Article

# THE ANALYSIS OF STORM SURGE IN MANILA BAY, THE PHILIPPINES

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## Abstract

In 2013, Typhoon Haiyan produced a storm surge over seven metres in San Pedro Bay in the Philippines that killed approximately 6,300 people. The event created significant public awareness on storm surges and exposed the lack of records and historical research in the Philippines. This study investigated the tidal height records during intense cyclone activities in 2016 and 2017 to provide accurate information about storm surge development in the largest and most populated coastal area in the country – Manila Bay. The results of this investigation indicated that there are consistencies in the characteristics of tropical cyclones that produce larger storm surges. The results also show that actual storm surge heights are generally smaller than predicted height values.

## Résumé

En 2013, le typhon Haiyan a provoqué une onde de tempête de plus de sept mètres dans la Baie de San Pedro aux Philippines, faisant près de 6 300 victimes. Cet événement a provoqué une importante sensibilisation du public envers les ondes de tempête et a mis en évidence le manque d'archives et de recherches historiques aux Philippines. La présente étude a examiné les enregistrements des hauteurs des marées au cours d'activités cycloniques intenses en 2016 et 2017 afin de fournir des informations précises sur le développement d'ondes de tempête dans la zone côtière la plus étendue et la plus peuplée du pays, la Baie de Manille. Les résultats de cette étude indiquent des points communs dans les caractéristiques des cyclones tropicaux produisant de plus grandes ondes de tempête. Les résultats montrent également que la hauteur réelle des ondes de tempête est généralement inférieure à la hauteur prévue.

## Resumen

En el 2013, el tifón Haiyan originó una marea tormentosa sobre una distancia de siete metros, en la bahía de San Pedro, en Filipinas, que causó la muerte de aproximadamente 6.300 personas. Este acontecimiento provocó una importante sensibilización pública sobre las mareas tormentosas y reveló la ausencia de archivos y de investigación histórica en Filipinas. Este estudio investigó los registros de las alturas de mareas durante las intensas actividades de los ciclones del 2016 y del 2017, para proporcionar información exacta sobre el desarrollo de las mareas tormentosas en la mayor y más poblada zona costera del país - la Bahía de Manila. Los resultados de esta investigación indicaron que hay coherencias en las características de los ciclones tropicales que producen las mareas tormentosas mayores. Los resultados también muestran que las alturas actuales de las mareas tormentosas son generalmente inferiores a los valores de las alturas predichas.

## 1. Background

The National Oceanic and Atmospheric Administration (NOAA) defines storm surge as the abnormal rise in seawater level during a storm, measured as the height of the water above the normal predicted astronomical tide. The surge is caused primarily by storm's winds pushing water onshore (***Figure 1***) (NOAA, 2019).

The amplitude of storm surge is attributed to several factors including the orientation of coast-line with respect to the storm track, strength of the storm, local bathymetry and coastline shape.

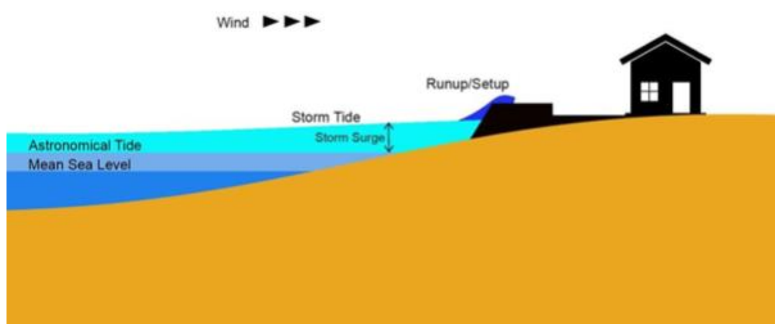


***Figure 1.*** *Illustration of Sea Level, Astronomical Tide and Storm Tide*

The Philippines is located along the paths of tropical cyclones. Based on the ranking made by NOAA using their International Best Track Archive for Climate Stewardship (IBTrACS) data-base (NOAA, 2018), the Philippines ranks third in terms of the total number of tropical cyclone hits by country and it is second when it comes to the ranking of tropical cyclone hits by country since 1970. Despite the damage received by the Philippines from tropical cyclones yearly, the effects of storm surge have not been given much attention by the Filipino public until Typhoon Haiyan, known as Super Typhoon Yolanda in the Philippines, occurred in 2013. Super Typhoon Yolanda caused a storm surge of more than seven meters (Soria et.al., 2015) above the normal tide. The Philippines' National Disaster Risk Reduction and Management Council (NDRRMC), in its Final Report on the Effects of Super Typhoon Yolanda (NDRRMC, 2013), stated that a total of 6,300 individuals were reported dead and more than Php 80 Billion (US$1.5 Billion) damages was assessed. The enormity of the damage from Super Typhoon Yolanda made every Filipino aware of the term "storm surge" and many equated it to the term "tsunami".

