# SURVEY OF STORM SURGE DUE TO TYPHOON RAI IN DECEMBER 2021 IN THE PHILIPPINES

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## INTRODUCTION

Typhoon Rai, the last typhoon in the Western Pacific basin in 2021, entered the Philippine Area of Responsibility (PAR) on the 14th December at 23:00 Philippine Standard Time with a minimum central pressure of 985 hPa and maximum sustained winds of 100 km/h (NDRRMC 2022). The typhoon made its first of nine landfalls at Siargao Island in Surigao del Norte on the 16th December 2021 13:30 PST and continued to bring strong winds and rainfall to the Visayas region. The storm was one of the strongest typhoons to have hit the Philippines in recent times, and the government declared a State of Calamity across 493 cities and municipalities (NDRRMC 2022). The typhoon damaged more than 1.1 million houses in the Central Visayas region, and caused a total of 220 total reported deaths and 546 injuries. In the present work, the authors surveyed the storm surge heights in a variety of coastal areas of Cebu and Bohol islands.

## METHODOLOGY

A field survey was conducted approximately two months after the passage of the typhoon, between the 18th and 28th of February 2022. The survey concentrated around the islands of Cebu and Bohol, and smaller islands located offshore of these two provinces. The main purpose of the survey was to ascertain which areas had suffered inundation due to the storm surge, clarify damage patterns, and determine inundation and run-up heights. The height of the storm surges (as indicated by interviewees at the various locations) were surveyed by using a laser ranging instrument, a prism and staffs. The precise location of each survey point was then recorded using GPS, following established surveying techniques for these types of exercises. Additionally, the authors conducted drone and bathymetry surveys to characterise the depth of the seafloor. All inundation heights were established using the sea water level as a reference point, and were corrected to the tidal height of nearby stations at the time of the storm surge's arrival by using WXTide, an open source global tidal prediction software.

## RESULTS

The measured storm surge inundation and run-up heights are summarized in Figure 1, showing that a total of 23 points were surveyed. The maximum storm surge height (4.24 m) was recorded at Tubigon port, in Bohol (See Figure 2). At this town, barge was carried by the surge and slammed into houses next to the port, though many of them were subsequently rebuilt. At a house next to this barge, the inundation level reached 1.07 m above the floor, though there was substantial run-up that reached the main church of the town (situated around 430 m from the shoreline). Nearby low-lying coral islands, such as Isla Batasan or Ubay, were completely flooded, with up to 90% of houses washed away (see Figure 3).

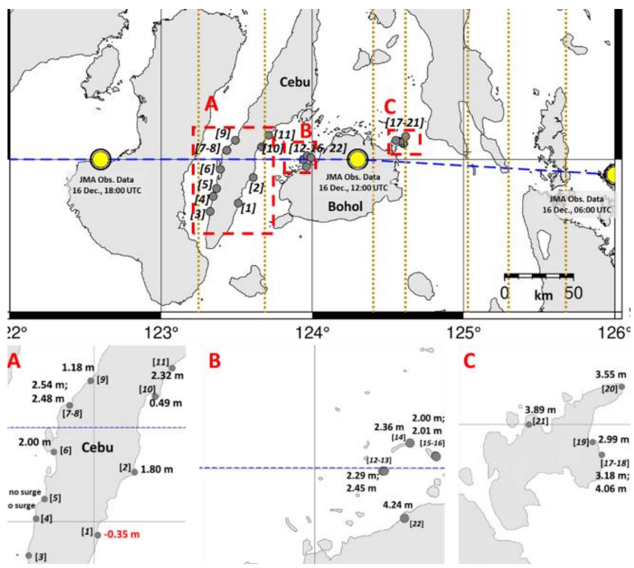


Figure 1. Path of the typhoon, location of the points surveyed (in m), and estimated storm surge.


Figure 2. Barge slammed into houses, Tubigon port.

Figure 3. Small islands offshore of Tubigon where badly hit, with 90% of houses destroyed. At the time of the survey some improvised constructions had been rebuilt using materials that were left after the passage of the typhoon.

In some areas in the west coast of Cebu, large stretches of roads were eroded, which were partially rebuilt at the time of the survey (see Figure 4). At several locations[,] a boulder ridge had been created by the typhoon by transporting coral stones from deeper within the reef (see Figure 5).

Figure 4. The road between Malabuyoc and Alegria suffered severe scour damage and in some places was completely removed, with recovery activities underway at the time of the survey.

Figure 5. Boulder ridge created by the typhoon offshore Badian.

## DISCUSSION

The measured storm surges at Bohol were generally higher than at Cebu, possibly due to the stronger wind speed and shallower bathymetry surrounding the former island. This was more evident at the islands surveyed near Tubigon, which were originally small sand banks with some vegetation situated on top of a double reef system – and hence the water around them is very shallow-, and which were already submerged during high tides following the land subsidence that took place during the 2013 Bohol Earthquake (Jamero et al. 2017, 2018).

The field surveys clarified that not all locations experienced a significant storm surge, as this phenomenon was heavily influenced by the wind field at the point of landfall. Eastern Cebu may have first experienced first the water receding, before it was pushed again towards the land as the wind field changed, explaining how the negative storm surge shown in Figure 1 was due to wind set-down, as the wind direction throughout the typhoon was away from the shore. This is typical in the northern hemisphere, and happens to the left side of the path followed by a typhoon, given the pattern of rotating winds due to these storm and the effects of the Coriolis force.

Given the poor quality of construction in many of the areas surveyed (many houses are built out of wood, or improvised mixtures of various materials –cement, corrugated steel roofs, etc), there was widespread destruction due to the winds and surges. In order to improve the resilience of such communities against future typhoon events[,] it is imperative that better construction regulations are put in place, so that the various settlements can build back better after each disaster.

## CONCLUSIONS

Typhoon Rai struck the Philippines on the 16th December 2021, damaging and inundating many coastal areas along the Visayas region of the country due to the high winds, storm surges and wind driven waves it generated. The maximum storm surge level measured were 2.54 m, 4.24 m and 4.06 m along the islands of Cebu, Bohol and President Carlos P. Garcia Islands, respectively.

## REFERENCES

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