STORM SURGE FORECASTING AND INUNDATION ESTIMATION DURING TROPICAL STROM PABUK 2019 IN THE SOUTHERN COAST OF THAILAND

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ABSTRACT

Tropical Storm Pabuk was the latest severe storm in the past two decades since Typhoon Linda in 1997 that had its landfall in the southern region of Thailand. It brought heavy rain, strong wind and high level of surge that caused widespread of coastal flooding especially in the low-lying area. This event had been monitored since the storm was formed in the South China Sea. Its formation and track were closely monitored and predicted for the strength, track and impacted area. The storm surge forecasting and early warning system for the Gulf of Thailand was developed using Delft-FEWS as operational platform. Delft3D-FM and SWAN models were used to compute the total water level that combined effect of tide, wave and surge. Finally, Tropical Storm Pabuk had hit the land at Pak Phanang, Nakhon Si Thammarat on 4 January 2019 afternoon with wind speed reaching 83 km/hr. It was found that the model could capture the whole phenomena satisfactory. The total water level, flow direction, time of landfall and impacted area were computed with good accuracy. The comparison between computed and observed water level from the water level stations showed strong correlation and good agreement. The inundation area was also estimated using wetting and drying scheme in Delft3D-FLOW. SRTM 90m was used for the land topography to simulate coastal flooding during the storm. The estimated inundation area using the model has been compared with observed flood map from RADARSAT-2 satellite. The results showed a good agreement especially in the low-lying area including estuary, mangrove and local community area.

Keywords: Gulf of Thailand, Tropical Storm Pabuk, Early warning system, Storm surge, Inundation

1. INTRODUCTION

The Gulf of Thailand has experienced severe storm surges due to tropical storm, especially Typhoon Gay (1989) and Typhoon Linda (1997) attacked the southern region of Thailand caused coastal flooding and serious damage to life and property. Tropical Storm Pabuk was the latest severe storm in the past two decades. Regarding to storm forecasting at that time, Tropical Storm Pabuk is expected to make landfall over Pak Phanang, Nakhon Si Thammarat on 4 January 2019. It will bring heavy rain lead to widespread flooding and can cause extreme wave and storm surge which are responsible for severe coastal flooding and property damage. Tropical Storm Pabuk were closely monitored and predicted for the strength, track and impacted area since the storm originated in the South China Sea. This paper describes the post-event analysis of storm surge and presents the manifestation of data and tools integration for decision making, issue warning and help to mitigate the losses of Thailand.

2. STORM SURGE FORECASTING AND EARLY WARNING SYSTEM

Forecasting of the storm surge by numerical models become a popular tool nowadays. The advanced technology in modelling made models more powerful, accurate and reliable. Hydro - Informatics Institute (HII) developed the operational storm surge forecasting system for the Gulf of Thailand since 2015. To simulate the important phenomena of storm surge, the system consists of 2 models. Delft3D-FM hydrodynamic model used to simulate the hydrodynamic effects caused by wind, atmospheric pressure and tidal forces and TPXO 7.2 global tide model data was input as tidal boundaries of Delft3D-FM model. SWAN wave model used to simulate the wind driven waves. The wave boundaries were obtained from

WAVEWATCH III global wave model. The hydrodynamic and wave models forced by WRF-ROMS model, a coupled atmosphere and ocean modeling system was developed by HII. The storm surge forecasting and early warning system based on Delft-FEWS, an operational forecasting and model integration platform, which integrated and linked data and models in real-time and automatically produced forecasts on a daily basis (Thanathanphon et al., 2016; Torsri et al., 2014).