The damage from the storm surge caused by Super Typhoon Yolanda, made a lasting impact not only to the residents of Leyte, but to every Filipino who witnessed through the media how high the storm surge was. Just like any phenomenon that is not fully understood, the term "storm surge" was subject to overuse and misconceptions. Without a definite measurement, storm surges in coastal areas such as Manila Bay can be overestimated and confused with wave run-up and set-up. Often, flooding in the coastal areas of Manila are now attributed to storm surge without any sufficient evidence. Whenever tropical cyclones develop, weather bulletins in the Philippines now include warnings of storm surge of several meters depending on the classification of the cyclone. The PAGASA Tropical Cyclone Warning System (PAGASA, n.d.) indicates that a storm surge of more than three meters is possible along coastal areas for Tropical Cyclone Warning Signal No. 5 or tropical cyclones that have maximum sustained winds of more than 220 kilometers per hour.

Despite the increased interest in storm surge and tides after Super Typhoon Yolanda, minimal effort has gone into analyzing the actual height of tides during the passage of tropical cyclones.

Most studies conducted on storm surge in the Philippines were modeling of the effects using the characteristics of previous storms and applying it to areas like Manila Bay. The study by Carl Drews and Weiqing Han (2009), concluded that if a Category 3 typhoon passes over Manila on a track similar to Typhoon Angela (Rosing in the Philippines) in 1995, Manila City will experience about one meter of storm surge in Manila Bay.

Metro Manila, or the National Capital Region, has been the focus of many studies on sea level rise and storm surge as it is the most populous region in the Philippines having thirteen million of the total 103.3 million population of the country. The City of Manila is the capital city of the Philippines and has 1.78 million population. Manila Bay is the biggest bay in Luzon Island and is also home to the biggest port in the country (***Figure 2***). Should a calamity impact the whole country, Manila is in danger of having the highest casualties and largest damage to properties because of its population and location of its infrastructures. A study by Lapidez et al. (2015) simulated storm surges for 30 cities and identified Metro Manila as one of the areas with a storm surge level as high as 3.90 meters.

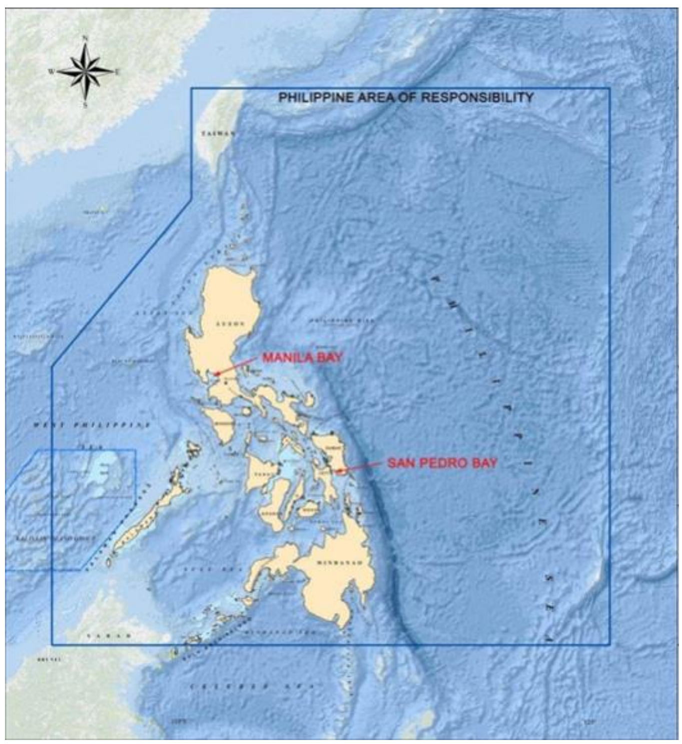


***Figure 2.*** *Map of the Philippines showing the locations of Manila Bay and San Pedro Bay*

Despite the susceptibility of Manila Bay area to natural calamities, the population growth is increasing with people from other regions looking for jobs in the capital city. The land in Metro Manila is already crowded with structures and the government's current remedy is to develop further reclamation projects in Manila Bay. Manila City recently approved a multi-billion-peso reclamation project in Manila Bay covering 318 hectares of the water area. The adjacent City of Navotas also has a proposed 650-hectare reclamation project. Every Local Government precinct within Manila Bay has a proposed reclamation project. If all the proposals are approved, the entire length of the natural coastline of Manila Bay will be replaced with infrastructures and the shape of the bay will be changed significantly.

