NUMERICAL ANALYSIS OF STORM TIDES ALONG THE NORTHERN COAST OF CAGAYAN, PHILIPPINES

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ABSTRACT

The northern coast of Cagayan in the Philippines is considered prone to storm surges because it receives the highest frequency of typhoons traversing the country and has a gentle sloping nearshore bathymetry. This study aims to simulate the storm tides produced by historical typhoons along the northern coast of Cagayan in order to assess and describe the water levels during the passage of strong typhoons. Four (4) recent strong historical typhoons are selected and simulated in this study, namely, Typhoon Nuri 2008, Typhoon Nanmadol 2011, Typhoon Noul 2015, and Typhoon Mangkhut 2018. The Advanced Circulation (ADCIRC) model is used to numerically simulate the historical storm tides along the northern coast of Cagayan and the typhoon wind and pressure fields are simulated using the Holland 1980 Typhoon Model. The hydrodynamic model is calibrated using the water level data from NAMRIA station at Port Irene, Cagayan. Results show that the maximum simulated storm tide level is below 2 meters along the northern coast of Cagayan with the maximum storm tide height occurring at the towns of Buguey and Gonzaga. The results of this study will be helpful in storm surge awareness and in the preliminary design of storm surge disaster prevention and mitigating measures in Cagayan, Philippines.

Keywords: Cagayan coast, storm tide, ADCIRC, Typhoon Mangkhut

1. INTRODUCTION

Since the onslaught of Typhoon Haiyan in 2013 which generated around 7 meters of storm surge in San Pedro Bay, people have become more aware of storm surges in the Philippines. Storm surge is the abnormal rise of seawater due to the passage of strong typhoons. In September 2018, Typhoon Mangkhut (local name Ompong) crossed the Northern Luzon, specifically the Province of Cagayan. Before the landfall of the typhoon, people were concerned about the possible storm surge height that would be generated by Typhoon Mangkhut. The northern part of Cagayan has a relatively shallow bathymetry, and this means that this area would be susceptible to storm surges. In addition, the Northern Luzon has the highest frequency of landfalling-typhoons. With the lack of adequate observed water level data along the coast in the Philippines, it is now possible to predict and understand the storm surge that could be generated by a typhoon in a coastal area using numerical modelling.

The goal of this research is to assess the possible storm tide height along the northern Cagayan coastline generated by historical typhoons using numerical modelling approach. The results of this study will be significant in storm surge awareness of the northern Cagayan coastal community for disaster preparedness and mitigation. In order to carry-out this research, the Advanced Circulation (ADCIRC) hydrodynamic model is used. ADCIRC, developed by Leuttich and Westerink, is a continuous Galerkin finite element model based on the depth-integrated equations of mass and momentum equations. Data for historical typhoons are gathered from the Japan Meteorological Agency (JMA) and the Joint Typhoon Warning Center (JTWC). In this study, four historical typhoons are selected based on the closest track, central pressure and maximum windspeed to the northern coast of Cagayan. The Holland Model 1980 is used to simulate the pressure and wind fields of the selected typhoons.

2. METHODOLOGY

2.1 Bathymetry

The study area is focused on the northern coast of Cagayan, Philippines. The general bathymetric data for the model is gathered from the General Bathymetric Charts of the Ocean (GEBCO) and the local bathymetry along the northern coast of Cagayan is provided by the National Mapping and Resource Information Authority (NAMRIA). Fig. 1(a) shows the local bathymetry of the study area to a depth of 50 meters. It can be seen that the bathymetry along the coast of the towns of Buguey and Gonzaga has relatively mild slope while the bathymetry in Aparri is characterized by having a steep slope.

2.2 ADCIRC Model Development

In this study, the Advanced Circulation (ADCIRC) model is used to numerically simulate the storm tide brought by selected historical typhoons. This model is based on the shallow water equations and solves the generalized wave continuity equations and momentum equations on a flexible triangular mesh (Leuttich and Westerink, 2015). The ADCIRC model domain and mesh used in this study is shown in Fig.1(b). The mesh is constructed using a paving technique with smallest element size along the Northern Cagayan coast of 30 m and a maximum of 30 km along the ocean boundary. The mesh has a total of 138,140 number of elements and 72,830 number of nodes. A constant manning's roughness of 0.02 is used in the simulation. The Generalized Wave Continuity Equation (GWCE) weighting factor used in the model is specified at 0.005. The ocean boundary is forced using tidal constituents of K1, M2, O1, P1, Q1 and S2 from the Le Provost Tidal database. The simulated tides of the model were then validated using the observed tides from Port Irene station gathered from NAMRIA.