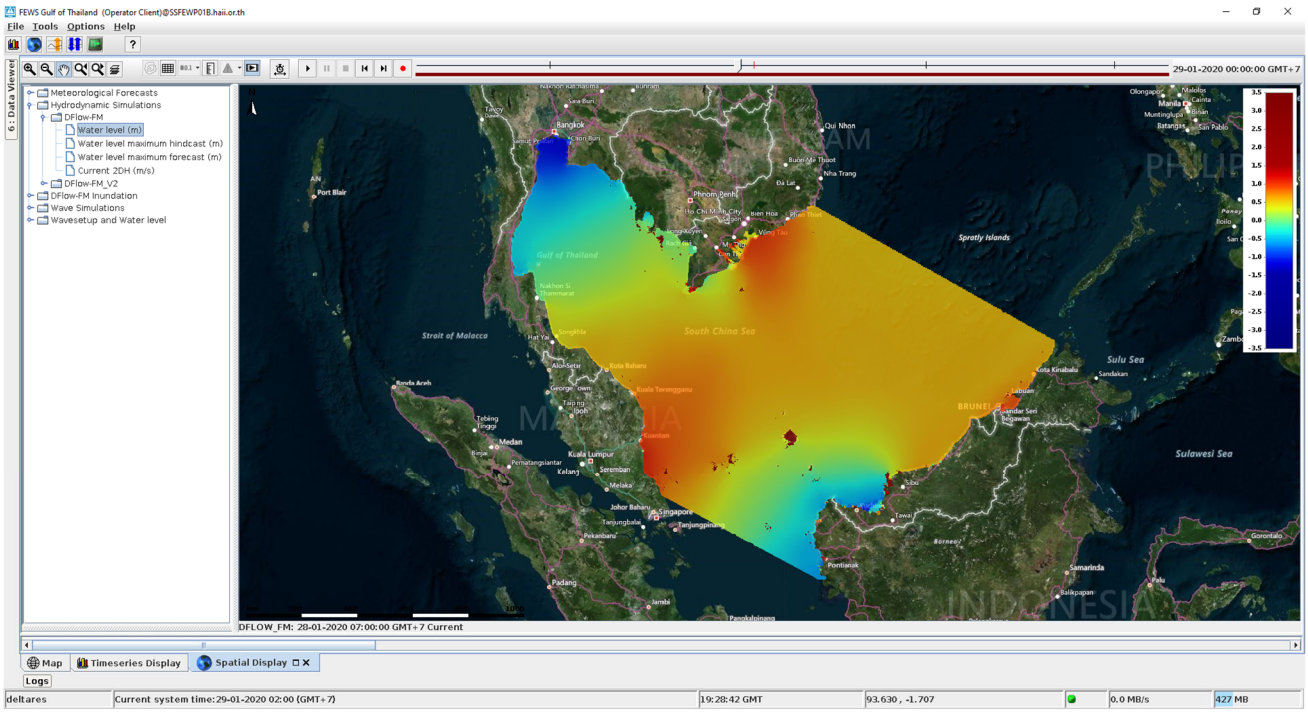

Figure 1. Forecasted water level map of the Gulf of Thailand in the storm surge forecasting and early warning system.

3. TROPICAL STORM PABUK

On 31 December 2018, a tropical depression formed in the South China Sea. Until 00UTC on 1 January 2019, this tropical depression was upgraded to tropical storm and was named Pabuk. Tropical Storm Pabuk accelerated its intensity for two days. It moved westward and entered the Gulf of Thailand on 3 January 2019. Tropical Storm Pabuk had made landfall over Pak Phanang, Nakhon Si Thammarat on 4 January 2019 afternoon with wind speed reaching 83 km/hr. Pabuk became the first tropical storm to hit the southern Thailand since Typhoon Linda in 1997. Pabuk weakened after it hit the land and dissipated after it entered Andaman Sea on the next few days. Figure 2 shows the best track of Tropical Storm Pabuk was obtained from National Oceanic and Atmospheric Administration (NOAA). Figure 3 shows the intensity of Tropical Storm Pabuk in the Gulf of Thailand was captured from NASA-NOAA's Suomi NPP satellite.

Figure 2. Tropical Storm Pabuk's best track.