Given these changes, it is important that the historical storm surge and tide in Manila Bay be studied to understand the behavior of the water movements within the Bay during tropical cyclones. This information is essential for the effective design of reclamation areas including the ground elevation above the sea level, the height of sea walls and the size of breakwaters. Furthermore, actual observation is needed since simulation may not represent reality especially when modeling does not include all factors needed for accurate prediction.

The purpose of this study is to quantify the storm surge in Manila Bay produced by previous tropical cyclones. The period of 2016 to 2017 is used in this study because it was the only period where there were three operational tide stations inside the Bay (***Figure 3***) that could provide sufficient records to analyze the effects of cyclone activity in generating storm surges. The Manila South Harbor (MSH) Tide Station is a Primary Tide Station with tidal height recordings since 1901. The other two stations, Limay and Puerto Azul, are temporary tide stations and were established during the 2016-2017 hydrographic survey of Manila Bay and then removed at the end of 2017. MSH station is located at the northeastern area and the two temporary stations are located at the mouth of the bay, one on the north side and the other on the south side. The data from these two stations were included to determine whether there was drying in the opposite side of the bay when flooding happens on the other side as predicted in some studies.


***Figure 3.*** *Location of the three Manila Bay tidal height stations*

National Hydrographic Offices such as the Philippines Hydrography Branch of the National Mapping and Resource Information Authority (NAMRIA) primarily measure tide heights to establish and update the vertical datum for navigational charts. However, hydrographic data are increasingly being used in other research fields besides charting purposes. Hydrographic data has proven useful in understanding the effects of natural disasters such as using bathymetric information to determine the possible magnitude of a tsunami in a certain area. Tidal height data are also important in the study of sea level rise. In storm surge analysis, tidal height measurements by hydrographic offices are not just a convenient source of data but are also the most reliable form of its measurement.

In September 2018, while the analysis of 2016-2017 storm tides was being conducted, Typhoon Mangkhut, known in the Philippines as Typhoon Ompong, hit the Philippines. It is the strongest typhoon to strike Luzon since Typhoon Megi in 2010, and the strongest typhoon to make landfall in the Philippines since Typhoon Haiyan in 2013. Mangkhut made landfall on the Island of Luzon on 15 September 2018 as a Category 5-equivalent super typhoon. It subsequently impacted Southern China including Hong Kong. Typhoon Mangkhut was the third-strongest tropical cyclone experienced worldwide in 2018. Due to the strength of Typhoon Mangkhut, the tide data during its passage was included in the study.

## *2. Area of the Study*

The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), which is the National Meteorological and Hydrological Services agency of the Republic of the Philippines, classifies tropical cyclones entering the Philippine Area of Responsibility (PAR) into five categories based on the maximum sustained winds in kilometers per hour - kph near the center (***Table 1***).

***Table 1.*** *PAGASA Tropical Cyclone Categories*

| Category | Type | Wind Strength (kph) |
|---|---|---|
| 1 | Tropical Depression (TD) | <61 |
| 2 | Tropical Storm (TS) | 62 - 88 |
| 3 | Severe Tropical Storm (STS) | 89 - 117 |
| 4 | Typhoon (TY) | 118 - 220 |
| 5 | Super Typhoon (STY) | >220 |

In 2016, fourteen tropical cyclones entered the PAR ranging from Tropical Depressions to Typhoons. In 2017, twenty two tropical cyclones entered the PAR, including one Super Typhoon, leaving a total damage of US$15.7 Billion. This study analyzed the height of tides during the passage of 34 of the 36 tropical cyclones that passed through the PAR during these two years. The heights of tides during two tropical cyclones, Typhoon Nina and Typhoon Auring, were not recorded due to repairs being undertaken on the tide stations when the tropical cyclones passed. The paths of the 36 tropical cyclones that entered the PAR between January 2016 and December 2017 are shown in ***Figure 4***.

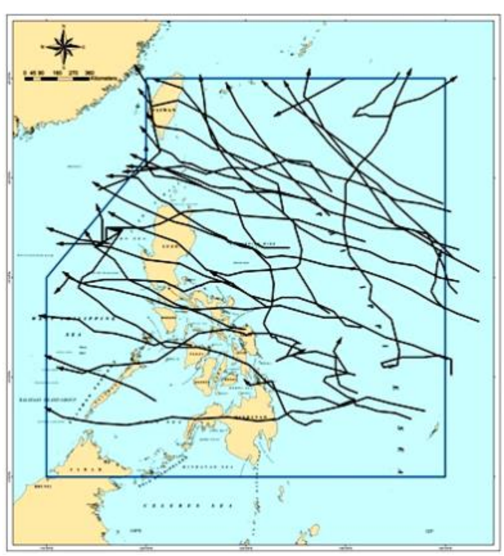

***Figure 4.*** *Paths of Tropical Cyclones that passed through the Philippine Area of Responsibility (PAR) in* 2016 and 2017

### 3. Determining Storm Surge Height

The height of the storm surge was determined as the residual by subtracting the observed water level from the predicted water level. The Manila South Harbor Tide Station is located in an area where it is sheltered from waves and is able to measure still water. Wave run-up and set-up were already eliminated from the recorded data.

