

## Super Typhoon Haiyan

Super Typhoon Haiyan—M. A. Lander and C. P. Guard

On the morning of 08 November 2013, Super Typhoon Haiyan (Fig. 1) (christened “Yolanda” by Philippine authorities) roared ashore in the Visayas Region of the Republic of the Philippines. This cyclone caused catastrophic destruction and thousands of casualties, particularly within Samar and Leyte Provinces. The city of Tacloban suffered heavy damage from the deadly power of the wind and enormous storm surge. The plight of this city became the focus of world media attention and subsequent international relief efforts. The Joint Typhoon Warning Center (JTWC) estimated Haiyan’s one-minute sustained winds at 315 km/h (195 mph) when the cyclone first touched land in Guiuan in eastern Samar. As yet unofficial and in need of validation, the JTWC wind speed makes Haiyan the strongest tropical cyclone at landfall, surpassing the old record of 305 km/h (190 mph) set by Atlantic Hurricane Camille in 1969. Earlier in its life, the eye of Super Typhoon Haiyan passed directly over Kayangel Atoll, the northernmost island in the Republic of Palau.

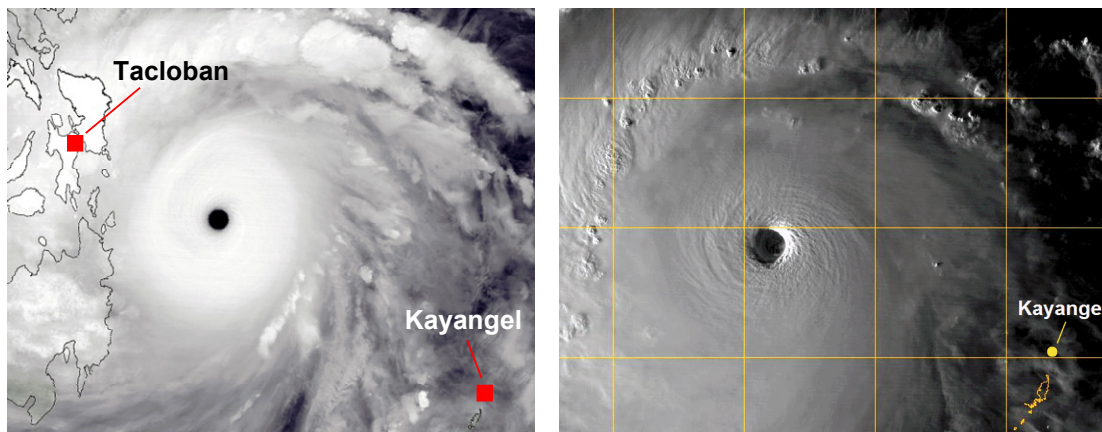


Figure 1. Super Typhoon Haiyan. Infrared image (left) and visible image (right).

The typhoon season of 2013 was overall near normal, with a relative quiescence through August balanced by a strong burst of activity during mid-September through early November. A record seven typhoons formed in the western North Pacific basin during October, and during the first week of November, the final typhoon of 2013, Super Typhoon Haiyan, formed at very low latitude south of Pohnpei Island and then proceeded quickly westward at low latitude in Micronesia. This cyclone became a super typhoon (i.e., maximum sustained 1-minute wind of 130 kt) to the east of Palau, just before it tracked directly over Palau’s northernmost atoll of Kayangel causing much destruction, but no loss of life. Continuing on a west-northwestward track it made landfall close to the city of Tacloban in Leyte province of the central Philippines. It was the second super typhoon in less than a year to directly affect and seriously impact the Republic of Palau – Super Typhoon Bopha passed near Palau in early December 2012 (Fig. 2). Bopha and Haiyan both severely impacted islands in the southern provinces of the Philippines.