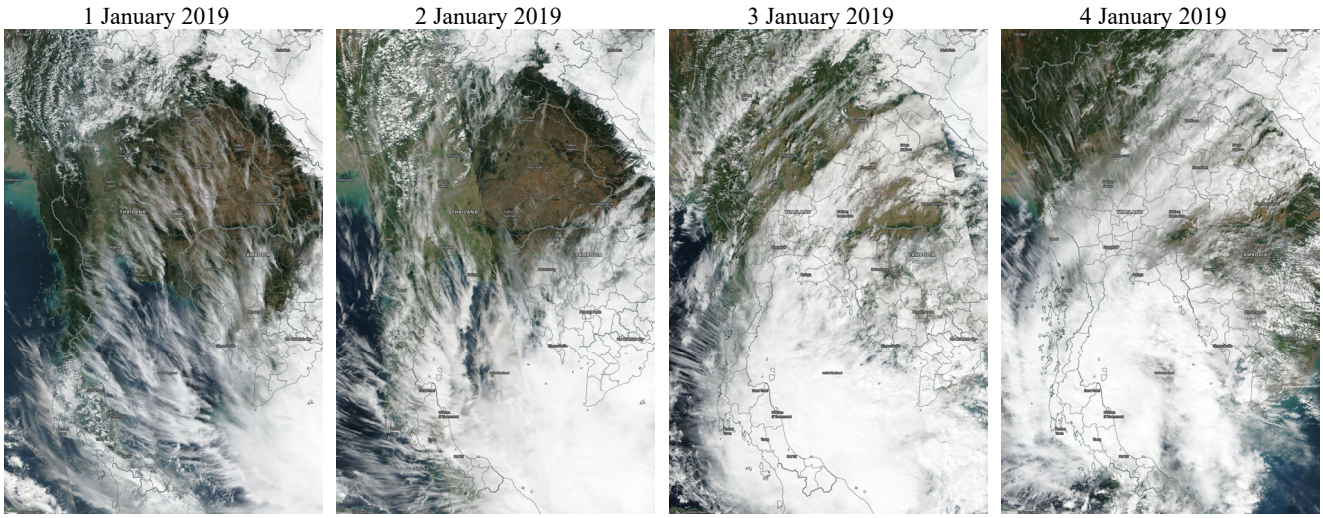

Figure 3. Suomi NPP satellite images of Tropical Storm Pabuk in the Gulf of Thailand on 1-4 January 2019.

4. STORM FORECASTING

Tracking tropical storm by numerical weather prediction model in order to identify its track and intensity is crucial for post-event evaluation. Forecasted storm track can compare with observed track from various tropical storm warning centers. At the end of season, the tropical storm warning centers will reanalyze and produce best track data of each storm. Best track typically consists of center positions, maximum surface wind speeds, and minimum central pressures, and may include quadrant radii of winds (WMO, 2013). This data is more accurate and useful for storm verification.

Tropical Storm Pabuk's track and intensity from WRF-ROMS model was verified with observed information collected from NOAA. Figure 4 shows the best track and forecasted tracks at different lead time. The forecasted tracks were slightly shifted to the north of best track and followed the same trend as best track. However, the forecasted tracks can be confirmed Tropical Storm Pabuk made landfall near Pak Phanang, Nakhon Si Thammarat. In addition to the forecasted tracks, the forecasted maximum wind speed and minimum central pressure were considered. Figure 5 shows the overall intensity of forecasted storm was stronger than the actual storm. For example, the forecast at 00UTC on 4 January 2019. The forecasted storm made landfall with maximum wind speed of 98 km/hr, while the actual storm made landfall with maximum wind speed of 83 km/hr (Figure 5A). In terms of the minimum central pressure at landfall location. The minimum pressure from simulation was 992 mb, while the actual storm reached a minimum pressure of 998 mb (Figure 5B). However, the forecasted storm made landfall at 09UTC on 4 January 2019 same as the actual storm but it shifted from the observed landfall location about 10 km that reveals a good forecasting skill and a good correlation between forecast and observation.