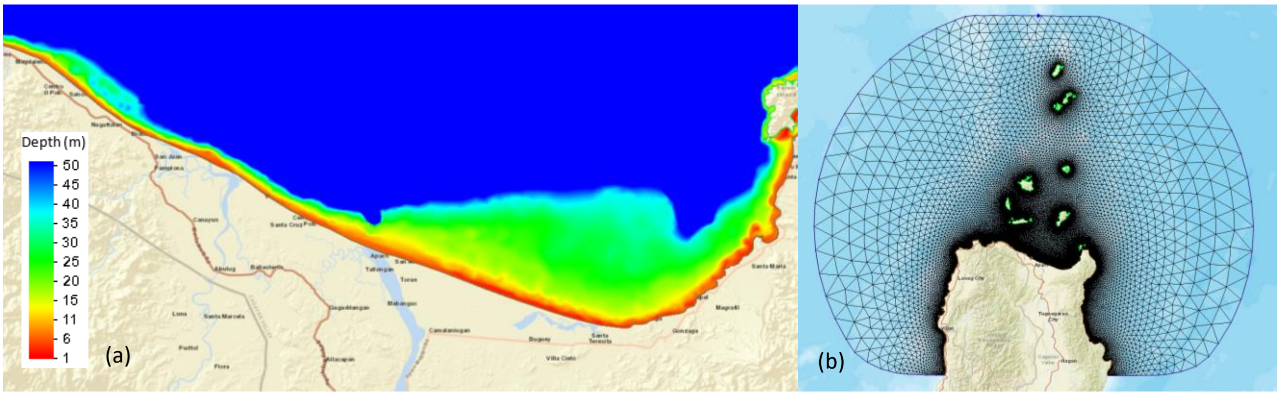

Figure 1. (a) Local bathymetry of the study area showing 0-50 m depth, and (b) ADCIRC model domain and mesh.

2.3 Historical Typhoons

The historical typhoon data were gathered from both the Japan Meteorological Agency (JMA) and the Joint Typhoon Warning Center (JTWC). A search radius of 150 km centered at the coast of Buguey is used to filter the typhoons that traversed the study area. A total of 145 typhoons from 1951 to 2018 were found using the JMA typhoon data. These typhoons were ranked according to the closest maximum 10-minute sustained windspeed and the distance of track from the northern coast of Cagayan. Among these typhoons, 60 typhoons were found to have no data on windspeed from 1951-1976.

The windspeed is an important factor in the generation of storm surges as higher windspeed produces higher surface shear stress that drives the water from offshore to the coast. The most occurring typhoons traversing the study area have 10-minute maximum sustained windspeed of 35 m/s and the highest 10-minute maximum sustained windspeed of a typhoon that passed the study area is 55 m/s.

In the modelling of the pressure and wind fields of the typhoons, the Holland Typhoon 1980 model is used. This typhoon model requires information on the central pressure, windspeed at radius of maximum winds and radius of maximum windspeed (Holland, 1980). The typhoon data from JTWC provides information on these needed typhoon parameters, however the available data is from 2001 to present only. From the ranking of the historical typhoons based on closest maximum sustained windspeed, minimum central pressure and typhoon track, four typhoons that have adequate data were selected. The selected historical typhoons are listed in Table 1 and the corresponding tracks are shown in Fig.2.

Table 1. Selected historical typhoons

Year	Typhoon Name	Central Pressure near Study Area (hPa)	Max 10-min sustained windspeed near study area (mps)
2008	NURI	955	55
2011	NANMADOL	950	45
2015	NOUL	925	55
2018	MANGKHUT	905	55