The graph in ***Figure 5*** shows the comparison between the observed and predicted water levels in the MSH Tide Station during non-storm days. The observed and predicted water level values closely match with each other when there is no weather disturbance.

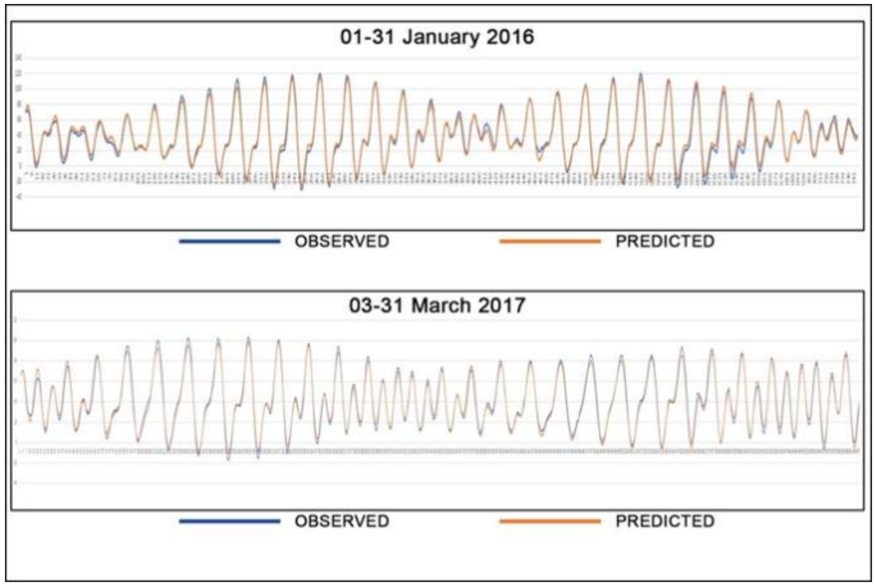


***Figure 5.*** *Water level at MSH Station during non-storm days in January 2016 (above) and March 2017 (below)*

In comparison, ***Figure 6*** shows the observed and predicted water levels at MSH Tide Station during the tropical cyclone periods and it can be seen that the water level rose when four tropical cyclones made landfall in the island of Luzon.Typhoon Mangkhut, one of the most damaging cyclones, produced a maximum storm surge of 50 centimeters when it made landfall in Luzon Island and was directly north of Manila.

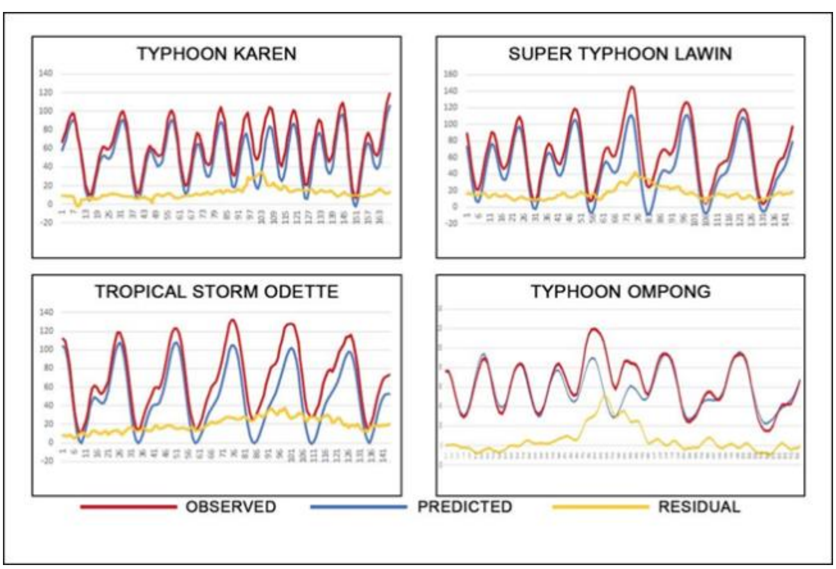


***Figure 6.*** *Water level at MSH Station during Tropical Cyclones Karen, Lawin, Odette and Ompong landfall*

The analysis also showed that there are tropical cyclones that have no obvious impact on water level when passing through the PAR. ***Figure 7*** shows that water levels recorded at MSH Tide Station during TD Bising, TS Jolina, TS Kiko and TD Ambo, seem to have not changed or deviated much from their predicted levels. Tropical cyclones that did not make landfall in Luzon were generally too far away to create significant rise in the water level in Manila Bay.

