A study on the storm surges along the Philippine coast caused by Typhoon Haiyan (2013) using the region ocean simulation system

利用區域海洋模擬系統研究2013年海燕颱風對菲律賓沿岸引起暴潮之過程

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Abstract

Super Typhoon Haiyan (2013) was one of the strongest storms on record, producing devastating storm surges. This study simulates storm surges caused by Typhoon Haiyan using the ROMS (Regional Ocean Modeling System) and CROCO (Coastal and Regional Ocean Community model), with a focus on wind stress, atmospheric pressure, and tidal effects.

Introduction

Typhoon Haiyan (2013)

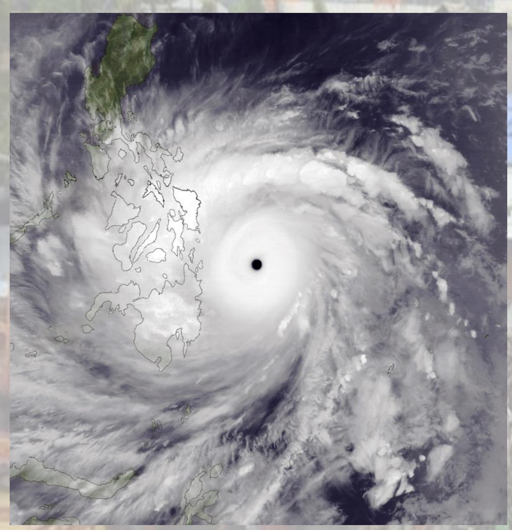


Fig.1. The satellite image of Typhoon Haiyan on November 7, 2013 from NASA, LAADS Web, HDF File processed by Supportstorm

- Formed on 3rd November.
- Made landfall in Leyte Gulf as a Category 5 typhoon.
- Highest wind speed of 87.6 m/s (170 kts)
- Lowest central mean-sea-level pressure of 895 hPa.
- Caused additional disasters including strong winds, flooding, landslides, and storm surges, which contributed to over 6,000 deaths and 28,000 injuries.
- One of the strongest storm surges in recent decades, with a surge over 6 meters recorded in Tacloban City.
- The deadliest typhoon disaster worldwide in 2013.

How Typhoons drive Storm Surge?

Storm surge happens mainly due to wind stress pushing water toward the coast and atmospheric pressure changes. Also, storm surges are influenced by additional factors like waves, tides, coastal topography and precipitation.

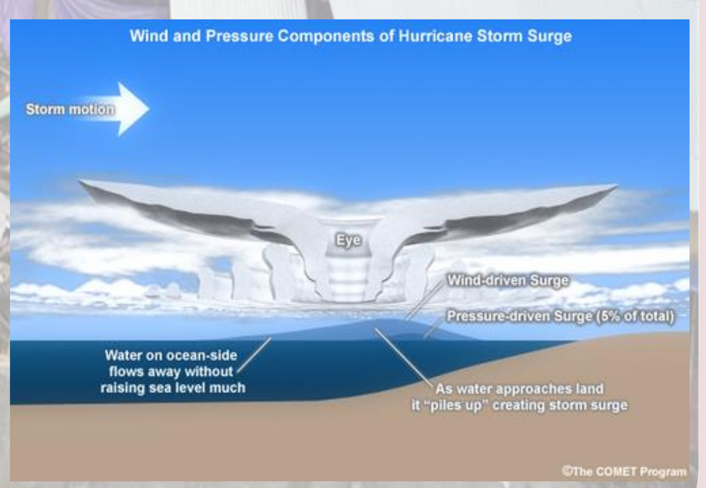


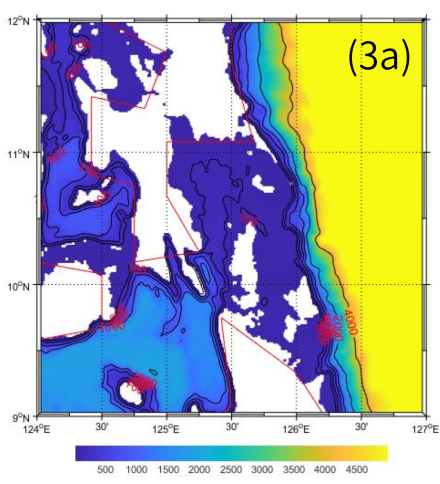
Fig.2. Schematic diagram of storm surges caused by a typhoon from National Oceanic and Atmospheric Administration (NOAA).