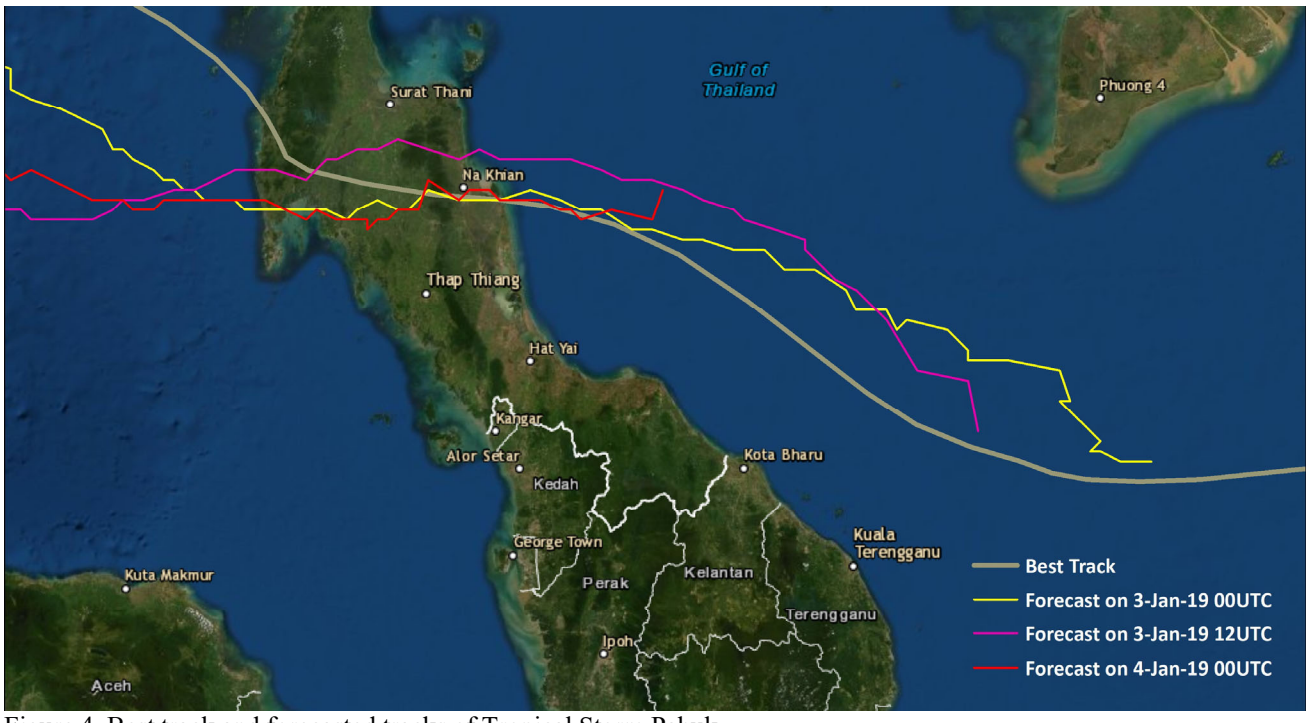

Figure 4. Best track and forecasted tracks of Tropical Storm Pabuk.

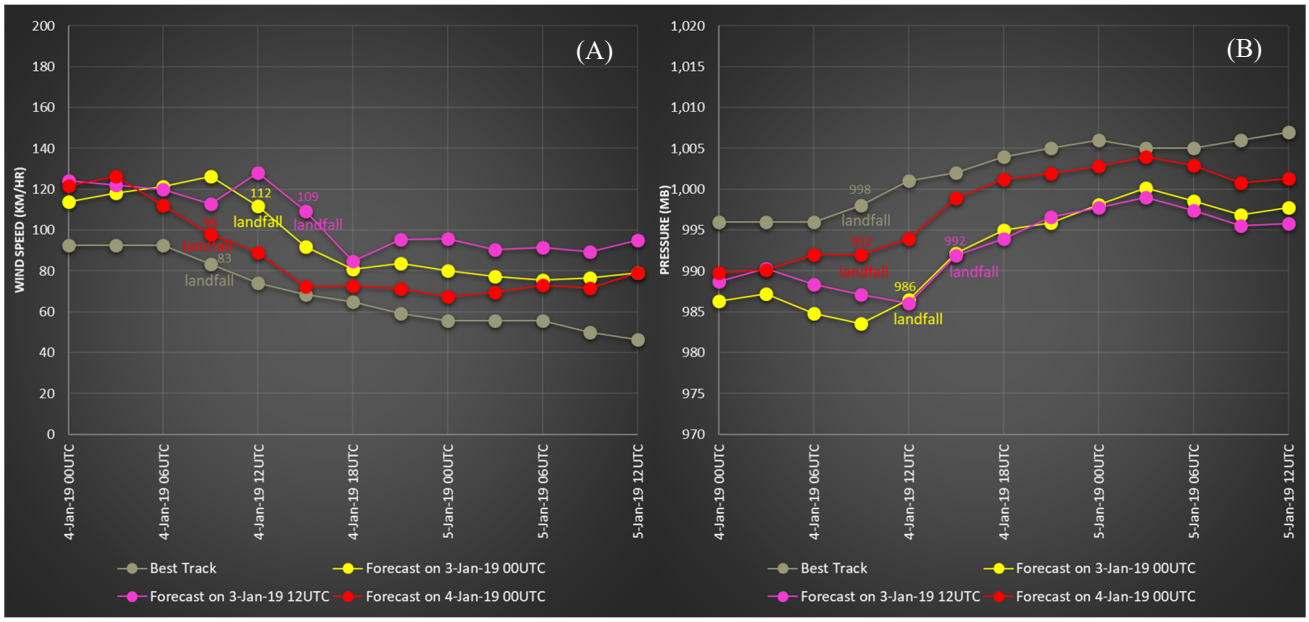

Figure 5. Comparison of maximum wind speed (A) and minimum central pressure (B) of Tropical Storm Pabuk.