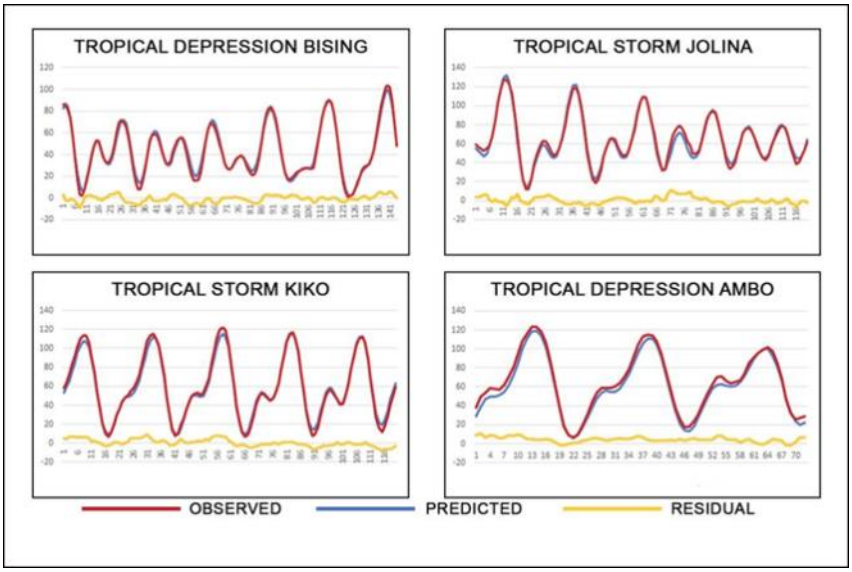


***Figure 7.*** *Tropical Storms that did not produce significant storm surge*

Out of the 34 tropical cyclones with recorded tide height data in 2016-2017, there were only four (STY Lawin, TY Paolo, TS Karen, TY Odette) that caused a storm surge of 30 centimeters (***Table 2***). These four tropical cyclones had different wind speeds and paths and one tropical cyclone did not make landfall (***Figure 8***).

**Table 2 :** Tropical Cyclones and their highest residual values

| CLASSIFICATION | MAXIMUM SUSTAINED WINDS NEAR THE CENTER | TROPICAL CYCLONE NAME (LOCAL) | HIGHEST RESIDUAL |
|---|---|---|---|
| SUPER TYPHOON | MORE THAN 220 KPH | LAWIN | 42 |
| TYPHOON | 118-220 KPH | GORIO | 22 |
| | | LANNIE | 21 |
| | | PAOLO | 30 |
| | | VINTA | 22 |
| | | BUTCHOY | 25 |
| | | DINDO | 11 |
| | | FERDIE | 15 |
| | | GENER | 15 |
| | | HELEN | 21 |
| | | IGME | 16 |
| | | KAREN | 35 |
| SEVERE TROPICAL STORM | 89-117 KPH | RAMIL | 22 |
| | | CARINA | 18 |
| | | ENTENG | 11 |
| TROPICAL STORM | 62-88 KPH | DANTE | 13 |
| | | EMONG | 11 |
| | | HUANING | 22 |
| | | ISANG | 15 |
| | | JOLINA | 11 |
| | | KIKO | 9 |
| | | MARING | 21 |
| | | ODETTE | 38 |
| | | QUEDAN | 22 |
| | | SALOME | 20 |
| | | TINO | 21 |
| | | URDUJA | 18 |
| | | JULIAN | 17 |
| | | MARCE | 14 |
| TROPICAL DEPRESSION | 61 KPH OR LESS | BISING | -9 |
| | | CRISING | 6 |
| | | FABIAN | -13 |
| | | NANDO | 17 |
| | | AMBO | 11 |

