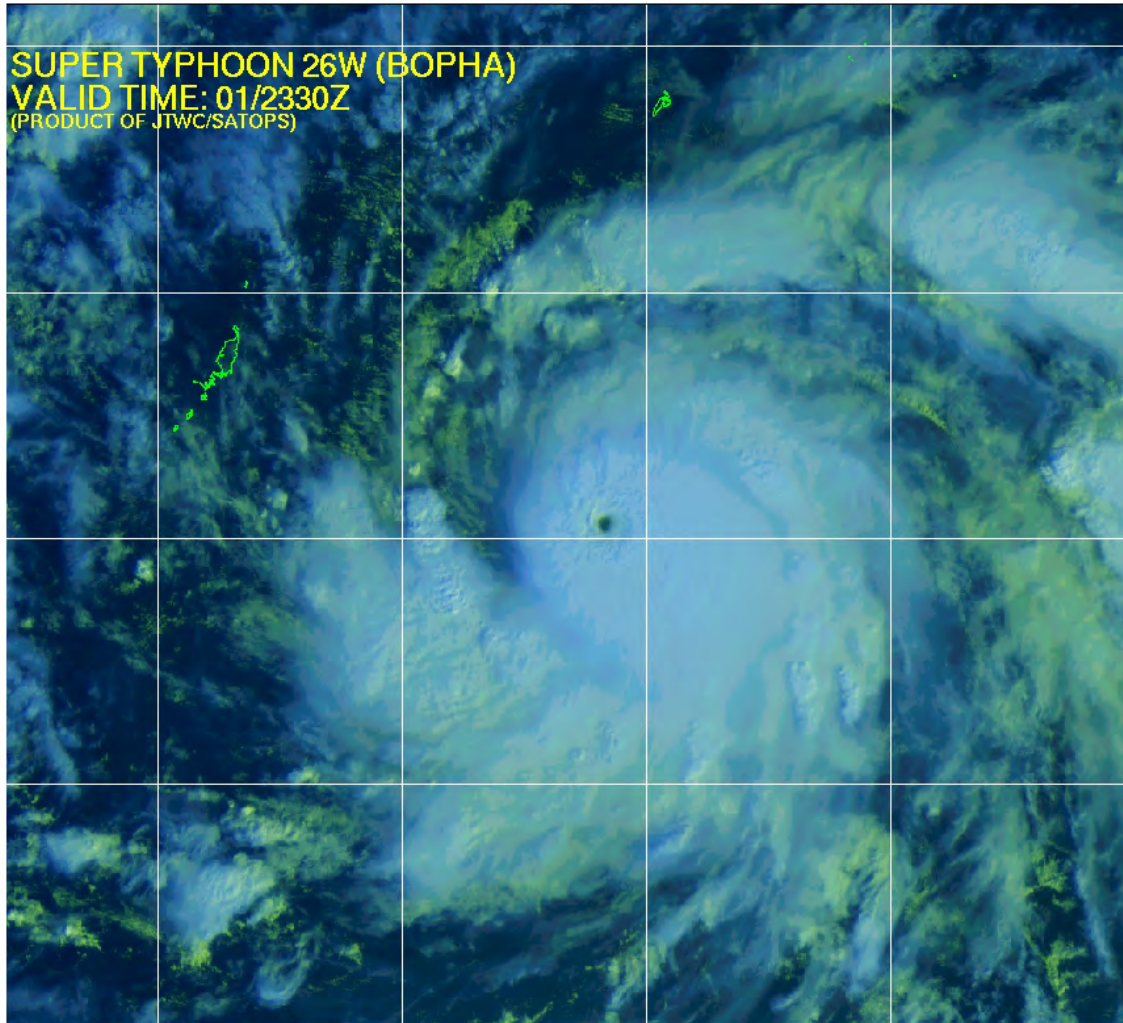




A Summary of Palau's Typhoon History 1945-2013



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Summary:

Since 1945 Palau has had 68 recorded typhoons, tropical storms or tropical depressions come within 200 nmi of its islands or reefs. At their nearest point to Palau, 20 of these were typhoon strength with winds ≥ 64 kts, or an average of 1 typhoon every 3 years. November and December had the highest number of significant storms; July had none over 40 kts and August had no recorded storms.

Data Compilation:

Storms within 200 nmi (nautical miles) of Palau were identified from the Digital Typhoon, National Institute of Informatics, Japan web site (<http://agora.ex.nii.ac.jp/digital-typhoon/reference/besttrack.html.en>). The storm tracks and intensities were then obtained from the Joint Typhoon Warning Center (JTWC) (<https://metoc.ndbc.noaa.gov/en/JTWC/>). Three storm categories were used following the JTWC: Tropical Depression, winds ≤ 33 kts; Tropical Storm, winds 34-63 kts; Typhoon ≥ 64 kts. All track data was from the JTWC archives. Tracks were plotted on Google Earth and the nearest distance to land or reef, and bearing from Palau, were measured; maximum sustained wind speed in knots (nautical miles/hr) at that point was recorded. Typhoon names were taken from the Digital Typhoon site, but typhoon numbers for the same typhoon were from the JTWC archives. Digital Typhoon and JTWC typhoon numbers were not always the same, and the total number of storms per year did not always agree, suggesting variability between the two agencies in categorizing the tropical depressions.

The limitations of this current data table and analysis are seen when reviewing the recorded impacts of Typhoon Sally (1967-02) on Koror. The data table shows a simple tropical storm, rather than the rapidly significant building storm that encompassed Palau and ended up having a critical impact on the country.

Results:

Palau has had 68 recorded typhoons, tropical storms or tropical depressions come within 200 nmi of its islands or reefs since 1945 (Table 1). At their nearest point to Palau, 29 storms (43%) had winds ≤ 33 kts, 19 (28%) had winds 34-63 kts, and 20 storms (29%) were typhoon strength at ≥ 64 kts (Figure 1). Of these 20 typhoons, 8 passed within 35 nmi, almost certainly having a significant affect (Figure 2). 12 other typhoons passed over 50 nmi away (50-200 nmi) (see also Fig. 2). A small jog in these latter typhoon tracks could have easily brought these storms closer to Palau. The storms appeared randomly scattered over the 68 year period, with two extended lulls, or periods of little activity: 1950-1958 and 1991-2001.

Table 1. Typhoons, tropical storms and tropical depressions that have come within 200 nmi of Palau between 1945 - 2013. Storms highlighted in yellow passed within 35 nmi of Palau at typhoon strength (≥ 64 kts). Data is from the Digital Typhoon, National Institute of Informatics, Japan (<http://agora.ex.nii.ac.jp/digital-typhoon/reference/besttrack.html.en>) and the Joint Typhoon Warning Center (JTWC) (<https://metoc.ndbc.noaa.gov/en/JTWC/>).