Photo by Selchow, Sabine

Methods and Data source

1. ROMS (Regional Ocean Modeling System) - IRD version
   - Three-dimensional high resolution ocean model
   - Adheres to hydrostatic balance and primitive equations. Utilizes fluid statics and Boussinesq approximation.
   - Employs stretched vertical coordinates and orthogonal curvilinear horizontal coordinates.
   - Simulates tidal and surge-induced changes in sea surface elevation.
2. CROCO (Coastal and Regional Ocean COmmunity model)
   - Based on ROMS (IRD), can coupled with wave and atmospheric model.
   - Integrates elements from coastal engineering as an ocean numerical model.

Experiment Setup



1. ROMS (wind stress only)
2. CROCO (wind stress only)
3. CROCO (wind stress + atmospheric pressure)
4. CROCO (nesting, wind stress + atmospheric pressure + tides)

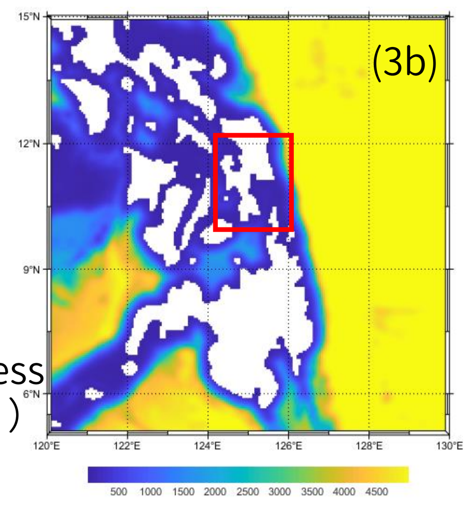


Fig.3. The topography of the study area, with color shading representing depth (m) for (a) Expt. 1, 2, 3 and (b) Expt. 4 The area highlighted in the red box is the subdomain for nesting.

Model	1.ROMS, 2. and 3. CROCO	4. CROCO (nesting)
Initial and boundary condition	HYCOM+NCODA Global 1/12° Analysis	
Variables	Sea surface height, salinity, temperature, U-velocity, V-velocity	
Wind Field	From Wang et al.(2022) Initial time at 11/7 0000 UTC	
Simulation time	2013/11/4 0000 UTC to 2013/11/9 0000 UTC / 120 hours (5 days)	
Time step	10 s	
Domain	9°N－12°N,124°E－127°E	5°N－15°N,120°E－130°E (9.8－12.3°N, 124.2－126.2°E,)
Horizontal resolution	0.01° (~1km)	0.05°,~5km (0.01°,~1km)
Grid cells	300×305 (91500 in total)	199×203 (200×255)
Vertical layer	20	
Topographic	GEneral Bathymetric Chart of the Oceans (GEBCO) 2023 (1/240 °)	

