAL CYCLONE REPORT

HURRICANE PALI

(CP012016)

7 – 14 January 2016

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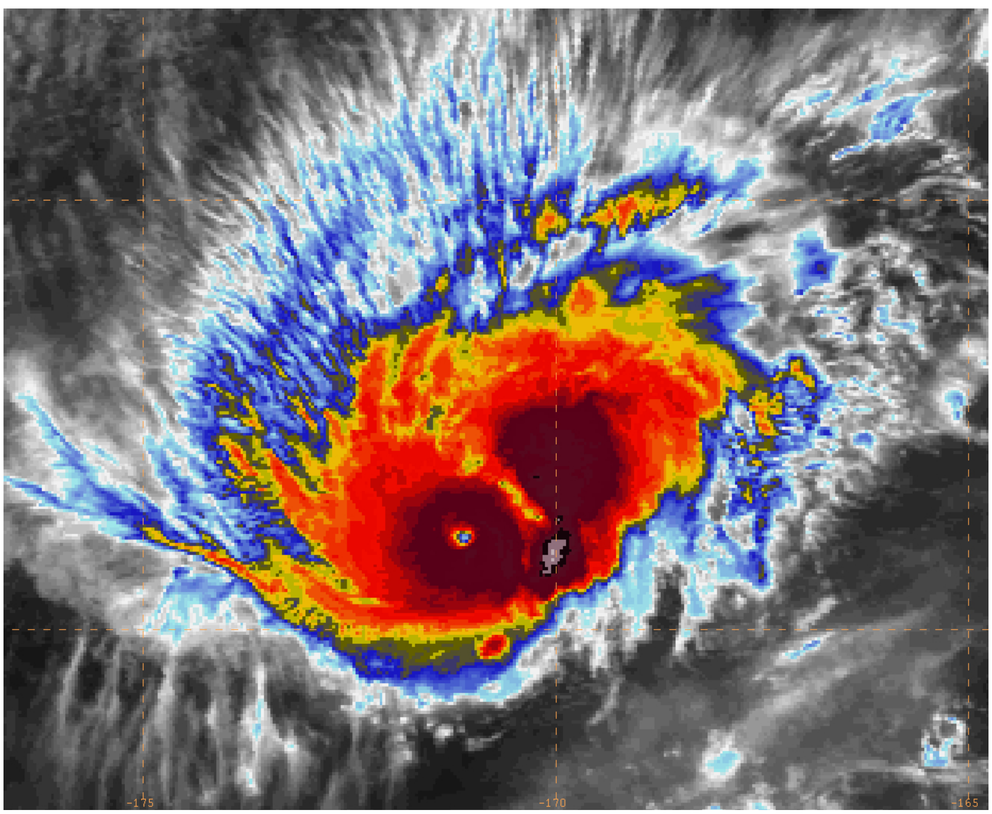

GOES WEST IMAGE OF HURRICANE PALI NEAR TIME OF MAXIMIUM INTENSITY ON 12 JANUARY 2016

Within the central North Pacific basin, Pali was the earliest tropical cyclone ever observed to form in a calendar year. Pali developed at an extraordinarily low latitude and spent its entire life cycle within the deep tropics just east of the International Date Line. Pali peaked as a category 2 hurricane (on the Saffir-Simpson Hurricane Wind Scale).

Hurricane Pali

7 – 14 JANUARY 2016

SYNOPTIC HISTORY

Although Pali developed in early 2016, its formation at extraordinarily low latitude arguably occurred as an extension of the record-breaking 2015 central North Pacific tropical cyclone season. One of the strongest El Niño events ever observed created an environment conducive for the highly active tropical cyclone season. As El Niño peaked in late December 2015 and early January 2016, a strong westerly wind burst, a classic El Niño signature, occurred along the equator across the western and central Pacific. During late December, this long-lived westerly wind burst spawned Tropical Depression Nine-C in the central North Pacific and its twin, Tropical Cyclone Ula, in the central South Pacific. Tropical Depression Nine-C quickly dissipated as the New Year was ushered in. However, a low-latitude, west-to-east oriented surface trough remained across the western and central North Pacific between 01N and 03N latitude as far east as 155W longitude. Easterly trade winds to the north of the trough and periodic bursts of fresh to occasionally near gale-force westerly winds to the south of the trough produced significant horizontal wind shear. At 0000 UTC 6 January, a weak surface low formed within this zone of high horizontal wind shear nearly 1,425 n mi southwest of Honolulu, HI at the extremely low latitude of 1.9N.