Year	Typhoon Name-JTWC No.	Month	Nearest Distance to Palau (nmi)	Storm Winds at Nearest Point-sustained (kts)	Nearest Point Location in Palau	Direction from Nearest Point
1947	No Name- 21	Nov	207	75	Kayangal	ENE
1947	No Name- 23	Nov	18	100	Kayangal	NE
1947	No Name- 27	Dec	115	80	Kayangal	NNE
1948	No Name- 26	Dec	0	25	Kossol	-
1949	No Name- 01	Jan	80	60	Kayangal	NE
1949	No Name- 03	Jul	0	20	Angaur/Peleliu	-
1949	No Name- 19	Nov	130	30	Angaur	E
1949	No Name- 21	Dec	16	30	Angaur	S
1949	No Name-22	Dec	43	40	Kayangal	E
1953	No Name- 23	Nov	0	30	Ngaraard	-
1954	No Name- 01	Mar	0	30	Angaur	-
1955	Violet- 01	Jan	7	30	Angaur	S
1957	Shirley- 03	Apr	5	35	Angaur	SSW
1959	Sally- 02	Mar	30	40	Kayangal	NNE
1959	Gilda- 22	Dec	26	110	Kayangal	NNE
1962	Lucy- 28	Nov	0	40	Angaur	-
1964	Louise- 36	Nov	12	100	Angaur	S
1964	Opal- 39	Dec	35	140	Kayangal	N
1967	Sally- 02	Mar	0	35**	Koror	-
1969	Susan- 03	Apr	0	35	Airai/Aimelik	-
1970	Nancy- 01	Feb	77	110	Kayangal	NNE
1970	Kate- 18	Oct	125	90	Angaur	SSE
1970	Louise- 19	Oct	8	25	Angaur	NW
1971	Jean- 15	Jul	40	35	Kayangal	N
1971	Elaine- 30	Jul	45	30	Angaur	SW
1972	Therese- 31	Dec	0	50	Koror	-
1975	Lola- 01	Jan	0	45	Northern Rfs	-
1976	Marie- 03	Apr	12	75	Kayangal	N
1979	Cecil- 03	Apr	0	45	Babeldaob	-
1979	Dot- 04	May	23	25	Angaur	SW
1979	Vera- 24	Nov	115	130	Kayangal	NNE

Table 1. (continued)

Year	Typhoon Name-JTWC No.	Month	Nearest Distance to Palau (nmi)	Storm Winds at Nearest Point-sustained (kts)	Nearest Point Location in Palau	Direction from Nearest Point
1982	Mamie- 01	Mar	0	55	Kayangel	-
1982	Nelson- 02	Mar	54	60	Kayangel	NNE
1982	Pat- 04	May	143	25	Kayangel	NNE
1984	Agnes- 27	Nov	66	90	Kayangel	NNE
1986	Judy- 01	Feb	34	50	Kayangel	NE
1986	Ida- 23	Nov	66	30	Angaur	SW
1988	Ruby- 23	Oct	80	45	Kayangel	N
1988	Skip- 24	Nov	56	95	Kayangel	N
1989	Dot- 05	Jun	20	25	Kayangel	NNE
1990	Percy- 07	Jun	93	85	Kayangel	NNE
1990	Mike- 27	Nov	0	135	Kossol***	-
1991	Sharon- 01	Mar	0	45	Koror	-
1993	Kyle- 34	Nov	55	20	Kayangel	N
1995	Sibyl- 20	Sep	0	25	Ngiwal/Ngaraard	-
1995	Dan- 35	Dec	0	20	RISL/Koror	-
1996	No Name- 01	Feb	33	20	Kayangel	NNE
2000	Damrey- 01	May	33	25	Kayangel	E
2000	Xangsane- 30	Oct	70	30	Kayangel	NNE
2000	Bebinca- 31	Oct	7	25	Angaur	SW
2001	Utor- 06	Jul	173	30	Babeldaob	E
2002	Mitag- 02	Mar	128	100	Kayangel	NNE
2003	Soudelor- 07	Jun	98	30	Kayangel	N
2004	Sudal- 03	Apr	154	120	Kayangel	NE
2004	Nida- 04	May	133	25	W Barrier Rf	W
2004	Omais- 06	May	117	55	Kayangel	NNE
2004	Dianmu- 09	Jun	93	30	Kayangel	ENE
2004	Nanmadol- 30	Dec	150	85	Kayangel	NNE
2006	Utor- 25	Dec	88	30	Kayangel	NNE
2008	Fengshen- 07	Jun	0	15	N Babeldaob	-
2008	Higos- 21	Oct	30	20	Kayangel	N
2009	Parma- 19	Oct	111	75	Kayangel	NE
2011	Songda-04	May	147	55	Kayangel	NNE
2011	Banyan- 23	Oct	0	20	Kayangel	-
2011	Washi- 27	Dec	0	35	RISL Koror	-
2012	Bopha- 26	Dec	25	135	Angaur	S
2013	Rumbia- 05	Jun	144	30	Kayangel	NW
2013	Haiyan- 30	Nov	0	155	Kayangel	-

**Storm rapidly intensified over Koror which did not show up in the data point closest to Palau; gusts to 75kts ~ midnight March 2nd.