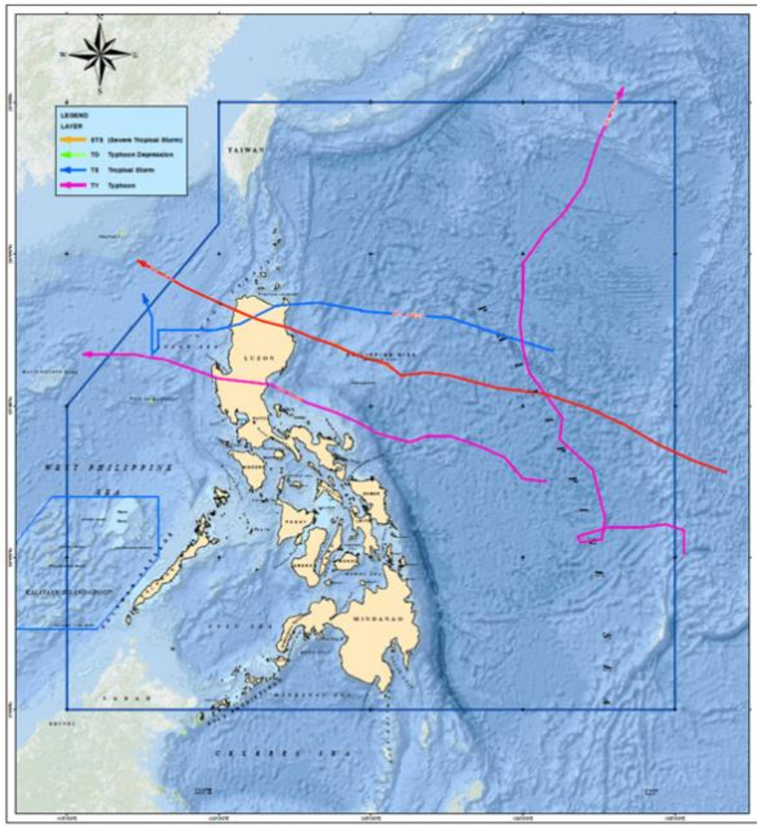


***Figure 8.*** *Path of the four Tropical Cyclones that produced the highest storm surge from January 2016 to December 2017*

The cyclone that produced the highest storm surge was STY Lawin with a highest wind speed of 270 KPH. The other two were Typhoons (Paolo and Odette) and the last was a Tropical Storm (Karen). All made landfall in Luzon and north of Manila Bay except for TY Paolo which entered the PAR at the same time as TY Odette was exiting the PAR. TY Odette may still have influenced the wind in Manila Bay even though it was outside of the PAR.

In comparison, TY Ompong created 50 centimeters of storm surge in 2018, despite having a similar path to the three tropical cyclones that generated storm surges.

## *4. Study Outcomes*

The data analysis suggests that the magnitude of a storm surge in Manila Bay can depend on the combination of a tropical cyclone's:

- sustained winds;
- distance from Manila Bay; and
- path.

The 2016-2017 data showed a consistency with respect to the path of the tropical cyclone and the height of surge produced. The highest rise in water level were created by tropical cyclones passing and making landfall north of Manila Bay. Tropical cyclones passing north of Manila produce onshore winds when it makes landfall in Luzon, thereby pushing the water towards the coastal area of Manila.

One interesting observation was that there is no obvious drying in the opposite side to the flooded part of Manila Bay. Carl Drews and Weiqing Han (2009) concluded that the northwest corner of Manila Bay will also experience rapid drying, followed quickly by storm surge heights up to 3 meters that could reach 5 km inland if a Category 3 typhoon passes over Manila on a track similar to Typhoon Angela in 1995. However, the actual tide height data does not show any obvious fall of water level below the predicted values at the Limay and Puerto Azul tide stations. ***Figure 9*** shows the recorded water levels in Manila South Harbor (MSH), Limay, Puerto Azul and the predicted tide in MSH in two different months in 2017. The upper image displays the month of May when there were no tropical cyclones. The predicted and recorded values in the three tide stations coincide with each other. In comparison, the data is quite different in October when cyclone activity occurred in the PAR. The water level in the MSH was higher compared to Limay and Puerto Azul.