Table 1. Simulation Experimental Setup and Data Sources

Results and Discussion

Validation

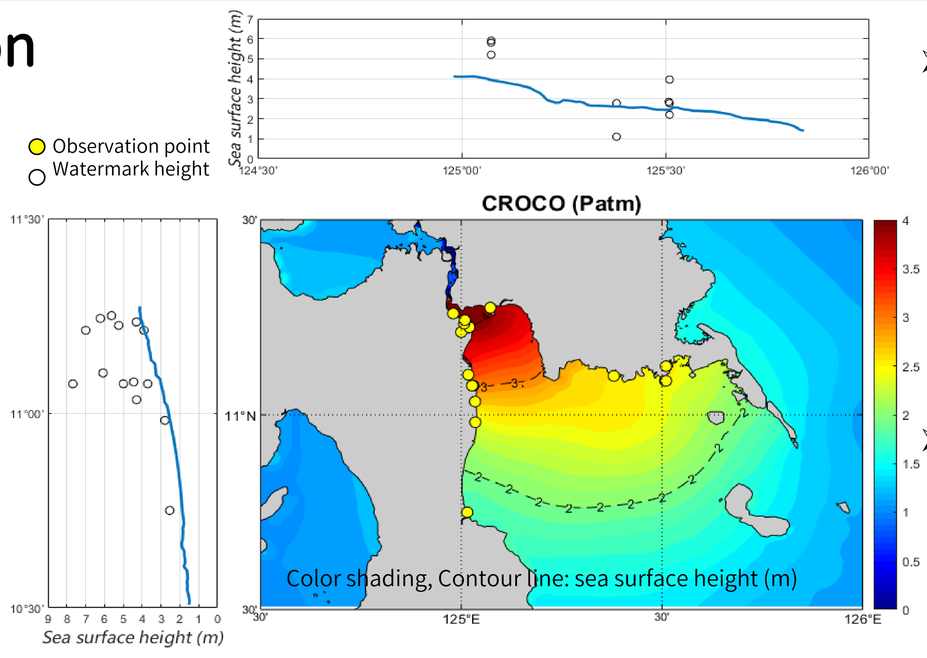


Fig.4. Comparison of the maximum sea surface height distribution from Expt 3. with field survey data by the Philippines Storm Surge Joint Survey Group (PSSJSG). (Nakamura et al., 2016).

- Due to the damage caused by Typhoon Haiyan to the instruments and power supply, there is only the maximum surge height measured from field survey watermarks can be used.
- The results mostly match the watermark records, although discrepancies exist in the inner Leyte Gulf.

Sea Surface Height

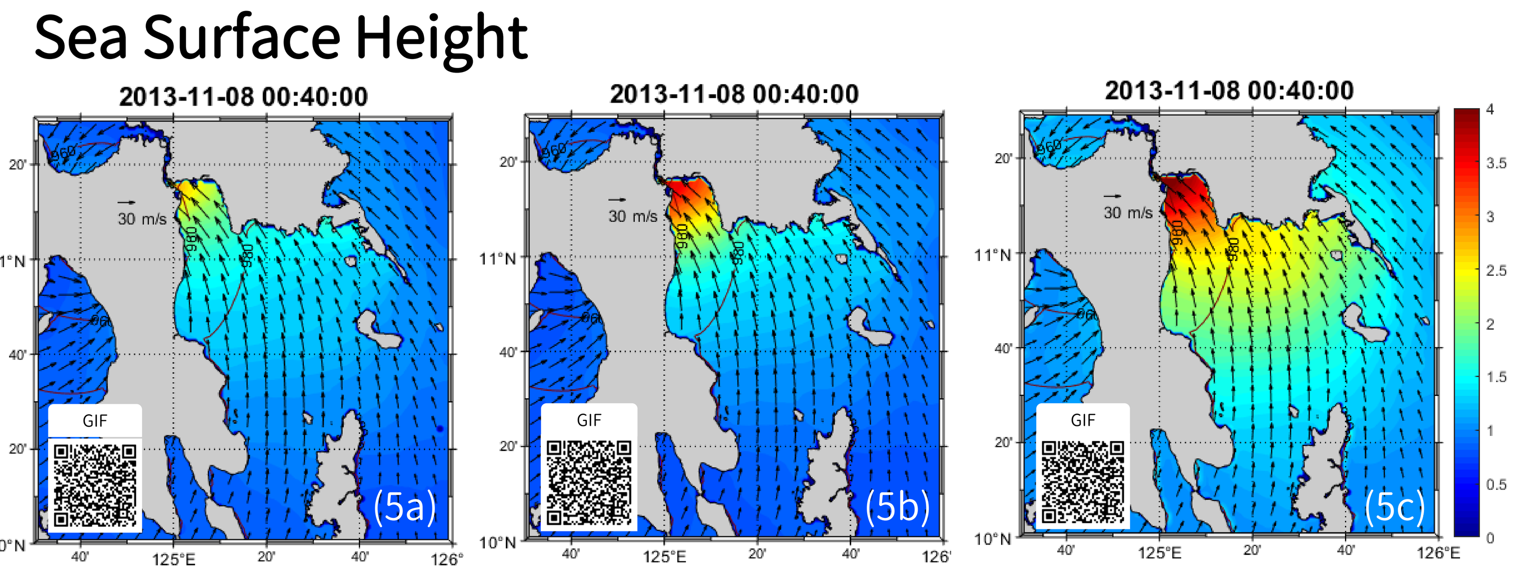


Fig.5. The maximum sea surface height distribution from (a) Expt. 1, (b) Expt. 2 and (c) Expt. 3 The color shading indicates sea surface height, the contour line represents the sea surface atmospheric pressure and the arrow represents 10m wind.

- As expected, the sea surface height increased as the typhoon approached. **Expt. 3 shows the highest sea level changes**, with low-pressure areas corresponding to sea level rise.