***10 nmi S of Kayangel & N of Ngarchelong

Palau Storms within 200 nmi (JTWC) 1945-2013

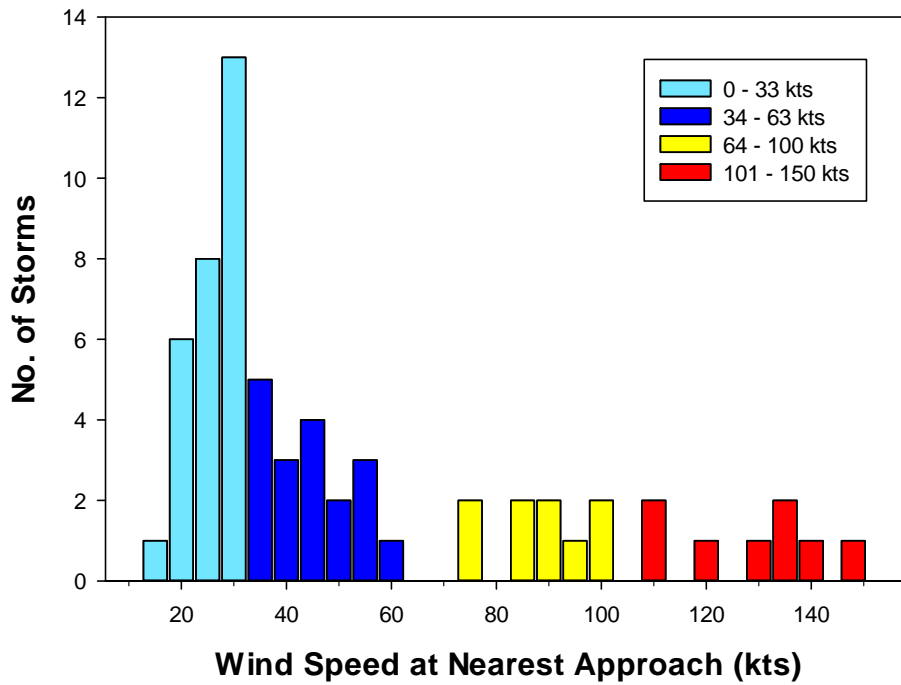


Figure 1. Distribution of Palau storms by wind speed at the point of nearest approach to Palau during 1954-2013. Data from JTWC.

Palau Storms by Year (within 200 nmi) 1945-2013

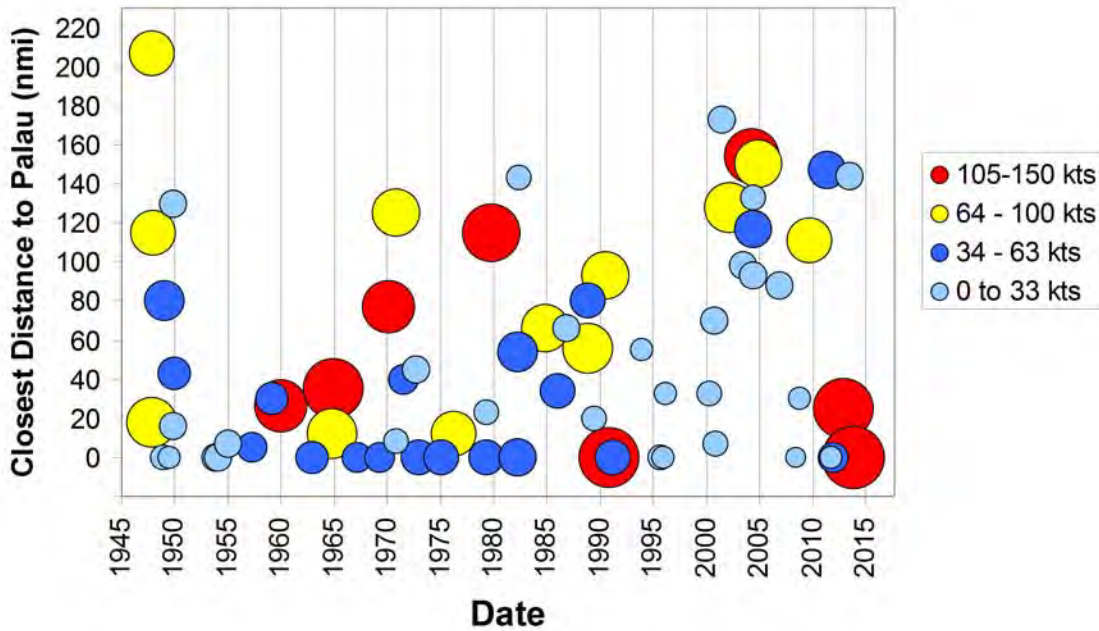


Figure 2. Distribution of Palau storms by year showing each storm's closest approach. Circle size is proportional to the sustained wind speed (kts). Colors separate storms into categories according to storm intensity.

40 storms (59%) passed over Kayangel or within 200 nmi north of it, 13 storms (19%) over Babeldaob/Koror, and 15 (22%) passed over or within 200 nmi south of Peleliu/ Angaur (Figure 3).

Palau Storms by Area (within 200 nmi) 1945-2013

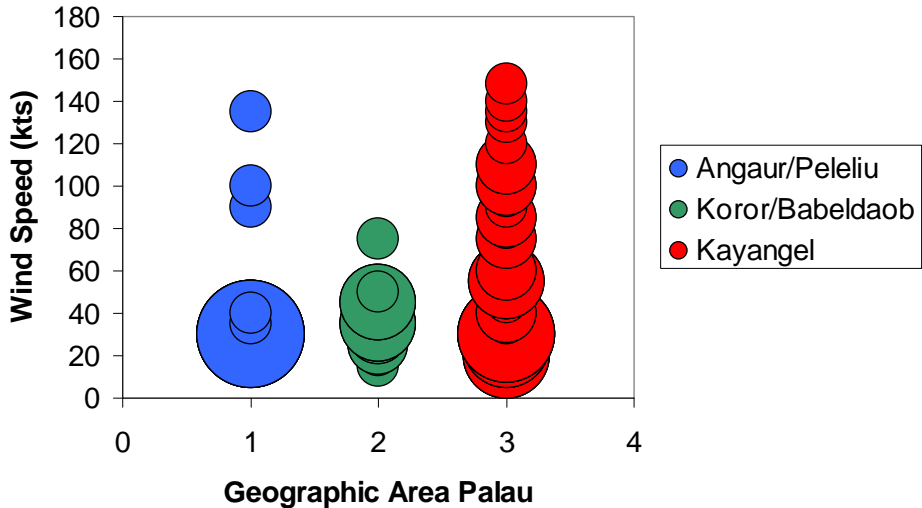


Figure 3. Distribution of all storms passing over or nearest to three geographical areas of Palau: Angaur/Peleliu, Koror/Babeldaob and Kayangel. Diameter of circles is proportional to the number of storms.

Over the 69 year period, November and December had the highest number of typhoons passing within 200 nmi of Palau (Figure 4). Typhoons were also recorded in February, March, April, June, September and October. July only had 3 storms of 40kt or less, and August had none.