5. STORM SURGE FORECASTING

Water level simulation of the Gulf of Thailand on 4 January 2019 from the storm surge forecasting system shows that at 00UTC on 4 January 2019 Tropical Storm Pabuk over the Gulf of Thailand was located about 120 km southeast of Nakhon Si Thammarat with maximum wind speed 92 km/hr. It generated water level in the Gulf of Thailand ranged between 1.5-2.0 m. At 09UTC on 4 January 2019, Tropical Storm Pabuk made landfall with maximum wind speed 83 km/hr. The coastal of Nakhon Si Thammarat experienced a higher water level reached to 2-2.5 m (Figure 6). Especially, the simulated maximum water level at Pak Phanang coast was 2.31 m and peak surge was 1.57 m (Figure 7).

Simulated water level has been compared with observation of 2 nearshore water level stations located at Phra Chulachomklao Fort, and Ko Lak obtained from Hydrographic Department of Royal Thai Navy and 2 offshore water level stations located at Benjamas and Plathong gas field operated by Chevron Thailand Exploration and Production, Ltd. The results show a relatively good agreement with correlation of 0.82 and 0.76 at nearshore stations (Figure 8A, 8B), 0.63 and 0.53 at offshore stations (Figure 8C, 8D), respectively.

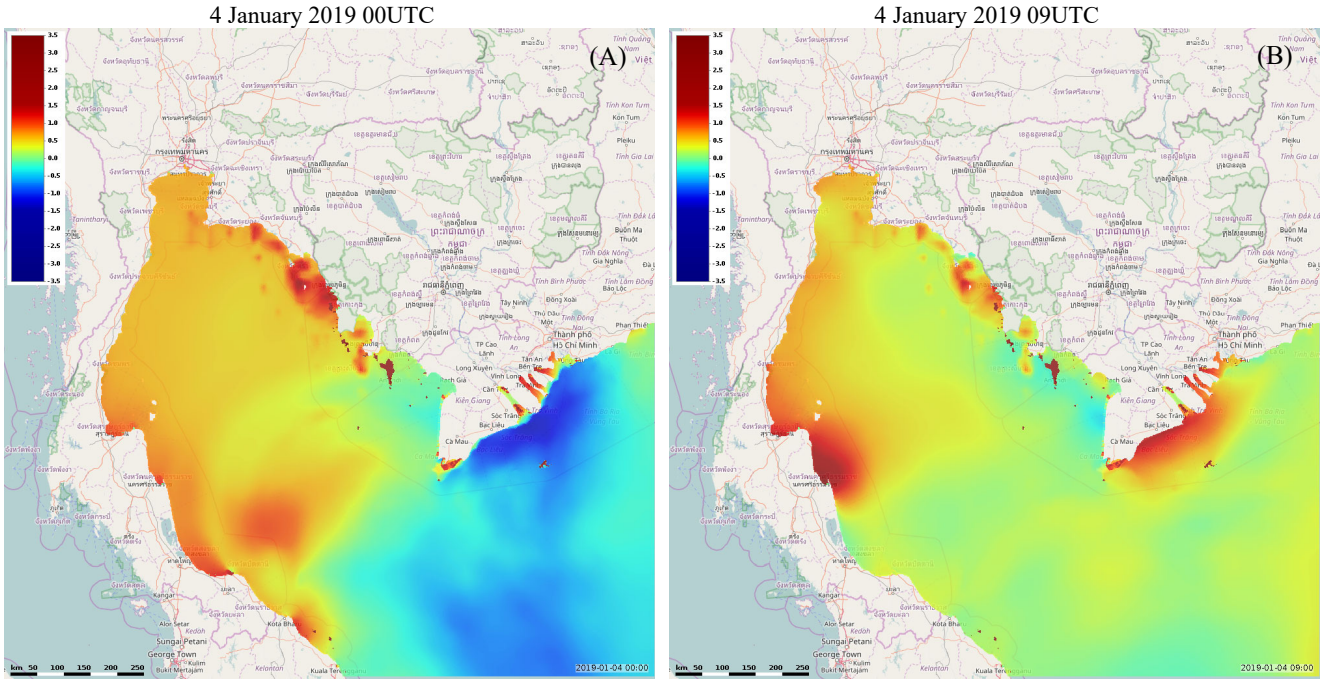

Figure 6. Simulated water level in the Gulf of Thailand on 4 January 2019 at 00UTC (A) and 09UTC (B).

