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ABSTRACT

The Gulf of Thailand receives a direct impact from the northeastern monsoon and normally receives the effect of tropical storm which can produce a larger wave propagating into the inner gulf. An abnormal of sea level rise at a coastline caused by very low pressure accompanied with very strong wind is called storm surge. Water is piled-up at the shore and spilled over lands. This causes serious hazards to coastal regions. There is a strong need for a forecasting and warning system that can provide accurate and reliable information on the possible storm surge.

KEY WORDS: The Gulf of Thailand; Storm surge; Forecasting; Warning system

INTRODUCTION

The Gulf of Thailand is characterized as an estuary of drowned river valley with the seabeds which was once emerged above sea surface. It is relatively shallow with the average depth ranging from 58-85 m. The main tidal characteristic is diurnal with average tidal range of about 2.6 m. Based on its location, the Gulf of Thailand receives a direct impact from the northeastern monsoon which can produce a larger wave propagating into the inner gulf. Strong wind and wave can induce coastal flooding and damages in the coastal area. Generally, the waves in the Gulf of Thailand are relative small with the average height of 1 - 2 m. An abnormal of sea level rise at a coastline caused by the driving forces in terms of a very high horizontal atmospheric pressure gradient and very strong surface wind is called storm surge. Water is piled-up at the shore and spilled over lands. This causes serious hazards to coastal regions, such as flooding, coastal erosion and devastating the properties of people who live in the areas. The previously 6 disastrous tropical cyclones crossed over Thailand as shown in Fig. 1, typhoon “VAE” (October, 1952) attacked the Upper Gulf of Thailand, typhoon “HARRIET” (October, 1962) caused disaster at Laem Talumpuk of Nakhon Si Thammarat province due to its devastation winds and surges causing 800 deaths, tropical storm “RUTH” (November, 1970) attacked Ko Samui and coastline of Surat Thani and Chumphon province, tropical storm Forrest (November, 1992) struck Nakhon Si Thammarat province, 3,000 people were evacuated and 1,700 houses were damaged, typhoon “GAY” (November, 1989) hit Pathio of Chumphon province, killed more than 400 people and 40,000 houses destroyed and typhoon “LINDA” (November, 1997) attacked at Thapsake of Prachuap Khiri Khan province, resulting in 30 people dead, 102 people missing, and more than 640 sq.km of agricultural land destroyed (Vongvisessomjai, 2009). Therefore, there is a strong need for a forecasting and warning system that can provide accurate and reliable information on the possible storm surge. In this study the Delft3D Flexible Mesh has been developed to simulate hydrodynamic condition and SWAN wave model to simulate wave characteristics in the Gulf of Thailand. The Delft-FEWS system has been employed for the operational forecasting platform. The wind forcing is derived from the WRF-ROMS forecasting system. The system is expected to run once per day and provide a sea level and wave forecast for the next 3 days.

Fig. 1 The 6 disastrous tropical cyclones crossed over Thailand

STUDY AREA

The Gulf of Thailand is a semi-enclosed sea located in the western part of South China Sea and bordered by Thailand, Malaysia, Cambodia and Vietnam. The boundary of the Gulf is defined by the line from Cape Camau in southern Vietnam to the coastal city of Kota Bharu on the east coast of Peninsular Malaysia. The Gulf of Thailand is relatively shallow. The average depth is 44 m and the maximum depth in the center of the gulf is 86 m (Department of Mineral Resources, 2012).

METHODOLOGY

The Modelling System

Generally, storm surge simulating system comprises meteorological, hydrodynamic and wave models. In this study, Delft3D FM hydrodynamic model used to simulate the hydrodynamic effects caused by wind, atmospheric pressure and tidal forces on unstructured grid. SWAN wave model used to calculate the wind driven waves. The forcing for hydrodynamic and wave models computed by the coupled WRF-ROMS numerical weather prediction model designed to simulate the atmospheric circulation is considered an air-sea interaction. An operational storm surge modelling system consists of the following 4 core components as shown in Fig.2

Hydrodynamic Model based on Delft3D Flexible Mesh (Delft3D FM) developed by Deltares. It can carry out simulations of flows, tide, water level, storm surge, water quality and ecology. The key component of Delft3D FM is engine for multi-dimensional (1D, 2D and 3D) hydrodynamic simulations on unstructured grids (Deltares, 2016). The hydrodynamic model covers the Gulf of Thailand extended to southern part of the South China Sea and simulated on different horizontal resolution grids are 250 m along Thailand coast, 1,000 m along other coasts and 8-16 km over deep waters (Fig. 3). Tidal boundary conditions obtained from satellite altimetry.

Wave Model based on Simulating WAves Nearshore (SWAN) developed by Delft University of Technology, a third-generation wave model computes random, short-crested wind-generated waves in coastal regions (The SWAN team, 2015). SWAN model was created in rectangular grid. The grids contain 1.5 km horizontal resolution for regional wave model, which covers 6°N-14°N latitude and 99°E-105°E longitude and 300 m horizontal resolution for local wave model simulated wave characteristics in shallow water along the coast of the southern part of Thailand from Nakhon Si Thammarat to Narathiwat province (Fig. 4). The offshore boundary conditions for regional wave model were derived the wave parameters from WAVEWATCH III simulation, which is operationally run at NOAA. The nested local wave model carried out with the boundary conditions obtained from a regional wave model simulation.