Palau Storms by Month (within 200 nmi) 1945-2013

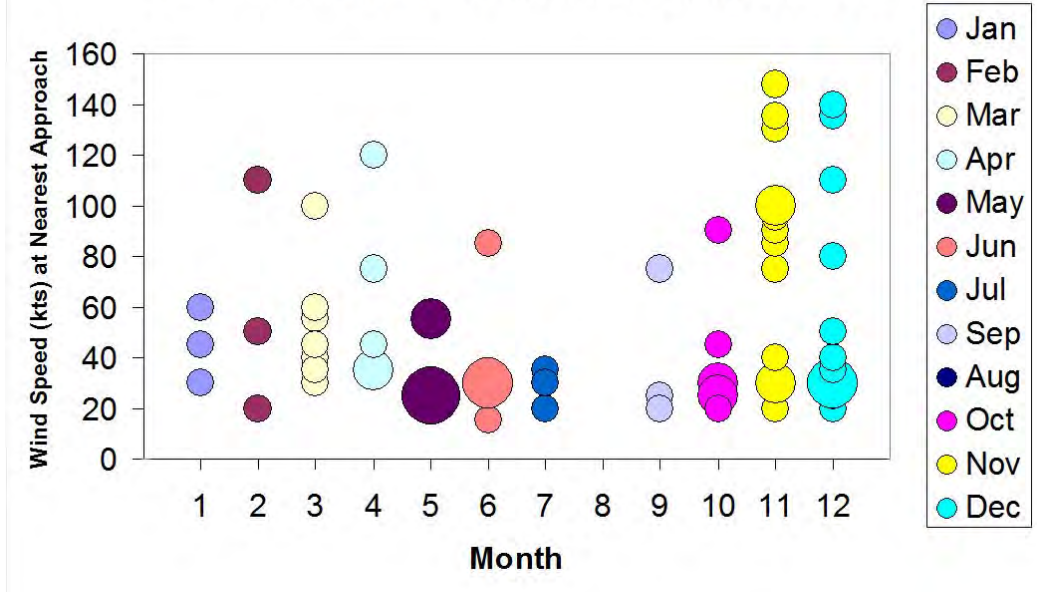


Figure 4. Distribution by month of all storms passing within 200 nmi of Palau between 1945 and 2013. Diameter of circles is proportional to the number of storms at a specific wind speed.

Notes on Past Typhoons:

Historical Records of Typhoons from Old Literature- "Typhoons are not uncommon, but records for Palau are poor." (Spennemann, 2004).

1833, March: Tobi. Given how far south Tobi is, the storm could have been a strong westerly wind burst, rather than a typhoon (Spennemann, 2004).

~ **1868/69, Nov/Dec/Jan:** A strong typhoon occurred causing extensive damage only to northern Palau and also affected Ngulu (surmised from collected readings by Kramer, as detailed in Kramer, 1917).

1872, between 4-22 Jan: Koror (Spennemann, 2004).

1904, Nov: A typhoon destroyed Pulu Ana and Merir, leading to the evacuation of residents to Koror (Kramer, 1917; Spennemann, 2004).

1905, Apr: Pulo Ana, Sonsorol (Spennemann, 2004).

1909, Mar 17-18: A storm was recorded by the German administration; 13.5 in. (35 cm) rain in 36 hours (Spennemann, 2004; van der Brug, 1984).

1912, Nov 22: A typhoon or tropical storm passed north of Palau (Kramer, 1917: 208).

1912, Nov 26: This typhoon took the Germans by surprise when northern Palau was severely damaged by a small diameter typhoon; Koror was not severely affected. The typhoon was well-recorded causing much damage to northern Babeldaob, where "no house was left standing." The barometer in Koror reached 988 MB at 11pm, where winds swung from NW to W to SW, indicating the eye passed to the north. Winds were significant in Melekeok with corrugated iron sheets wrapped around trees, and missionary buildings in Melekeok and Aimeliik were destroyed. Melekeok was in or near the southern eye wall of the storm as it passed. Statements from missionaries in Ngarchelong indicated it was far worse; it was in the NE quadrant of the storm. Taro patches of villages on the NW side of the island were flooded with salt water and storm surge was said to have reached 7 ft (2.1 m). On Kayangel all houses were destroyed. Wind directions were reported as N, E and then S, indicating the eye passed to the south of Kayangel. (Kramer, 1917:208-210; Spennemann, 2004).

1927, May: This storm was the worst recorded during the Japanese administration where 80% of all houses were damaged; all 5 villages were destroyed on Peleliu (van der Brug, 1984).

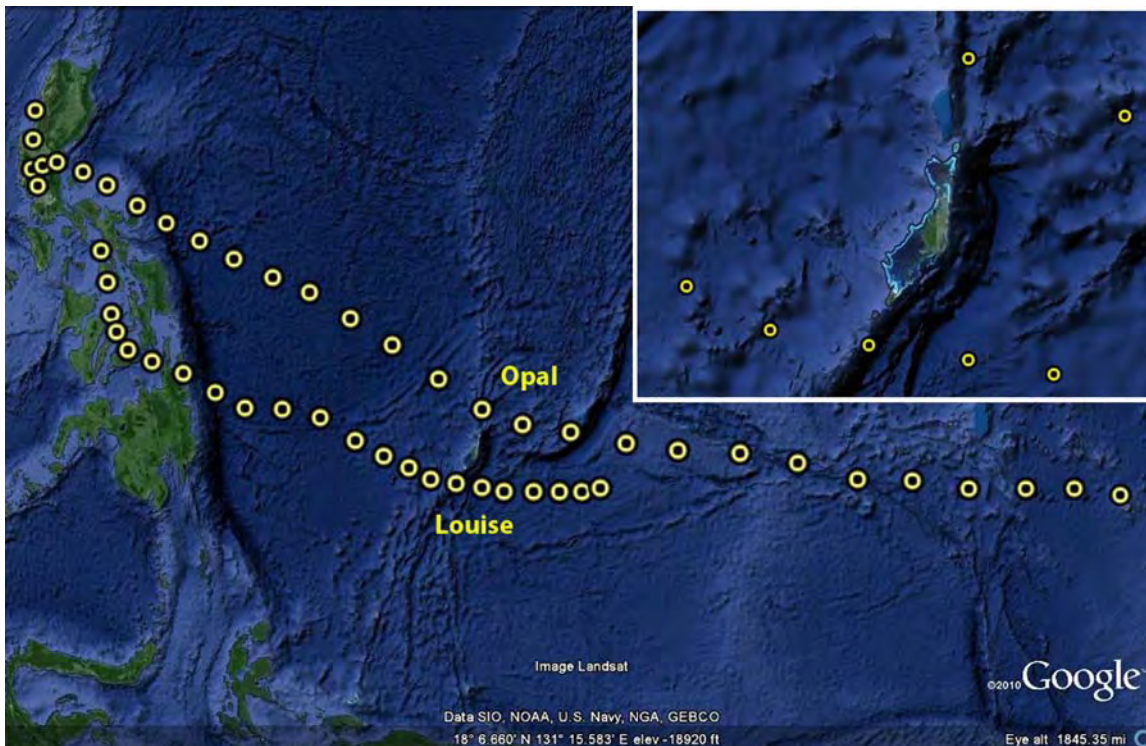
1928, May 28: A typhoon, accompanied by a massive storm surge, leveled most buildings in Koror (Spennemann, 2004).