ROMS vs. CROCO

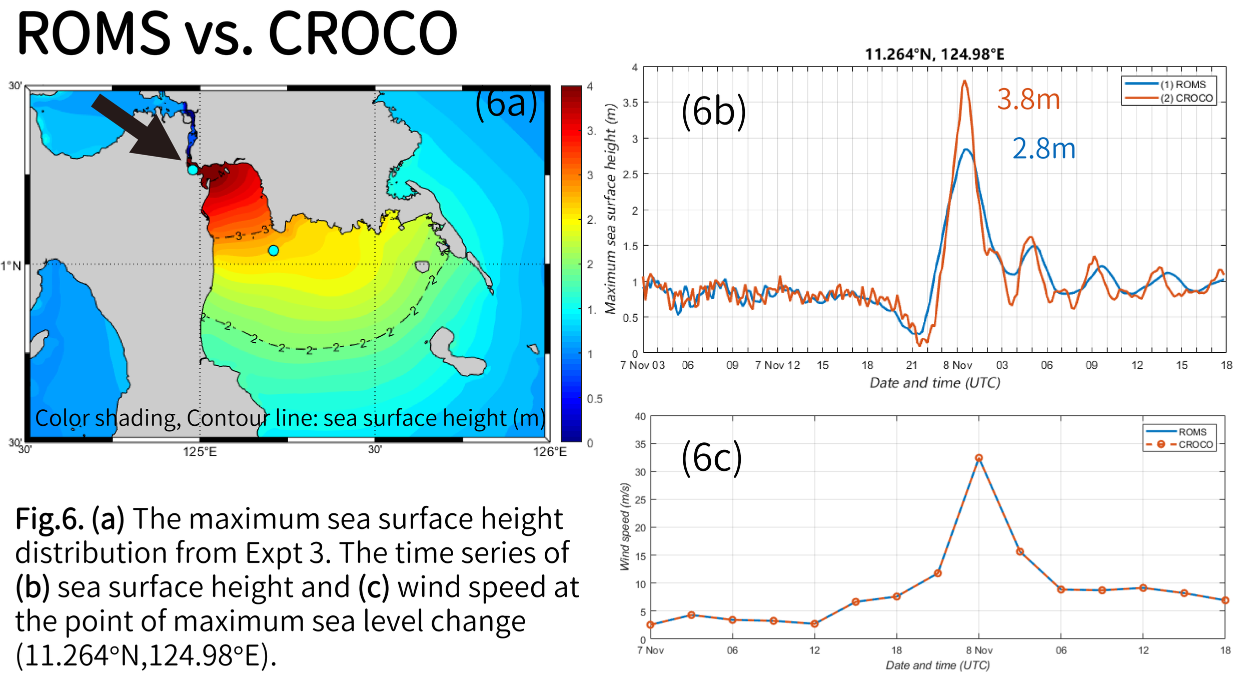


Fig.6. (a) The maximum sea surface height distribution from Expt 3. The time series of (b) sea surface height and (c) wind speed at the point of maximum sea level change (11.264°N,124.98°E).

- Although the wind speeds are the same, **CROCO handle nearshore bathymetry and coastal topography better**, allowing it to **more accurately capture nearshore processes**. This resulted in about a 1m difference in peak sea surface height.