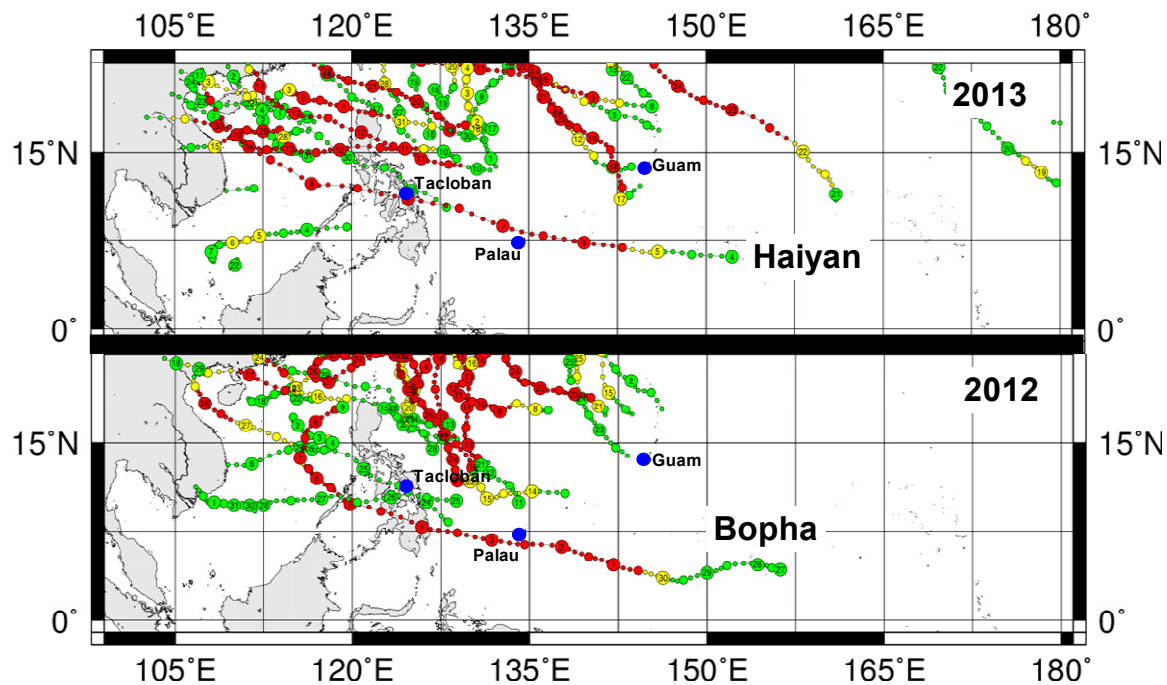


Figure 2. Tracks of 2012 and 2013 typhoons in the western North Pacific reveal the unusual similarities of location and movement of Bopha and Haiyan.

When on the 7<sup>th</sup> of November 2013, the Joint Typhoon Warning Center (JTWC) estimated the intensity of Haiyan to be 170 kt, history was made. This was the highest wind speed ever assigned to a tropical cyclone by the JTWC, and surpassed by 5 kt the previous record wind speed of 165 kt assigned to Super Typhoon Tip during October 1979. The word “assigned” is appropriate because Tip’s 165 kt peak wind was not actually measured, but was based on a wind-pressure relationship. Haiyan’s 170 kt peak wind was based on the wind-speed equivalent for a Dvorak satellite signature of T8.0 (the highest on the Dvorak scale).

Haiyan’s extreme intensity and deadly power immediately fueled speculation on the role of climate change in its occurrence and behavior. Haiyan’s behavior certainly was unusual on at least several counts: (1) high intensity at low latitude (i.e., ~5°N); (2) extreme intensity; (3) record-setting landfall intensity; (4) destructive and deadly power of the massive storm surge and high wind in the Philippines; and, (5) its eerie one-year follow-on to a similar unusual low-latitude intense typhoon (Bopha).

Whereas even elderly residents of Tacloban could not remember a typhoon such as Haiyan striking their city during their lifetimes, there are two historical occurrences over 100 years ago of typhoons with similar impact. An intense typhoon in late October 1897 had similarities with Haiyan in terms of its path, destructive capacity, and very high storm surge. The communities and churches of Samar and Leyte, including Guiuan, Tacloban and Palo were destroyed. Hundreds were killed. Similar to Haiyan, the 1897 typhoon first made landfall near Guiuan in Samar Province, then proceeded to Tacloban.

Hernani on the eastern Samar coast experienced a storm surge of 7.3 meters. The storm surge reached 4 to 5 meters in the vicinity of Tacloban.

Another extremely powerful typhoon swept along a path similar to Haiyan in November 1912. The Washington Herald issue of 20 November, 1912 ran a story headlined, "15,000 die in Philippine storm". It reads, in part:

*"The typhoon swept the Visayas and is said to have practically destroyed Tacloban, the capital city of Leyte, and to have wrought enormous damage and loss of life at Capiz, ... ..15,000 persons were probably killed and wounded in a typhoon ... probably half the population of the two cities had been lost."*