Notes on Recent Significant Typhoons:

1964- Typhoons Louise and Opal:

In 1964, typhoon Louise's center passed 12 nmi S of Angaur with 100 kts sustained winds on November 17th. Less than one month later, on Dec 12th, Typhoon Opal's center passed 35 nmi N of Kayangel with 140 kts sustained winds. There was no mention of these storms' effects on Palau in the 1964 Climatological Data National Summary; the report focused on their affects on the Philippines. Both were strong typhoons upon landfall in the Philippines, at 140 kts and 100 kts, respectively. Angaur and Peleliu must have been significantly affected locally by Louise. A photo of Quonset huts on Peleliu from WWII has a caption saying they were all destroyed in the 1964 typhoon.

Comparing Typhoon Bopha of 2012 to Louise, they both took similar tracks, passing south of Angaur, but Louise formed and gathered strength much closer to Palau so there was less time for the wind and wave forces to build and produce a tidal surge on the east coast of Babeldaob and other islands.

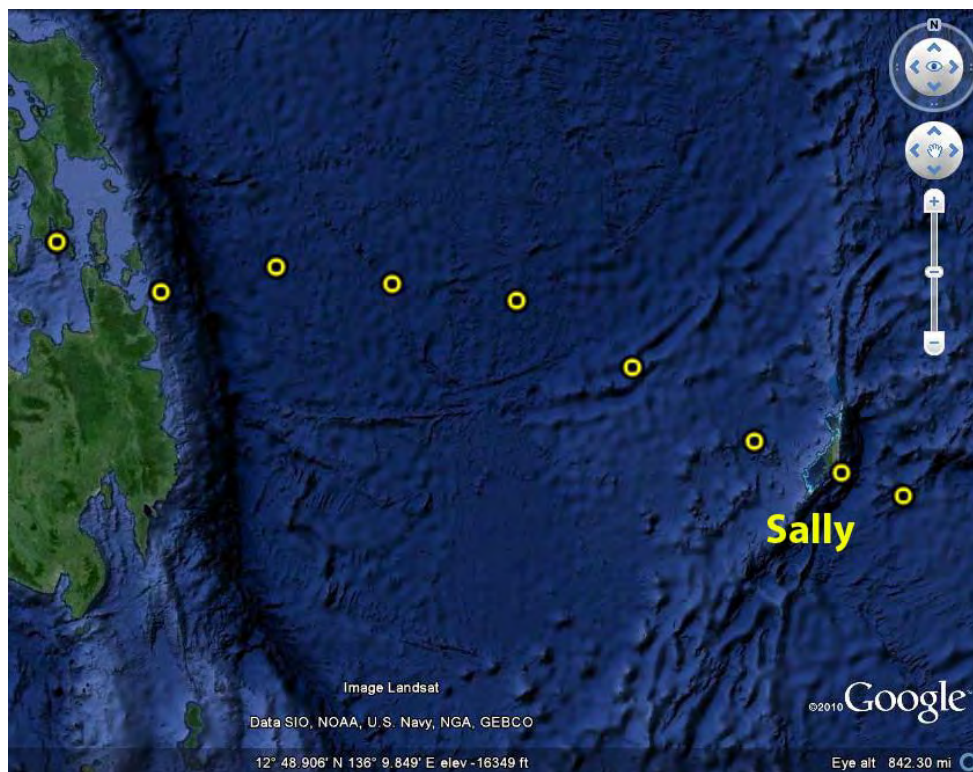


1967- Typhoon Sally:

This storm was memorable in Koror, although this is not apparent from the track data. It intensified right over Koror, with normal 8 kt winds and rising pressure at 8PM on 1 March to 65 kt gusts with rapidly decreasing pressure at 11PM [on 1 March], as recorded at the

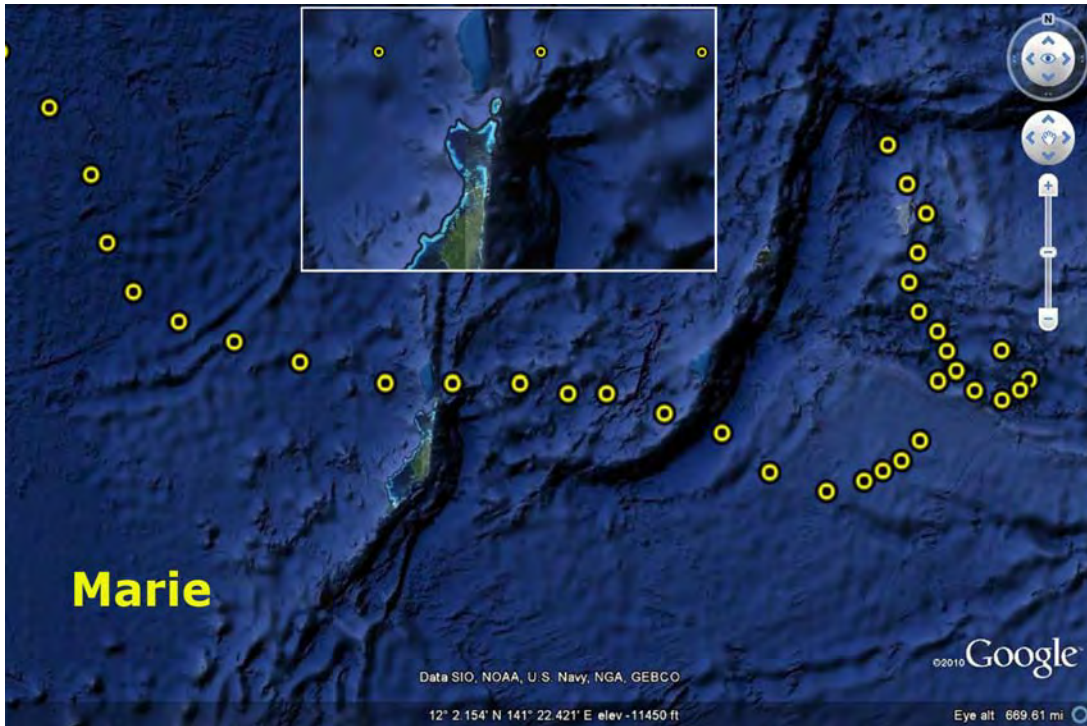
Koror weather station (Stevenson, 2009). It is believed the eye passed near Koror sometime after midnight, which recorded 72kt winds first from the North (approaching) and then from the South (moving away) and was moving with a forward speed of more than 18 kt (Stevenson, 2009).