The weak surface low remained embedded in the west-to-east oriented surface trough throughout 6 January. The low and the trough drifted northward as the subtropical ridge stretching roughly across 25N latitude was significantly weakened by a passing North Pacific cold front. Deep convection was active near the low and along a broad section of the trough between 165W and 175W longitude, and a ridge aloft centered directly overhead produced poleward outflow. However, thunderstorms failed to consolidate near the center of the low, which remained extraordinarily close to the equator south of 03N latitude.

The amount and degree of organized deep convection around the low increased steadily through 7 January, and by 0600 UTC, the system became Tropical Depression One-C while located near 03N latitude. While this event could be considered to be an extension of the record-breaking 2015 tropical cyclone season, the formation of One-C marked the earliest in a calendar year that a tropical cyclone has ever been observed to form in the central North Pacific. The "best track" chart of the tropical cyclone's path is given in Fig. 1 and in Fig. 2. The best track positions and intensities are listed in Table 1[1].

Intensification continued through 7 January as the system drifted northward. The ridge aloft shifted to the north during this time, imparting easterly vertical wind shear but also

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

producing enhanced outflow aloft. This enhanced outflow likely supported a marked increase in deep convection around the center of the system, and the cyclone strengthened to Tropical Storm Pali at 1200 UTC.

Pali intensified through the first half of 8 January and nearly reached hurricane strength before easterly vertical wind shear became strong enough to disrupt the system. As Pali approached 07N latitude, the deep easterly trade wind flow to the north exerted a greater steering influence. This, combined with the easterly flow aloft, led to the turn toward the northwest.

Steady weakening occurred late on 8 January and continued through 9 January as Pali drifted westward. Under continued easterly vertical wind shear, deep convection was displaced to the west of the low-level center and intermittently pulsed. This led to a dramatic decrease in intensity, and by the end of 9 January, Pali barely maintained tropical storm strength. The lack of persistent deep convection led to a shallower system that was less affected by the easterly winds aloft. Since Pali remained embedded in the roughly west-to-east oriented surface trough, the steering currents weakened, causing the forward motion of Pali to decelerate significantly.

Pali re-intensified through much of 10 and 11 January. The ridge aloft weakened and retreated southward on 10 January, causing vertical wind shear to gradually diminish. As a result, persistent deep convection redeveloped near the center of Pali and within its western quadrant. Pali nearly came to a halt during this time due to a lack of significant steering. On 11 January, the ridge aloft passed directly over Pali, leading to the reestablishment of poleward outflow and eventual development of southwesterly flow aloft. Intensification continued as deep convection slowly increased in coverage and organization within all quadrants. Pali began a slow motion toward the northeast during this time, likely due to the development of southwesterly winds aloft in the weak steering regime.

Pali continued to intensify on 12 January, under light vertical wind shear and high sea surface temperatures of 28 to 29C. At 0000 UTC 12 January Pali reached hurricane strength, becoming the earliest hurricane ever observed in a calendar year within the central North Pacific. By 1800 UTC, Pali displayed a well-defined eye on geostationary satellite imagery and achieved its maximum intensity with sustained winds of 85 kt. A 2316 UTC GCOM pass (Fig. 3) shows the structure of the eye at the low latitude of 5.7N. Throughout 12 January, Pali was driven southward as a deep ridge built to the north.

Weakening began on 13 January and accelerated through 14 January as Pali continued to move southward, close to where it initially formed. Under modest southerly vertical wind shear, the eye became indiscernible by 0600 UTC 13 January. Vertical wind shear increased steadily throughout 13 January and exceeded 20 kt by early 14 January. During this time, Pali continued to move southward, from near 06N latitude at the start of 13 January to near 03N latitude by the beginning of 14 January. Increasing vertical wind shear and perhaps a steady loss of planetary vorticity caused a rapid decay in the organization of deep convection. By 1800 UTC 14 January, Pali weakened to a remnant low near 02N latitude and was barely discernible within the west-to-east oriented trough where it had spent its entire life cycle. It is also worthy to note that after its highly unusual January formation at extraordinary low latitude, Pali completed its broad, looping track by dissipating little more than 50 n mi from where it initially developed.