The major cause of damage and loss of life during Haiyan's passage through the Philippine archipelago appears to have been the storm surge, with the concentration of devastation on the east coast of Samar and Leyte, with a particular focus on Tacloban. The tremendous storm surge may have been as much as 7.5 meters (24.6 feet) high, which would make it a candidate for the highest storm surge ever observed in the Philippines and all of east Asia, surpassing the confirmed surge of 7.3-meter that struck the Philippines in 1897 (Arafiles et al. 1978). Much of the city of Tacloban sits less than 5 meters above sea level. Early surge estimates at Tacloban are 6.5 m at the airport and perhaps 8.53-9.14 m (28-30 ft) in downtown Tacloban. The downtown surge height estimates are based on eyewitness accounts from the iCyclone chase team (Morgerman et al. 2014):

*"The storm surge rose very suddenly and rapidly at our location between 7:30 and 7:45 am, and we estimate it probably peaked between 8:00 and 8:15 am—well after the center's closest approach. By 8:45 am, it was already noticeably receding—so its impact at our location was significant but short-lived. During the peak surge, the hotel flooded to a depth of ~4 ft. If the elevation at this location is truly 26 ft—as indicated by USGS that suggests a storm surge of up to ~30 ft. It's possible the elevation may have been as low as 15 ft, in which case, the surge was ~20 ft."*

As some videos emerging from the site show, the surge came rapidly in some locations with nearly the same irresistible force and rapidity of a destructive tsunami (e.g., see video at <http://www.youtube.com/watch?v=rS0gv4Xbw7w>). The configuration of the coastline, and its location at the head of San Pedro Bay on the northwest reaches of Leyte Gulf, make the city of Tacloban particularly vulnerable to storm surge. Early modeling results (e.g., Deltares Engineering Group, 2014) indicate a surge height of at least 5 m at Tacloban given the parameters of Haiyan (Fig.4).

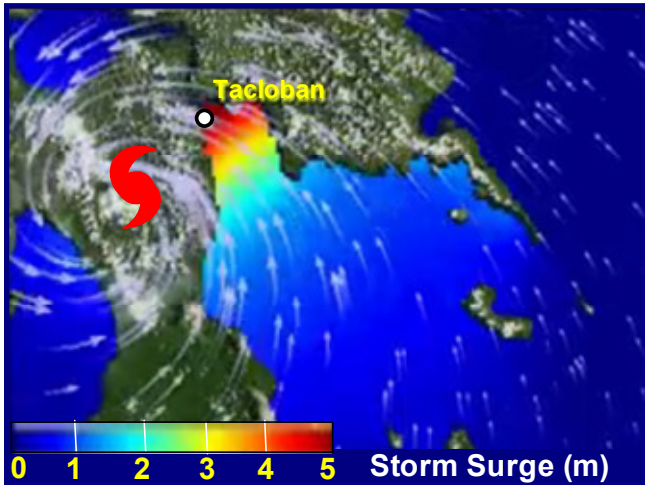


Figure 4. Model simulation of Haiyan's storm surge, developed by Deltares engineering group in the Netherlands, shows how Haiyan's winds generated a surge that targeted Tacloban, with water levels exceeding 5 meters (not including any effect from the tide or wave heights).

Some political leaders and climatologists have connected the severity of Super Typhoon Haiyan to climate change, as an extension of the notion that tropical cyclones may be both more numerous and reach higher intensities in a warmer world. With the extreme intensity of Haiyan still uncertain, it has yet to receive its proper ranking among the world's most extreme tropical cyclones. The connection of climate change to the storm surge is another matter: the sea level in the region of the central Philippines (and eastward into Micronesia) is at historical highs. Since 1970, the mean sea level at Legaspi in the Visayan Island group of the central Philippines has risen 20 cm. Most of this rise is attributable to an increase of the Pacific trade winds, and not directly tied to the rise of the sea due to climate warming. Regardless of the cause, the 20 cm rise of mean sea level is roughly 20% of the magnitude of the range of the astronomical tide at Tacloban (Fig. 5). The peak surge at Tacloban during Haiyan, however, came at a time of relatively low water. Adding 20 cm to the low astronomical water level at the time would still have left the water level .5 m below the expected high tide for that day.