Photos from aircraft reconnaissance after Sally passed showed evidence of selective strips of damage to vegetation on southern Babeldaob, suggesting tornadoes were embedded in the circulation (Stevenson, 2009). Records show 80% of the island's buildings were destroyed or damaged (Climatological Data National Summary, 1967). Palauans still talk about this storm.



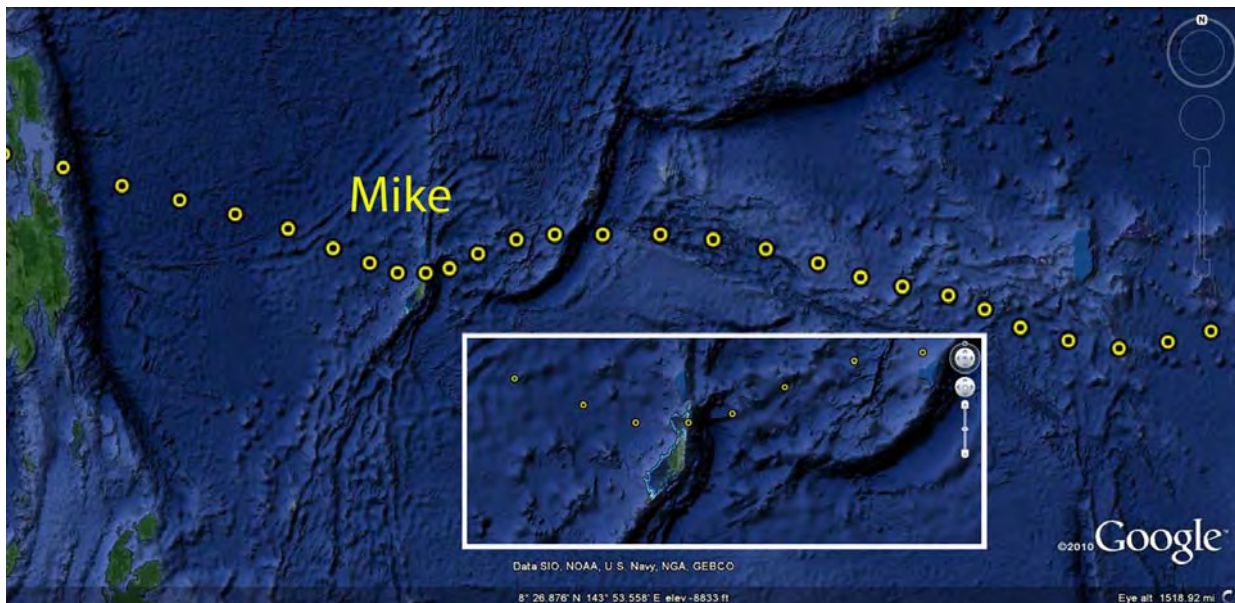
1976- Typhoon Marie:

Typhoon Marie is not discussed much in Koror, but it appears it was a significant typhoon for Palau. On April 7th it passed 12 nmi N of Kayangel. Track data indicates it had sustained winds of 75 kt at that time. In Koror the peak wind gusts recorded were 75 kts with 993 MB pressure. “While no deaths or injuries were reported, damage of more than \$4 million was incurred on the Palau Islands. Crop destruction was extensive, as was damage to buildings and public utilities. As a result, Palau was declared a major disaster area.” (Stevenson, 2009).



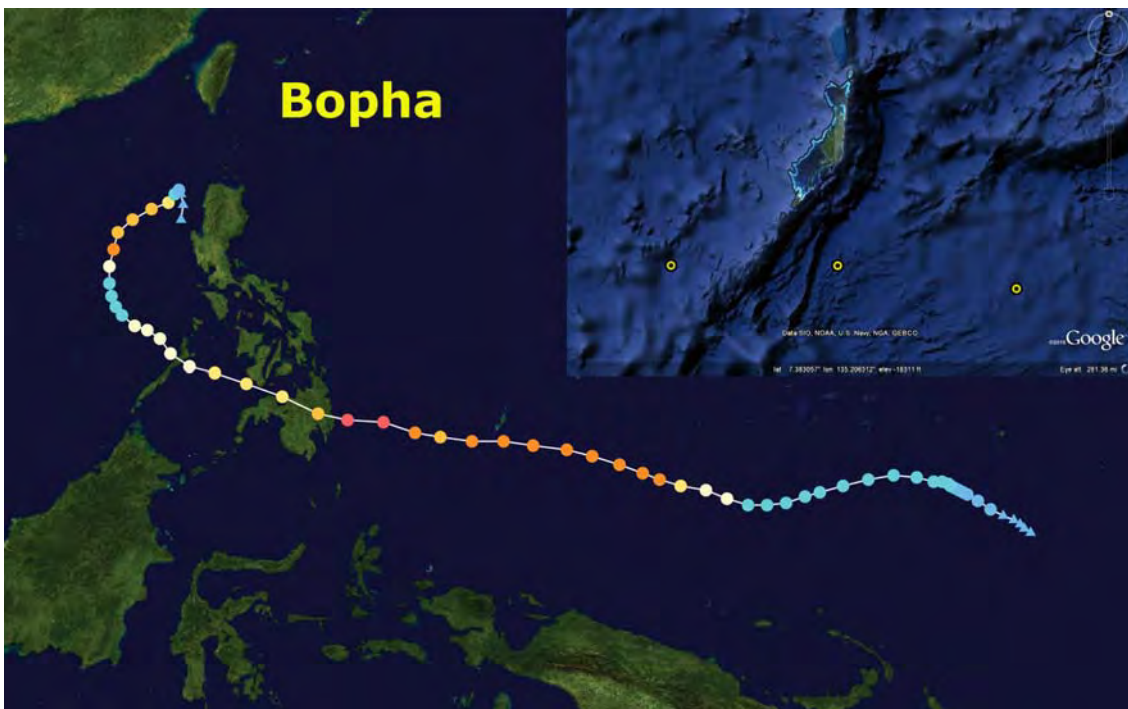
1990- Typhoon Mike:

This was a significant typhoon for Palau, passing the night of November 10th. It measured 135 kts sustained winds as it crossed the northern reefs, increasing to 150 kts 6 hr later. The eye was recorded 10 nmi S of Kayangel and 10nmi N of Ngarchelong. Being in the NE quadrant of the storm, Kayangel would have had E winds and took almost a direct hit. This storm formed just south of Chuuk, so traveled a significant distance before hitting Palau. It went on to hit the central Philippines with 130 kt winds.