METEOROLOGICAL STATISTICS

Observations in Pali include subjective satellite-based Dvorak technique intensity estimates from the Central Pacific Hurricane Center (CPHC), the Satellite Analysis Branch (SAB), and the Joint Typhoon Warning Center (JTWC), as well as objective Advanced Dvorak Technique (ADT) estimates from the Cooperative Institute for Meteorological Satellite Studies/University of Wisconsin-Madison (CIMSS). Data and imagery from NOAA polar-orbiting satellites including the Advanced Microwave Sounding Unit (AMSU), 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 Pali.

The peak intensity of 85 kt is based on several inputs, including Dvorak satellite estimates from CPHC, SAB, and JTWC, as well as ADT from CIMSS. No ship reports of tropical-storm-force winds associated with Pali were received.

CASUALTY AND DAMAGE STATISTICS

There were no reports of damage or casualties[2] associated with Pali.

FORECAST AND WARNING CRITIQUE

The genesis of Pali was poorly anticipated (Table 2). This is not surprising, given the extraordinarily low latitude at which it developed and the record-breaking timing of its formation in January. In early 2016, CPHC only produced genesis forecasts for a 48 h period, and since Pali developed outside of the official hurricane season, genesis forecasts were disseminated by Special Tropical Weather Outlooks. The first outlook was issued at 0600 UTC 6 January, 24 h before actual genesis, and the system was given a "medium" (40-60%) chance of development. The second and third Special Tropical Weather Outlooks were issued at 1537 UTC 6 January and 0300 UTC 7 January and kept the chance of development within the medium range. Genesis occurred at 0600 UTC 7 January.

A verification of CPHC official track forecasts for Pali is given in Table 3a. Official forecast track errors were comparable to the mean official errors for the previous 5-yr period.

[2] 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).

Given the highly unusual time of year, location, and motion of Pali, official forecast track errors comparable to the previous 5-year period can be considered a success. A homogeneous comparison of the official track errors with selected guidance models is given in Table 3b. The official forecast track errors were comparable to or lower than the dynamical guidance through 48 h. At 72 h and beyond, the GFS, the GFS ensemble mean, and GHMI had lower errors. Of particular note, the ECMWF track errors were the greatest of all the dynamical guidance and were greater than the official forecast track errors at all forecast periods. TVCE had lower errors than the official track forecast at all forecast periods and had the lowest track error of all guidance through 48 h.

A verification of CPHC official intensity forecasts for Pali is given in Table 4a. Official forecast intensity errors were greater than the mean official errors for the previous 5-yr period. This is not surprising, given the highly unusual time of year, location, and motion of Pali. A homogeneous comparison of the official intensity errors with selected guidance models is given in Table 4b. For the dynamical guidance, GHMI had the best overall performance, and its intensity errors were less than the official forecast errors for all except the 96 h forecast period. However, HWRF intensity errors were smaller than the official forecast errors and the GHMI errors at forecast periods from 12 to 48 h. The statistical guidance (DSHP and LGEM) intensity errors were comparable to though slightly greater than the official intensity forecast errors through 48 h, with mostly better performance at forecast periods beyond 48 h. The consensus guidance (ICON) intensity errors were comparable to though less than the official forecast errors at all except the 96 h time period.

Watches and warnings were not required.

Table 1. Best track for Hurricane Pali, 7 January – 14 January 2016.