Atmospheric pressure

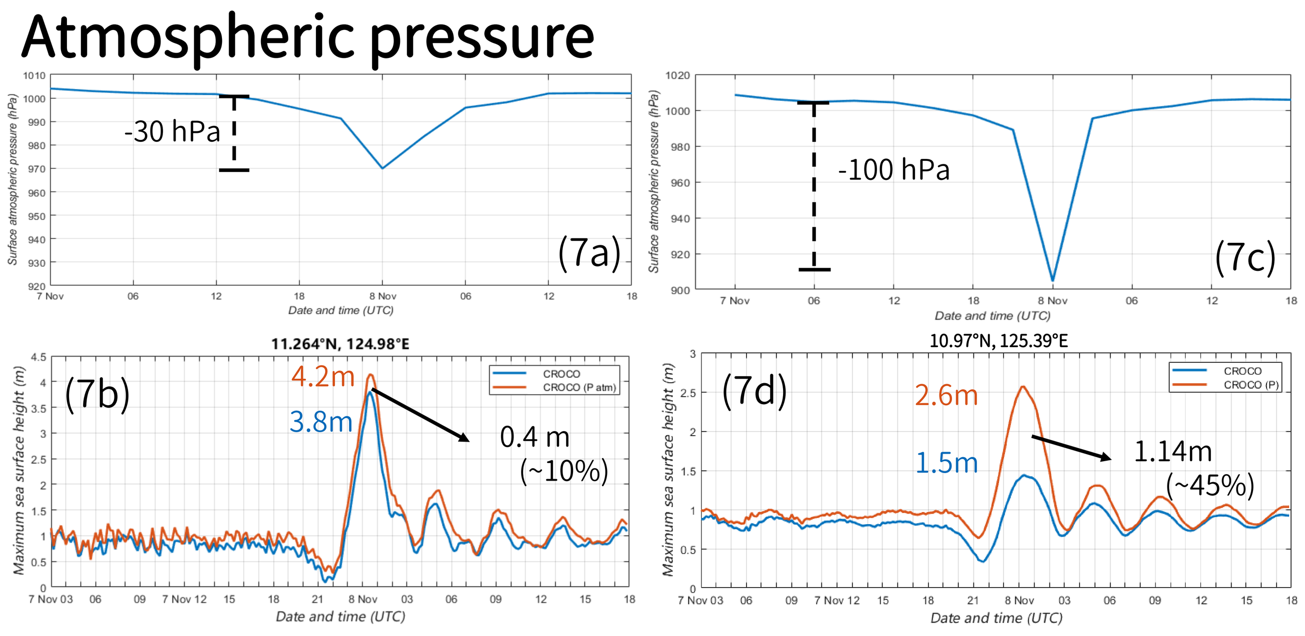


Fig.7. The time series of (a) sea surface atmospheric pressure and (b) sea surface height for Expt. 2, 3 at the point of maximum sea level change. The time series of (c) sea surface atmospheric pressure and (d) sea surface height for Expt. 2,3 at the point of maximum sea level change contribution by P_{atm}.

- The contribution of atmospheric pressure to sea level changes **varies depending on the pressure difference.**

Tides

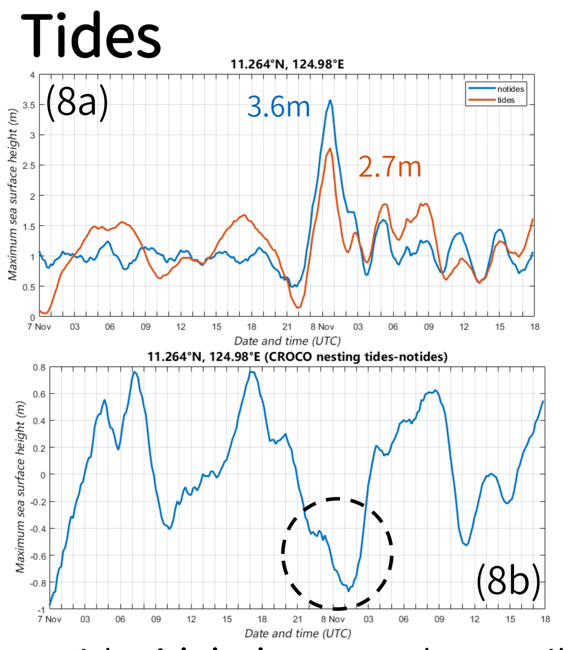


Fig.8. The time series of (a) sea surface height and (b) sea surface height variation from Expt. 4, with and without tidal influence, at the point of maximum sea level change.

- With **tidal changes**, there will be different variations in sea surface height.
- During Typhoon Haiyan's landfall, it coincided with **ebb tide**, resulting in a **negative contribution to sea surface height.**

Conclusion and Future work

- In this case, **wind stress had the greatest impact**, followed by atmospheric pressure, and finally, tides.
- **The Experiment 3**, the CROCO model which includes wind stress and atmospheric pressure, provided **the best match** according to the validation.
- Interestingly, **tidal effects** played a role in **suppressing changes in sea level height** in this study. In other words, if Typhoon Haiyan had coincided with flood tide, the disaster would have been significantly worse.

- **Obtaining more accurate bathymetry and land data** because the process of simulating a storm surge is sensitive to the terrain.
- **Expanding the domain of the study** to obtain usable sea level measurements for more convincing validation.
- **Adding wave effects**, whether by enabling CROCO's built-in wave function or coupling with an wave model.

Reference

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