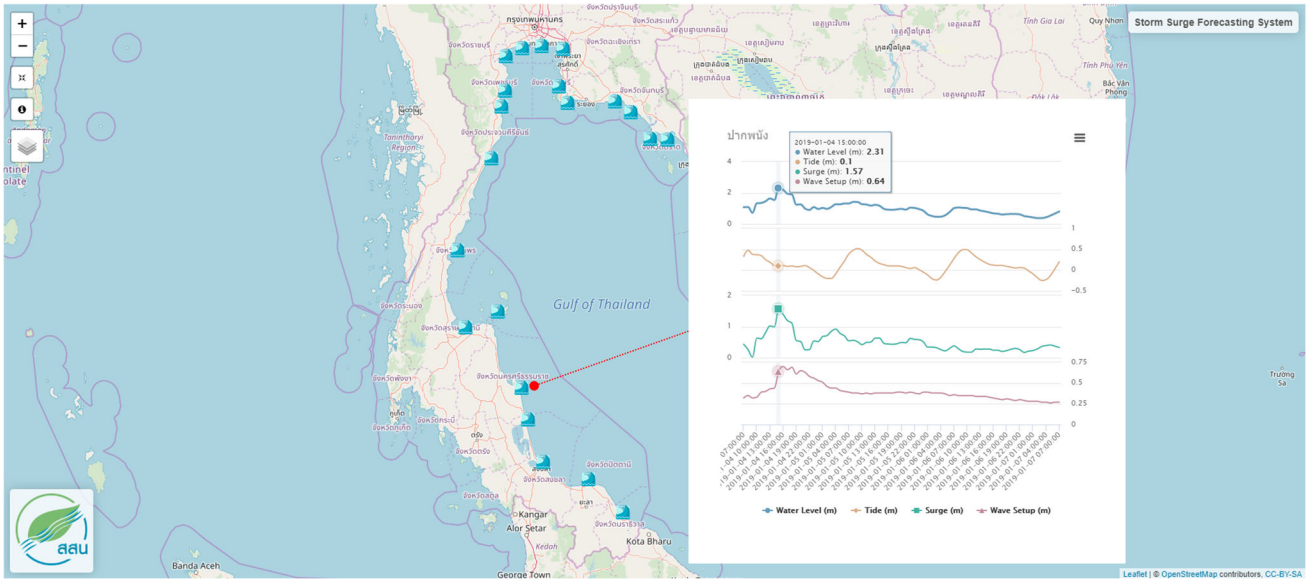

Figure 7. Simulated water level at Pak Phanang, Nakhon Si Thammarat on 4 January 2019.