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
06 / 0000	1.9	171.7	1007	25	low
06 / 0600	2.1	171.6	1007	25	“
06 / 1200	2.3	171.5	1007	25	"
06 / 1800	2.6	171.4	1007	25	“
07 / 0000	2.9	171.3	1007	25	“
07 / 0600	3.3	171.2	1005	30	tropical depression
07 / 1200	3.8	171.1	1003	35	tropical storm
07 / 1800	4.4	171.0	1000	45	"
08 / 0000	5.1	171.1	998	50	“
08 / 0600	5.9	171.3	996	55	"
08 / 1200	6.8	171.8	994	60	"
08 / 1800	7.3	172.4	996	55	"
09 / 0000	7.6	172.9	998	50	"
09 / 0600	7.8	173.3	1000	45	"
09 / 1200	7.9	173.7	1002	40	"
09 / 1800	7.9	174.0	1003	35	"
10 / 0000	7.8	174.2	1003	35	“
10 / 0600	7.7	174.3	1003	35	“
10 / 1200	7.7	174.2	1002	40	"
10 / 1800	7.7	174.0	1000	45	"
11 / 0000	7.6	173.7	998	50	"
11 / 0600	7.8	173.4	996	55	"
11 / 1200	8.1	173.0	996	55	"
11 / 1800	8.3	172.5	994	60	“
12 / 0000	8.2	172.0	988	70	hurricane
12 / 0600	7.7	171.7	985	75	“
12 / 1200	7.1	171.4	982	80	"
12 / 1800	6.4	171.2	978	85	"
13 / 0000	5.7	171.0	982	80	"

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
13 / 0600	5.0	171.1	986	75	"
13 / 1200	4.3	171.3	991	70	“
13 / 1800	3.7	171.5	995	60	tropical storm
14 / 0000	3.3	171.8	999	50	"
14 / 0600	2.9	172.1	1003	40	“
14 / 1200	2.6	172.3	1006	30	tropical depression
14 / 1800	2.3	172.5	1008	25	low
15 / 0000					dissipated
12 / 1800	6.4	171.2	978	85	maximum winds and minimum pressure

Table 2. Number of hours in advance of formation of Hurricane Pali associated with the first CPHC 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 in 48-Hour Outlook
Low (≤ 30%)	-
Medium (40%-60%)	24
High (≥ 70%)	-

Table 3a. CPHC official (OFCL) and climatology-persistence skill baseline (OCD5) track forecast errors (n mi) for Hurricane Pali. 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	120
OFCL	**27.8**	44.4	59.1	75.1	**110.9**	193.0	**238.2**
OCD5	51.4	115.7	193.6	313.1	413.7	339.9	421.6
Forecasts	23	21	19	17	13	9	7
OFCL (2010-14)	27.9	44.1	56.7	73.9	132.3	183.7	258.9

Table 3b. Homogeneous comparison of selected track forecast guidance models (in n mi) for Hurricane Pali. Errors smaller than the CPHC official forecast are shown in boldface type. The number of official forecasts shown here will generally be smaller than that shown in Table 3a due to the homogeneity requirement.

Model ID	Forecast Period (h)						
	12	24	36	48	72	96	120
OFCL	27.8	44.4	59.1	75.1	110.9	193.0	238.2
OCD5	51.4	115.7	193.6	313.1	413.7	339.9	421.6
GFSI	29.3	**44.0**	62.0	**71.4**	**91.3**	**143.1**	**150.7**
GHMI	**27.3**	**44.1**	61.9	85.1	**109.5**	**127.4**	**169.6**
HWFI	30.4	50.8	72.7	93.2	112.8	**190.9**	281.7
EMXI	33.4	56.3	80.0	102.2	173.3	320.8	521.7
GFEX	30.6	48.0	66.4	81.0	113.5	204.6	296.0
TVCE	**26.4**	**38.9**	**51.8**	**64.5**	**96.5**	**165.9**	**222.5**
TVCX	27.9	**40.8**	**54.9**	**69.7**	**108.6**	**189.4**	267.1
AEMI	28.5	**44.3**	59.6	**65.6**	**85.2**	**112.5**	**149.7**
Forecasts	23	21	19	17	13	9	7

Table 4a. CPHC official (OFCL) and climatology-persistence skill baseline (OCD5) intensity forecast errors (kt) for Hurricane Pali. 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	120
OFCL	10.4	15.7	20.0	19.1	**16.5**	25.6	32.9
OCD5	10.7	20.1	27.6	24.7	22.1	22.1	**18.6**
Forecasts	23	21	19	17	13	9	7
OFCL (2010-14)	4.8	8.6	11.6	13.8	18.5	19.3	20.4