2012- Typhoon Bopha:

This was a very significant typhoon for Palau, with apparently little to no living memory of the dramatic inundation by storm surge on the east side. Typhoon Bopha passed 25 nmi south of Angaur around midnight on 2-3 Dec 2012. Maximum sustained winds estimated by the JTWC at its closest approach to Angaur were 135 kts. Barring information of any closer weather stations, the CRRF tower weather station (TWS- elevation ~100 ft. (30m) above sea level) on Ngeanges Island and SIO XMET station (station elevation ~10 ft. (3m) above sea level) on Ongingiang Island, both in the rock islands approx 50 nmi. from the storm track, measured weather during the typhoon. The TWS measured maximum sustained winds of 52 kts at 23:15 (2 Dec) and maximum gusts of 73 kts at midnight, 2/3 Dec. The XMET measured average winds of 43 kts with the peak gust of 62 kts. The Koror NOAA weather station in town measured the peak 2-minute sustained wind speed of 35 kts and the peak 5 second wind speed of 61 kts. The Palau airport recorded peak winds of 51 kts with winds of increasing speed from the NE, swinging to the E and then to the SE as the winds decreased in strength.



Damage from Bopha in Palau was extensive, with much of the eastward reef faces from Angaur north to the northern extreme of Babeldaob being severely damaged. Although the storm passed 25 nm south of Angaur, it produced high swell, waves and winds on the entire eastern side of the main Palau group. As the storm approached, wave models predicted significant wave heights of 30-40 ft (9-12 m) along the east side of Babeldaob (Eric Terrill, Scripps Inst. Oceanography, pers. comm.- Figure 5). Low-lying villages along this coast had dramatic storm surges that destroyed most homes. Also along the east side, reef materials (coral heads, rocks and boulders) were broken loose, which scoured and battered

the reef to the extent that many areas were swept clean to bare rock from the shallows to depths over 130 ft (40 m).

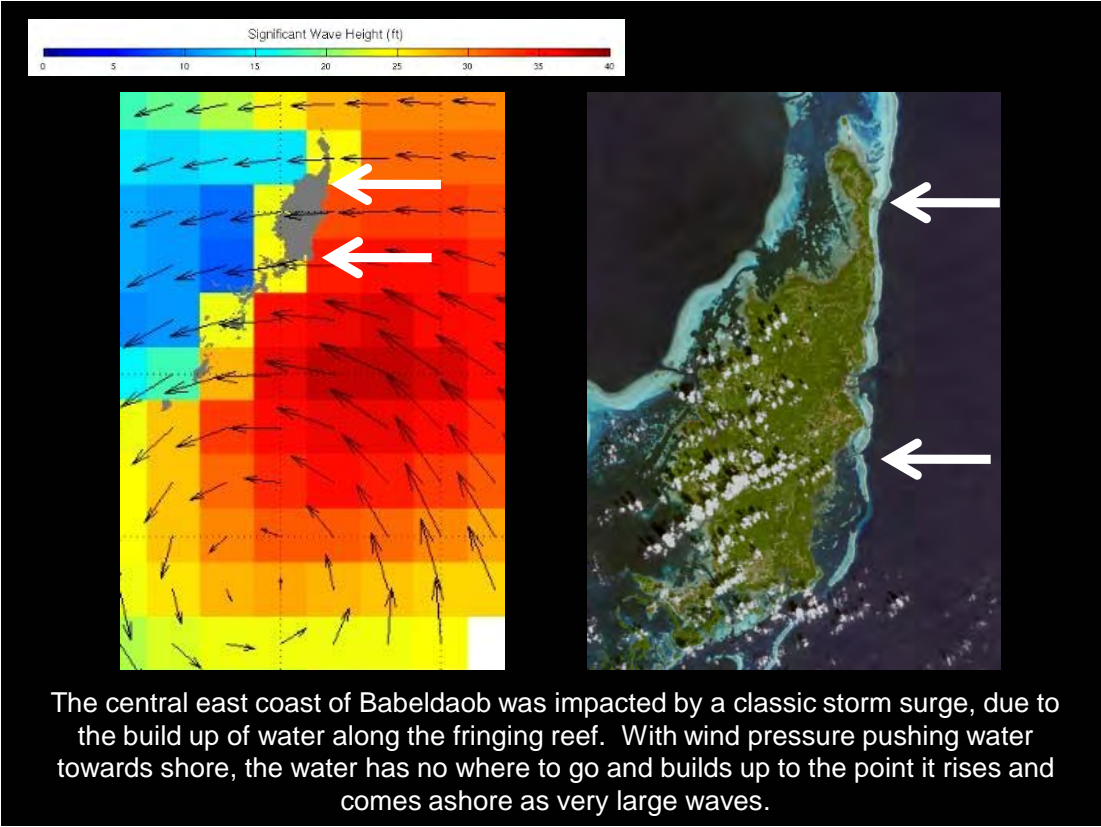


Fig. 5. Storm surge model (left) showing corresponding area of inundation on the east side of Palau from typhoon Bopha.



Figure 6. A large rubble berm from typhoon Bopha created a small lagoon on the east side of Angaur. Photo taken on 5 Dec 2012, 3 days after typhoon Bopha passed.

Sand berms (Fig. 6) were deposited just seaward of the shore of many east side areas (eg. Angaur, Peleliu & Lighthouse Reef) creating small lagoons along some of their length behind them. The storm caused suspension of huge amounts of sediment from the damaged reef structure and sediment bottoms which experienced unprecedented disturbance. Massive plumes of sediment (Fig. 7) from the entire Palau reef tract were visible from space for months afterwards, extending more than 100 miles to sea.