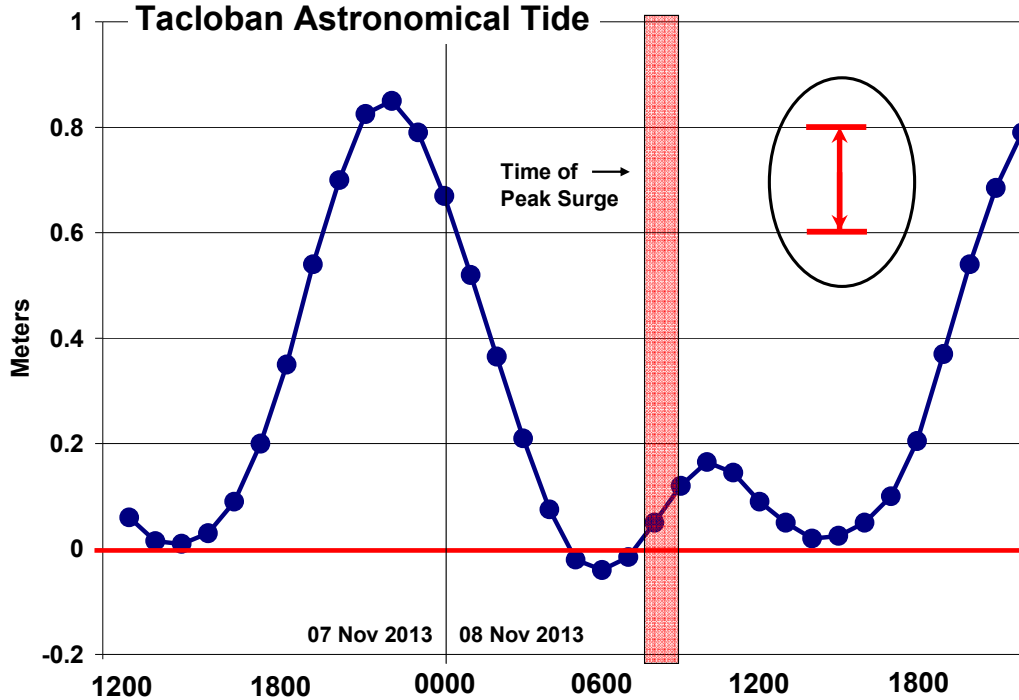


Figure 5. The astronomical tide at Tacloban for the period 1200 Local 07 November to 2200 Local 08 November 2013. Shaded region is the timing of the peak storm surge. The inset in the black oval illustrates the comparative magnitude of the 20 cm rise of mean sea level in the region from 1970 to present.

In summary, the following facts are known:

(1) the 170 kt intensity bestowed upon Haiyan by the JTWC on its warning valid at 1800 UTC 07 November 2013 was the highest ever assigned to a typhoon by the JTWC, surpassing the 165 kt bestowed upon Super Typhoon Tip on 11 October 1979 after a reconnaissance plane found Tip's central pressure to be 870 mb. Tip's wind was not a measurement, but was derived from a wind-pressure relationship. Ironically, the 895 mb central pressure assigned to Haiyan by the JTWC was not measured, but based on a recently updated wind-pressure relationship for a wind speed of 170 kt

(2) Haiyan reached the top T8.0 value found in Dvorak's satellite tropical cyclone intensity estimation techniques (Fig. 6). It did so with an impressive very cold cirrus cloud canopy that was much colder than the Atlantic conditions used to develop Dvorak's codifications. There is no consensus on how to handle in Dvorak classifications the much colder western Pacific tropopause.

With Haiyan possibly achieving the world-record historical typhoon wind intensity, it is likely that a special team will have to be assembled to investigate the legitimacy of the

new world record, and to place Haiyan in its proper ranking among the cohort of the world's most powerful tropical cyclones.

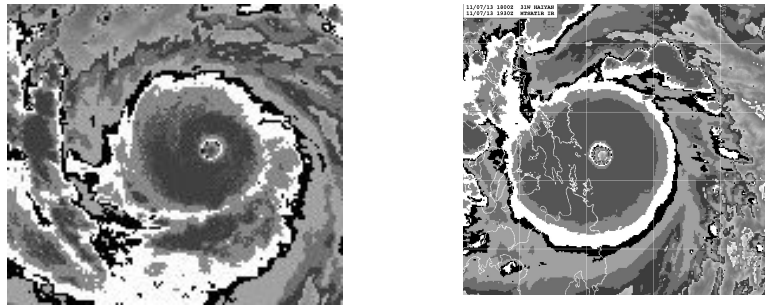


Figure 6. Enhanced Infrared images of Tip (left) and Haiyan (right) at peak intensities of 165 kt and 170 kt, respectively. Note the cold dark gray (CDG) shading of the eye wall cloud tops, indicative of temperatures less than  $-81^{\circ}\text{C}$ .

<http://www.rappler.com/move-ph/issues/disasters/typhoon-yolanda/44062-leyte-1897-typhoon>

<http://www.philstar.com/headlines/2013/11/19/1258482/1912-reports-tacloban-storm-killing-15000-resurface>