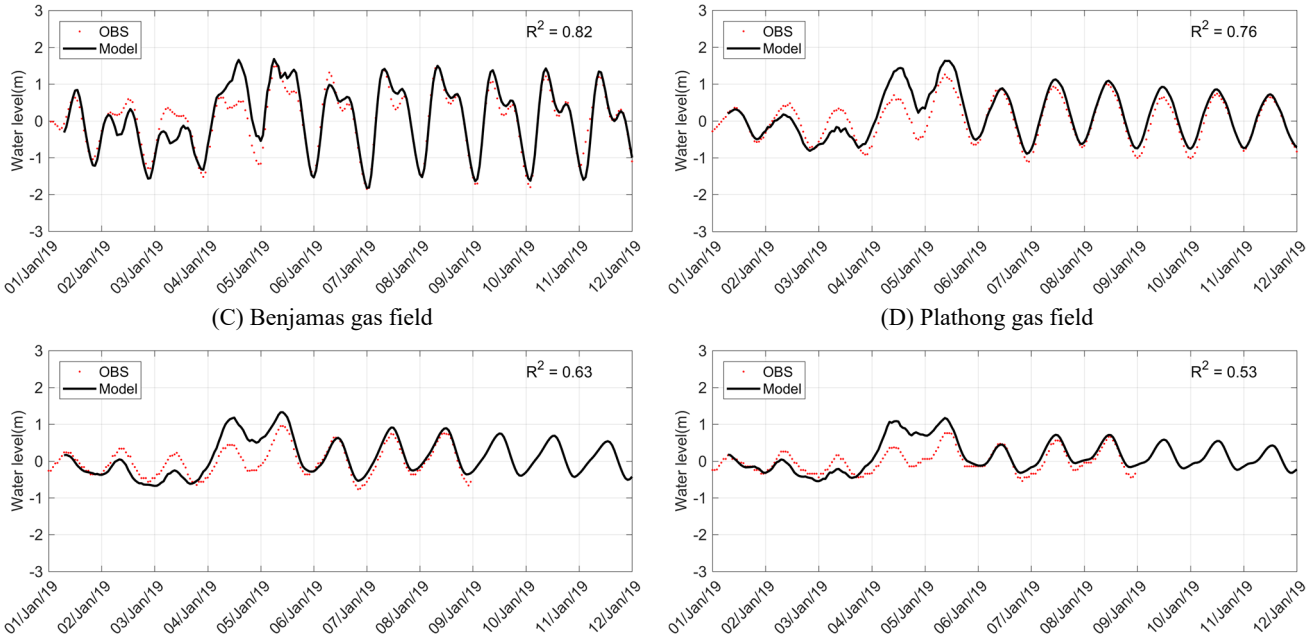

Figure 8. Comparison of simulated and observed water level at nearshore stations (A, B) and offshore stations (C, D).

6. INUNDATION ESTIMATION

Storm surge is a large dome of water that inundates the coast. Surge is part of the total inundation associated with the storm. Other components of the inundation also include tide and wave setup (Nott, 2015). Low-lying coastal area is susceptible to damage caused by storm surge as storm make landfall.

Delft3D-FLOW model was used to simulate storm surge and inundation caused by Tropical Storm Pabuk along the southern coast. The wetting and drying scheme in Delft3D-FLOW model is the important process. Therefore, the sea bathymetry and SRTM 90m land DEM were interpolated to simulate inundation area. The actual inundation area occurred during Tropical Storm Pabuk was extracted from the high-resolution imagery from RADARSAT-2 which processed by Geo-Informatics and Space Technology Development Agency (GISTDA) and it was used to validate the model.

Figure 9 shows the simulated inundation area from model (Figure 9A) and observed inundation area from satellite (Figure 9B) in the risk area of storm surge flooding based on the elevation of coastal area of Nakhon Si Thammarat which is lower than 0.5 m above mean sea level. The simulated coastal inundation was found in the low-lying areas including estuary, mangrove and local community area. It demonstrates that the simulated inundation areas are in satisfactory with the observed inundation areas from satellite and local reporting. Although the simulated inundation areas were slightly overestimated but reasonably acceptable. However, satellite may fail to capture the signal reflected by water when the weather is cloudy. Furthermore, the revisit cycle of satellite is several days, so remote sensing cannot capture the daily or even hourly state of inundation.