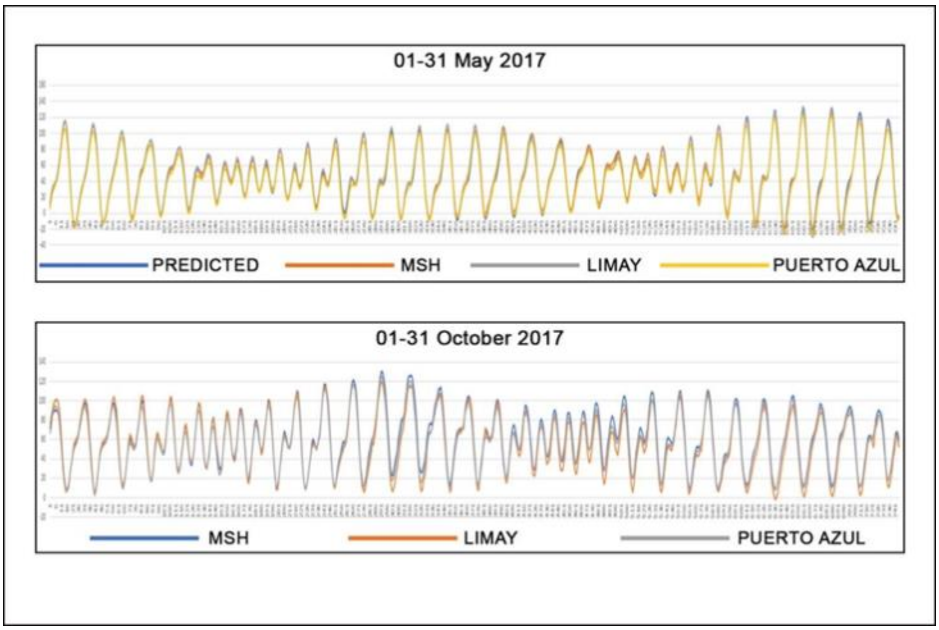


***Figure 9.*** *Comparison of Tide Levels at Manila South Harbor, Limay and Puerto Azul Tide Stations*

The observed residuals from the tropical cyclones in the study period are generally smaller than the predicted heights from modeling studies. No tropical cyclone, including the strongest super typhoon, produced more than one meter of residual. STY Mangkhut produced only 50 centimeters of storm surge. Mangkhut had the ideal wind direction, strength and path to produce a large storm surge. However, it did not create the expected storm surge in Manila Bay when compared to the storm surge that Haiyan produced in San Pedro Bay.

The shape of Manila Bay may help to prevent the development of large storm surges. In comparison, San Pedro Bay is funnel shaped, is located at the east side of the archipelago and faces the Pacific Ocean. Tropical cyclones normally develop in the east side of the Philippines and travel westward towards mainland Asia. Manila Bay is semi-enclosed and located on the west side of the country. The location and configuration of Manila Bay likely reduces the movement of water that can create larger storm surges.

The study data indicated that floods that occur during tropical cyclones are not caused by storm surge. Seawalls along Manila Bay are generally higher than the recorded storm tide levels. Flooding has been caused by wave run-up and set-up. ***Figure 10*** shows the condition in Manila Bay when there is no weather disturbance.

***Figure 10.*** *Sea condition in Manila Bay during calm weather and at high tide*

***Figures 11 to 13*** were taken during the morning of 15 September 2018 during TY Mangkhut. ***Figure 11*** and ***Figure 12*** are the same spot (breakwater) as ***Figure 10***. ***Figure 13*** is a sheltered portion behind that breakwater. ***Figures 11***, ***12*** and ***13*** were taken just a few seconds after each other and portray the different situations during TY Mangkhut. ***Figure 13*** shows the condition behind the breakwater – big waves do not form. Figure 11 shows the level of the water when there is no wave, whilst ***Figure 12*** shows the height of the waves striking the breakwater. The series of images shows that the maximum storm surge tide level was lower than the tops of the breakwater and seawalls. However, flooding was still experienced because water was thrown to the other side of the seawall by breaking waves. Floods did not occur because the water level was above the seawalls, rather it was due to the water from breaking waves exceeding the tops of the barriers. It is therefore important to differentiate storm surge which is sustained over a long period of time from waves which are generated within short periods.

***Figure 11.*** *A breakwater in Manila Bay during the time TY Mangkhut passed trhough Manila (15 September 2018)*

***Figure 12.*** *Waves hitting the same breakwater in Figure 11 during the time TY Mangkut passed trough Manila (15 September 2018). It was taken a few seconds after Figure 11 was taken*

***Figure 13.*** *Behind the breakwater in Figure 11 (15 September 2018). Waves do not form behind the breakwater*

The study of the tidal height levels during the period of many cyclones in the two-year study period (2016-2017) did not show any obvious residuals between the observed and predicted tidal heights. However, this does not reduce the importance of understanding storm surge nor lead to neglect the potential damage in Manila Bay area.

The generated storm surge may increase when the configuration of Manila Bay is changed through land reclamation for example. Other factors that may increase the Bay's water height level during a storm include the discharge from the Pasig River, atmospheric pressure and the tide phase. When the storm produces a large volume of rain and increases the discharge from the Pasig River into the Manila Bay and this coincides with the highest tide of the cycle, the water level may go higher than previously recorded storm surge levels. Tropical cyclones also differ in characteristics. If a Super Typhoon moves very slowly from east to west passing through Manila, water may accumulate inside Manila Bay to produce higher than normal storm surge tide levels.

It must be noted that the study focused on the storm surge in Manila Bay. Due to the complexity of the shape of the Philippine archipelago, the rise of water level is not the same throughout the country. The storm surge may be higher in other areas even if there is no rise in water level in Manila Bay.