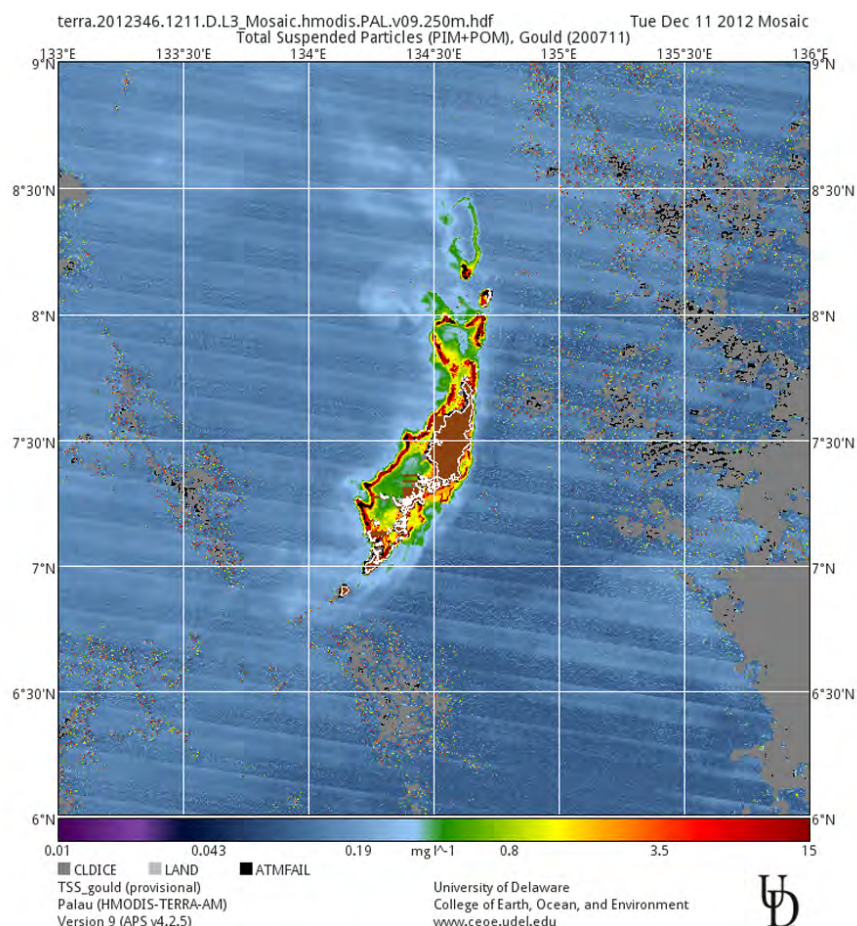
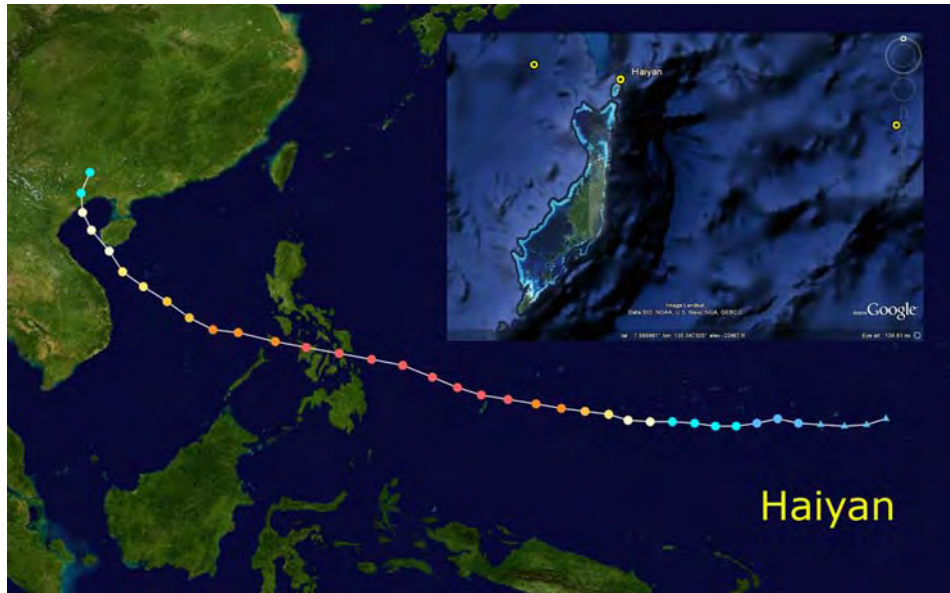


Figure 7. Satellite image of Palau from 11 Dec 2012, 9 days after typhoon Bopha passed, showing whitish sediment plumes coming off the Palau reefs.

2013- Typhoon Haiyan:

Super Typhoon Haiyan had a significant effect on Kayangel and Ngeruangel, and also did damage in the northern Babeldaob states. The storm was near category 5 as it approached Palau, hitting 6-7 Nov 2013. It tracked north of Koror saving the main population center from a direct hit, but the eye went directly over Kayangel and Ngeruangel. Sustained winds were estimated by the JTWC to be 155 kts as it passed over Kayangel. Most structures were destroyed on Kayangel, though no lives were lost.



The SIO XMET weather station (station elevation ~10 ft. (3 m) above sea level) located on Ngeruangel recorded its last reading of 64 kts maximum gusts at midnight on 6/7 Nov before it was destroyed. Wind direction was from the north, indicating the typhoon eye was approaching. Residents from Kayangel described a period of calm, indicating the ~10 nm diameter eye passed over the island. Winds at the Palau airport averaged 38 kts with peak gust at 50 kts, from the W to SW. The Koror NOAA weather station in town measured peak 2-minute sustained winds of 35 kts and peak 5 second wind speeds of 67 kts, from the SW.

On Kayangel, few trees and structures were left standing (below left) and stories tell of families hiding in cement bathrooms or water tanks during the storm. The tide was ebbing as the typhoon approached, reaching low tide at 4AM on 7 Nov. Consequently, the island was not fully overwashed, though there was saltwater damage to the fresh water lens. Interestingly, the sea grass bed on the lagoon side of Kayangel island was little affected.



Figure 8. A photo mosaic Kayangel Island taken one day after typhoon Haiyan passed. The red line shows the area of inundation on the east side of the island from ocean waves during the storm.



Figure 9. The main village center and dock on Kayangel Island after Haiyan (left) compared to less than 2 months before the typhoon (right).



Figure 10. Taken on 8 Nov 2013, this view looks north along Kayangel Island showing the extreme damage to structures and the environment following typhoon Haiyan.

The seas from Haiyan swept over Ngeruangel and deposited about a foot or more of new rock and rubble onto the island (Figure 11). The large stone cairn on the island was swept away with not even a single stone remaining to mark its location. The island was swept clean of all marine debris. Ngeruangel island moved about 15 m westward, grew somewhat in size and became higher. The shape of the island also changed. Within 1 month of the passage of the storm, crested terns were nesting with eggs on the island.



Figure 11. Ngeruangel Island after typhoon Haiyan passed on 6-7 Nov 2013 (left) compared to an old aerial image from 2004 (right). Images are georegistered, showing the westward expansion of the island.

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