Table 4b. Homogeneous comparison of selected intensity forecast guidance models (in kt) for Hurricane Pali. Errors smaller than the CPHC 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	96	120
OFCL	10.4	15.7	20.0	19.1	16.5	25.6	32.9
OCD5	10.7	20.1	27.6	24.7	22.1	**22.1**	**18.6**
HWFI	**7.1**	**11.2**	**15.2**	**14.8**	21.1	38.8	42.1
GHMI	**8.9**	**14.5**	**16.2**	**16.5**	**14.7**	26.4	**29.0**
DSHP	10.8	16.7	20.5	19.4	**13.9**	**24.9**	34.4
LGEM	10.7	16.5	20.8	21.0	**16.1**	**21.1**	**27.6**
ICON	**9.2**	**13.8**	**17.1**	**15.8**	**14.3**	26.8	**26.6**
GFSI	**8.8**	**13.8**	**16.5**	**15.8**	22.9	34.9	48.9
EMXI	11.9	15.9	**17.3**	**17.6**	17.8	28.4	35.0
Forecasts	23	21	19	17	13	9	7

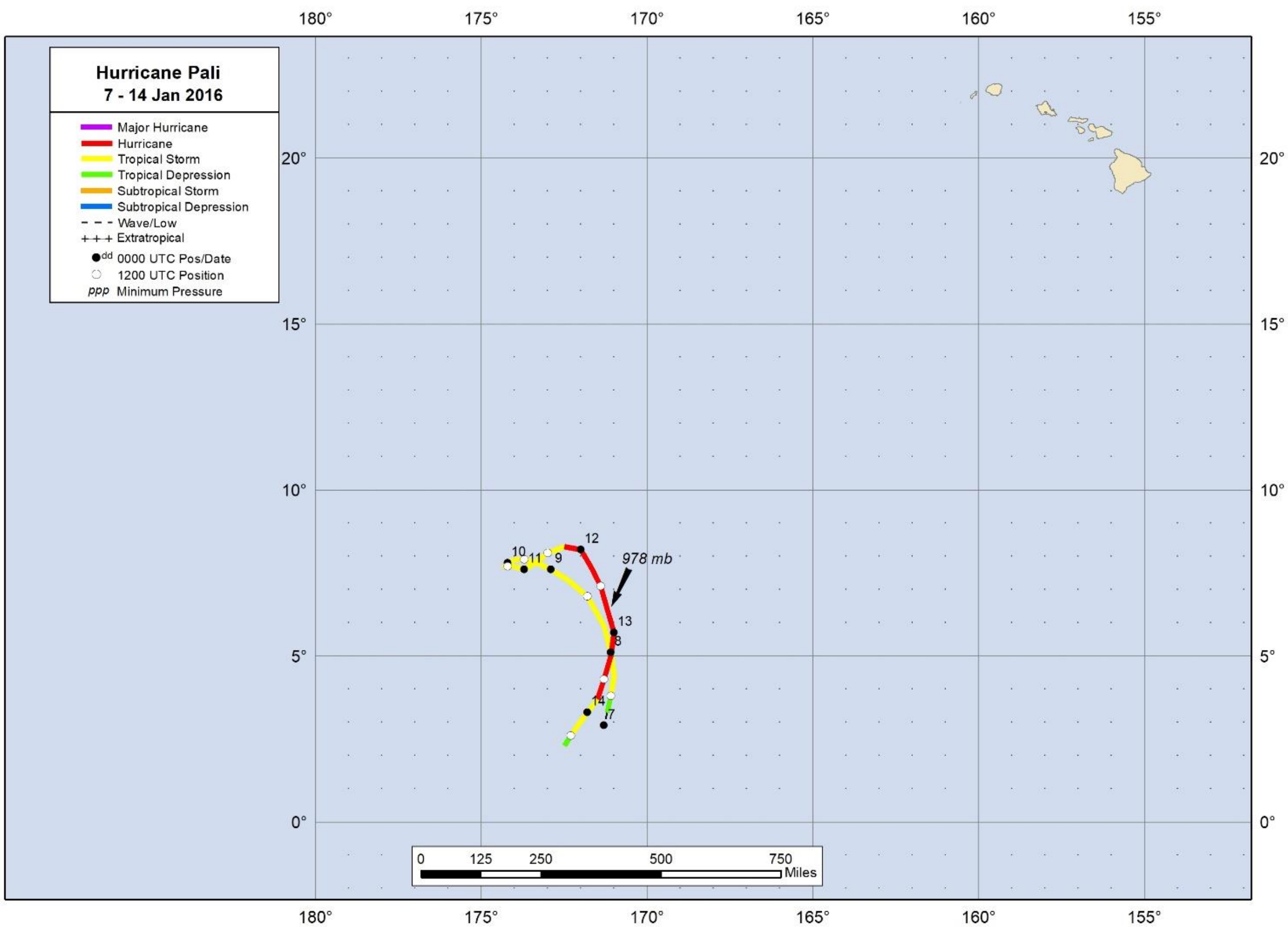

Figure 1. Best track positions for Hurricane Pali, 7 – 14 January 2016.