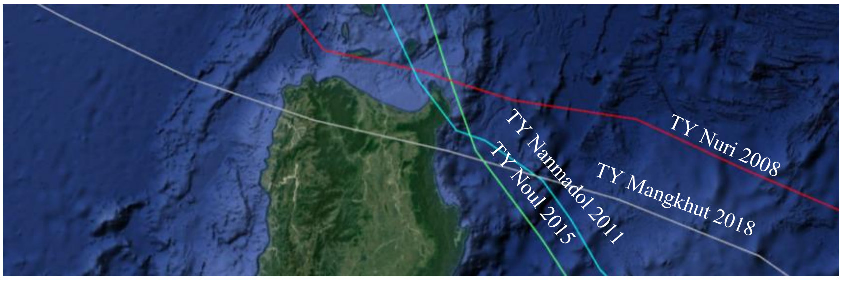

Figure 2. Tracks of selected historical typhoons

3. RESULTS

Fig. 3 shows the surface plots for the simulated maximum water surface elevation of Typhoon Nuri 2008, Typhoon Nanmadol 2011, Typhoon Noul 2015, and Typhoon Mangkhut 2018, respectively. The maximum water surface elevation is the maximum storm tide which is the storm surge on top of the astronomical tide. The highest storm tide only reaches up to 1.8 m, which is generated by Typhoon Nanmadol 2011. The tracks of Typhoon Nuri 2008 and Typhoon Nanmadol 2011 are considered critical to the northern Cagayan coastline based from the simulated storm tides.

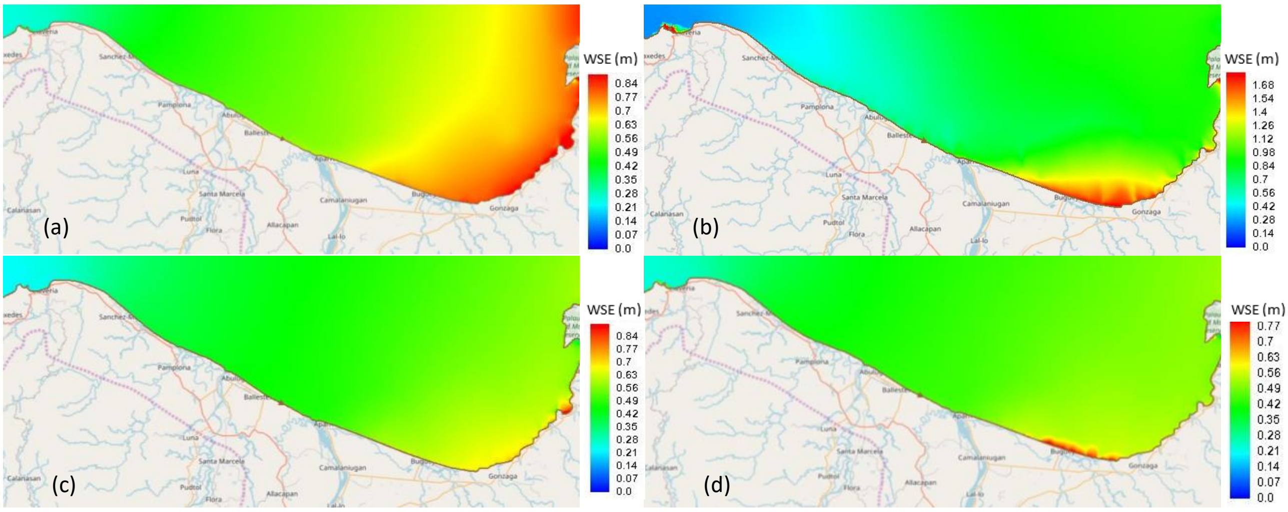

Figure 3. Surface plots for simulated maximum water surface elevation (WSE) in meters of (a) Typhoon Nuri 2008, (b) Typhoon Nanmadol 2011, (c) Typhoon Noul 2015, and (d) Typhoon Mangkhut 2018

4. CONCLUSIONS AND RECOMMENDATIONS

This study focuses on estimating the maximum storm surge height along northern Cagayan coastline generated by historical typhoons using the ADCIRC model. Typhoon tracks similar to Typhoon Nanmadol 2011 are considered the most critical as it traverses the northern Cagayan coast directly. The maximum 10-minute sustained windspeed in the recorded typhoon history that traversed the 150 km search radius centered in Buguey coast is 55 m/s. From the results of this numerical study, the maximum simulated storm tide only reaches up to 1.8 m along the coast of Buguey and Gonzaga.

Further numerical analysis could be done using synthetic typhoon tracks that are closest to the northern Cagayan coast with the maximum sustained windspeed of 55 m/s to determine the possible maximum storm surge height along the coast. A more detailed numerical simulation could further be done using finer bathymetric resolution for specific areas and using a numerical model validated by available wind data and water level data.

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