The amount of rain discharged by a typhoon can create more extensive damage than the wind as experienced during TY Ketsana (TS Ondoy in the Philippines). TS Ondoy's rainfall created flash floods that caused more damage than other Super Typhoons with higher wind intensity, but lower rainfall.

Further, reclamation projects will change the configuration of Manila Bay and this may either increase or reduce the magnitude of the storm surge. Continuous observation should be made to understand the effect of all factors that determine the impact of storm surge in Manila Bay.

The major differences between Manila Bay and San Pedro Bay are their location and orientation with respect to the usual track of tropical cyclones. San Pedro is facing the Pacific Ocean where tropical cyclones commonly originate. Thus, it is impacted by tropical cyclones before it makes landfall. Manila Bay is located on the West side of the archipelago and is impacted by tropical cyclones after passing through land. Generally, tropical cyclones weaken as they move inland because of the source of warm water is cut off. The mountain ranges in Luzon may also contribute to the weakening of the tropical cyclones.

San Pedro Bay has a funnelling shape and the bathymetry shallows as it reaches the narrow part. Its orientation with respect to the usual northwest path of tropical cyclones provides a long fetch of water or the horizontal distance over which wave-generating winds blow. On the contrary, Manila Bay has a constricted opening that limits the entry of water.

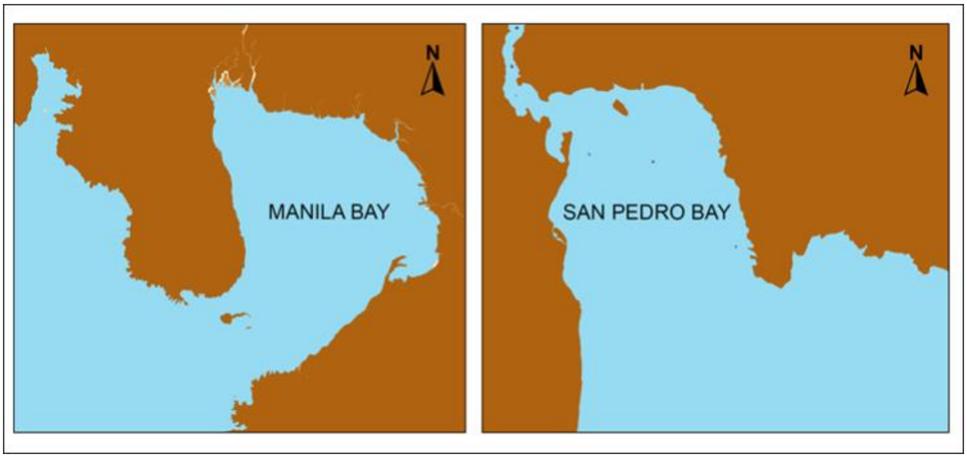


***Figure 14.*** *Manila Bay and San Pedro Bay*

## *5. Conclusions*

Understanding storm surge is important in an archipelagic country (such as the Philippines) frequented by tropical cyclones. It is even more critical in coastal, highly urbanized cities where damage and potential loss-of-life can be severe due to the population density and complex infrastructures. Many studies have identified Manila Bay as susceptible to storm surge and through modelling have predicted water level rise of several meters when a storm surge occurs.

This study used observed measurements from tide stations to determine how high the water level rose in Manila Bay during the passages of tropical cyclones. Tide stations in the Philippines were established primarily to monitor the sea level (mainly due to astronomical factors) for the support of hydrographic surveys. However, these records proved beneficial to other uses such mean sea level rise monitoring and storm surge analysis.

The results of the study highlighted that there is no single characteristic that is responsible for producing the largest storm surges in Manila Bay. Tropical cyclones rarely follow the same path nor have the same strength. Thus, the amplitude of storm surge varies from storm to storm. If a tropical cyclone changes its course sharply and deviates from the usual path such as Typhoon Chanchu in 2006 (not shown in this article), it may generate larger storm surge than what was measured in this study.

It is recommended that further studies be made to evaluate the contribution of other factors such as central pressure of tropical cyclones and characteristic of bathymetry for better understanding of storm surge generation and its impact in the country.

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## *8. Biography*

Commander Carter S Luma-ang is currently the Chief of the Maritime Affairs Division of the NAMRIA Hydrography Branch (Philippines). He earned his Master Degree in National Security Administration from the National Defense College of the Philippines (2016) and his Bachelor of Science in Civil Engineering from the St. Louis University, Baguio City (1999). He completed the Category "B" Hydrographic Surveying Course at the Japan Hydrographic and Oceanographic Department of the Japan Coast Guard (2006) and attended the Rhodes Academy of Oceans Law and Policy (2012) and the Yeosu Academy of Oceans Law and Policy (2014).

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