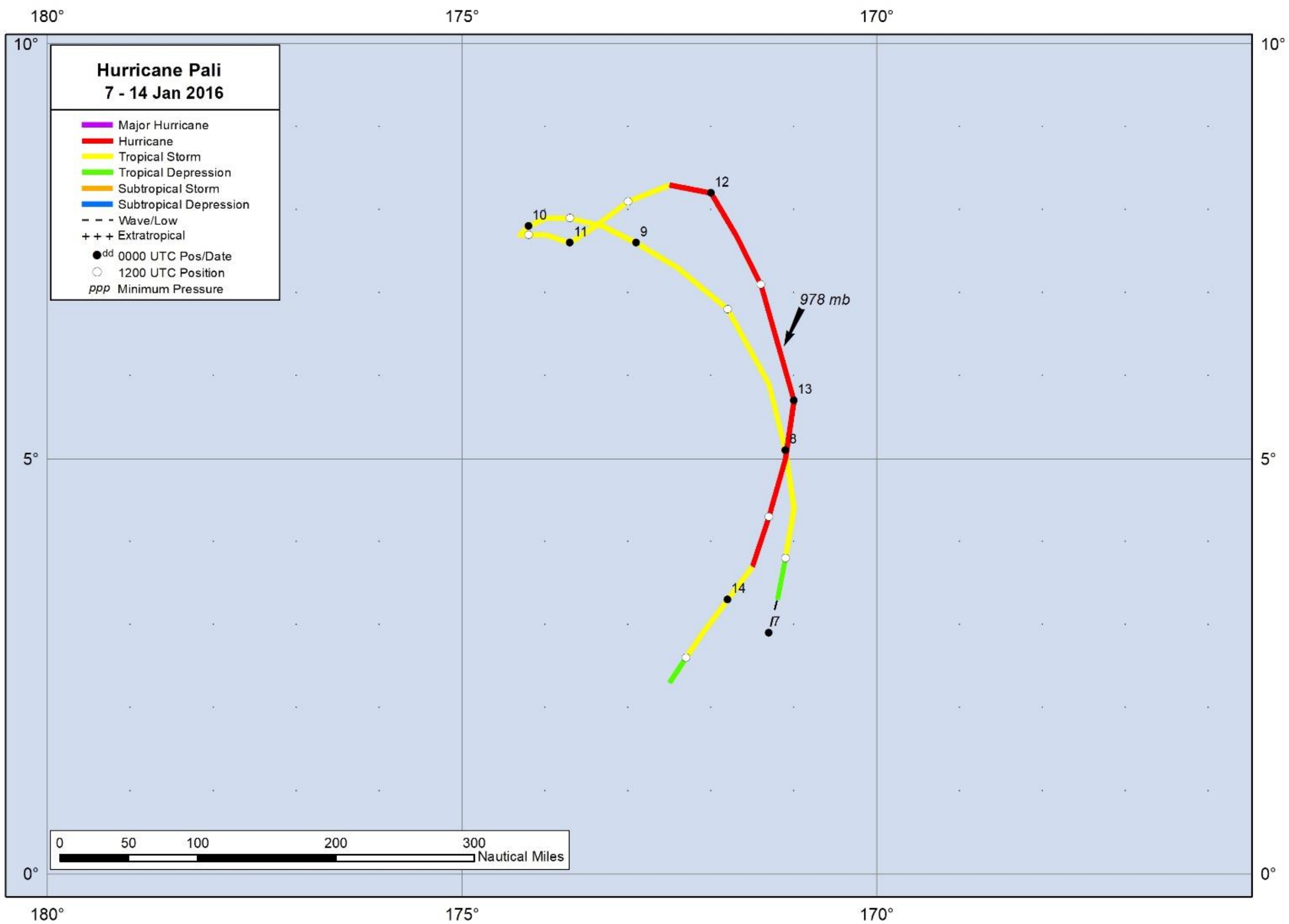

Figure 2. Best track positions (close in) for Hurricane Pali, 7 – 14 January 2016.