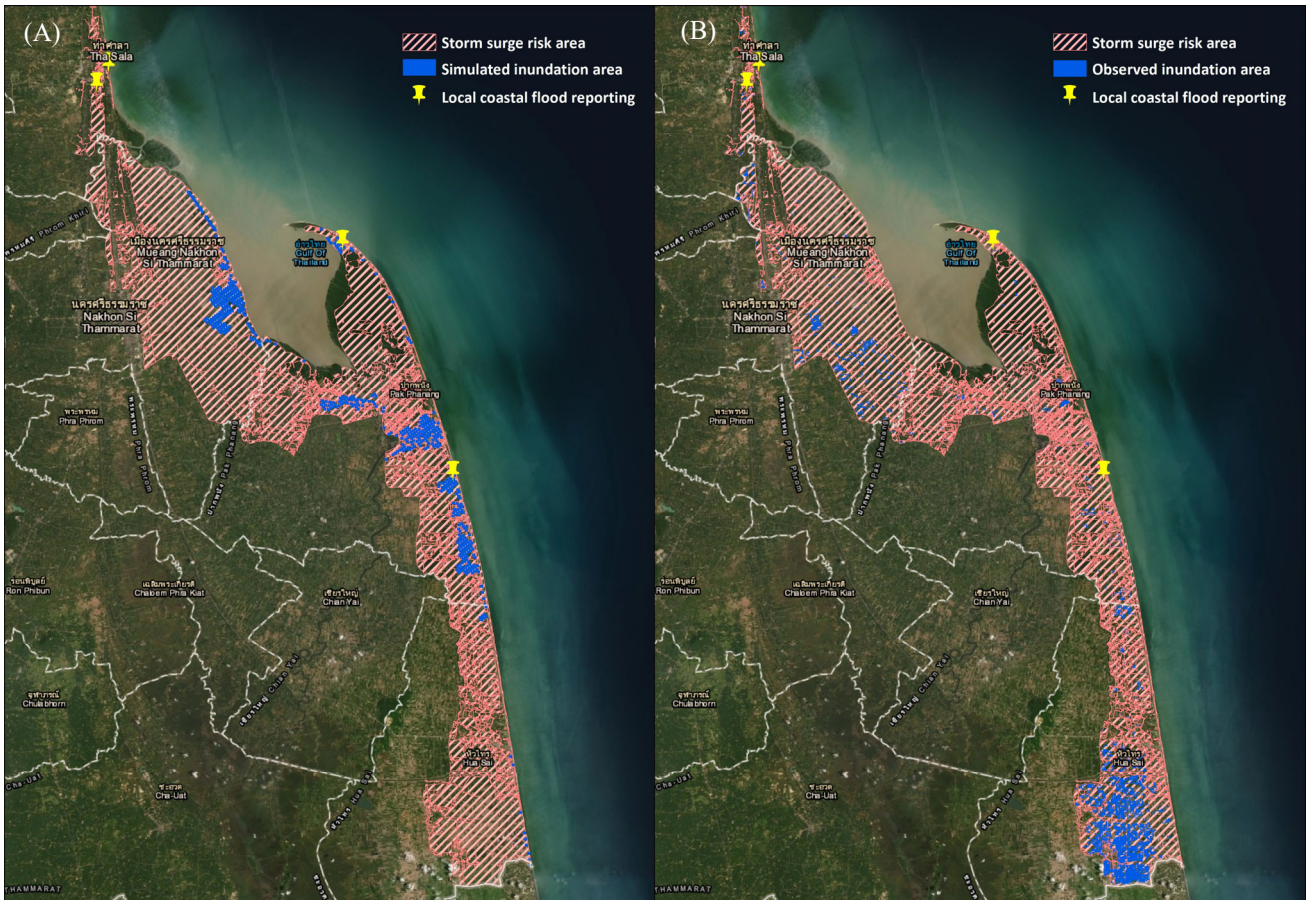

Figure 9. Simulated (A) and observed (B) inundation along the coastal area of Nakhon Si Thammarat during 3-6 January 2019.

7. CONCLUSIONS

Low pressure and strong wind associated with a tropical storm are the major cause of storm surge. For storm surge forecasting, it is important that the weather prediction model can predict location and intensity of tropical storm accurately. The predicted track and intensity of Tropical Strom Pabuk from WRF-ROMS model was verified and revealed a good forecasting skill. Delft3D-FM and SWAN models have been applied to the storm surge forecasting system. Models were capable to simulate water level and surge for Tropical Strom Pabuk which are well agreed with the observation. The results show a reasonable prediction of storm surge along Nakhon Si Thammarat coast.

The coastal inundation can be severe during storm surge event particularly when it coincides with a high tide and result in overtopping and breaching (Brown et al., 2007). However, overtopping or breaching in this event has been observed from local coastal flood reporting in the low-lying area of Nakhon Si Thammarat coast. The simulated inundation from model revealed that model is a promising tool for forecasting and monitoring coastal flooding due to storm surge because it can simulate the dynamic of inundation area and fill in the gaps of inundation monitoring from remote sensing.

The severe storm surge was back in October 1962. Typhoon Harriet directly hit to Laem Talumphuk, Nakhon Si Thammarat which killed 900 people. According to Department of Disaster Prevention and Mitigation report (DDPM, 2019). During Tropical Storm Pabuk, 31,665 people in the southern Thailand were evacuated and 5 casualties were reported. Even though Tropical Strom Pabuk was not powerful and comparable to Typhoon Harriet, the accurate information and reliable early warning system are very important for disaster preparedness. The results from the storm surge forecasting system have been used to support Thai government in decision making, issue warning and help to mitigate the losses.

ACKNOWLEDGMENTS

Authors would like to thank Hydrographic Department of Royal Thai Navy, Chevron Thailand Exploration and Production, Ltd. and Geo-Informatics and Space Technology Development Agency for providing data for model validation.

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