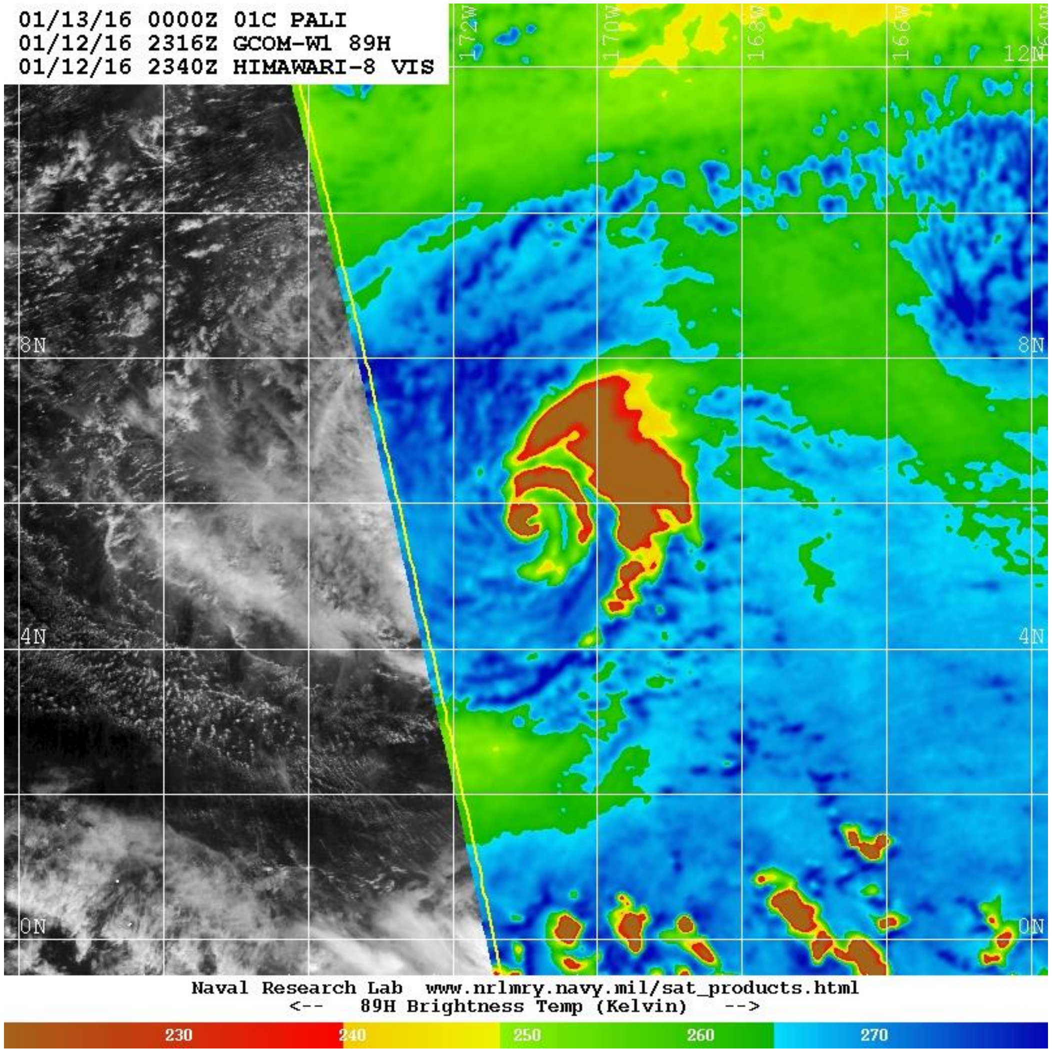

Figure 3. An 89 GHz image (courtesy of the Naval Research Laboratory) from the AMSR2 instrument aboard the GCOM satellite at 2316 UTC 12 January shows the eye wall structure of Hurricane Pali near the time of maximum intensity.