Numerical Weather Prediction Model, Hydro and Agro Informatics Institute (HAII) has been developing a coupled atmosphere and ocean modeling system since 2014. The component models consist of the Weather Research and Forecasting Model (WRF) and the Regional Ocean Model System (ROMS). The system setup in high performance computer and used parallel processing. The WRF-ROMS model covers the areas of Asia, Southeast Asia and Thailand with 3 different resolutions are 27, 9 and 3 km respectively (Torsri *et al.*, 2014). Presently the WRF-ROMS model is processed twice per day. It can forecast precipitation, wind and other weather parameters 7 days in advance (available on http://www.thaiwater.net/). The u and v components wind at 10 m above the sea surface and the surface pressure from 9 km WRF-ROMS output used in this storm surge forecasting system

Early Warning System based on Delft-FEWS, an operational forecasting platform, the key features of the system is its flexibility in integrating and linking data and models in real-time and automatically producing forecasts on a daily basis (Werner *et al.*, 2013). The objective of Delft-FEWS Gulf of Thailand is connecting Delft3D FM hydrodynamic model and SWAN wave model, linking multi-data sources as input for models and provide daily accurate water level, storm surge, and wave forecasts automatically with various data exports.

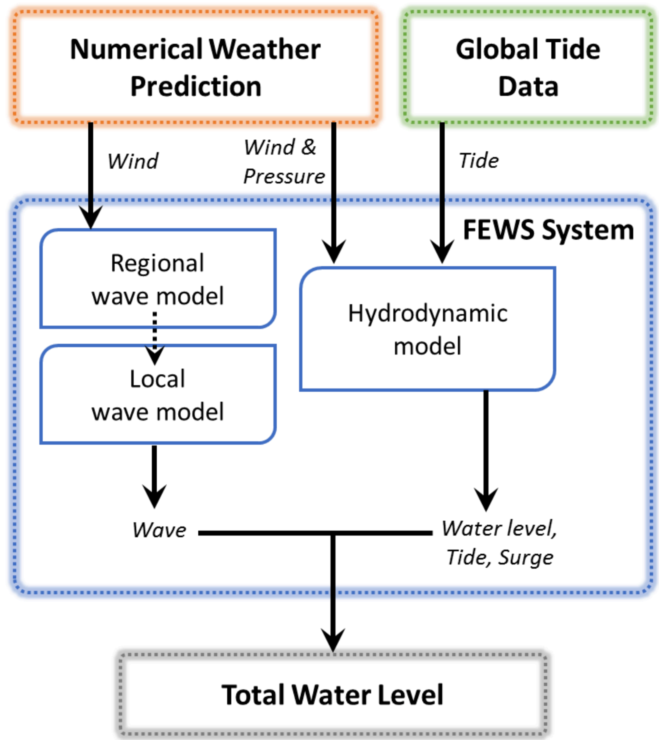

Fig. 2 The components of storm surge modelling system

Fig.3 Delft3D FM hydrodynamic model extent

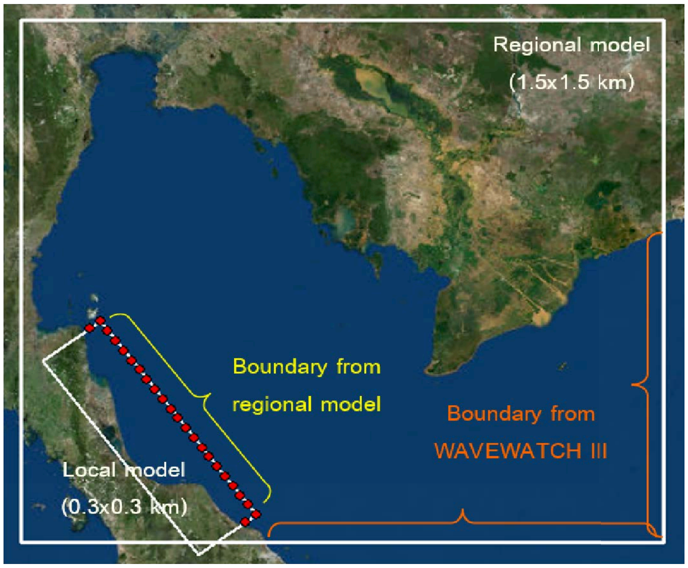

Fig. 4 SWAN regional and local wave models extent

Bathymetric Data

The bathymetric data used for hydrodynamic and wave models was combined from 3 sources as Fig. 5 the bathymetry consists of 1) local data in the upper Gulf of Thailand surveyed by Department of Mineral Resources (pink area) 2) the nautical charts produced by Thai Royal Navy (orange area) and 3) the global GEBCO 30 arc-seconds bathymetry from the British Oceanographic Data Centre (green area). The global bathymetry is satellite-derived gravity data and works best in deep water that are not otherwise surveyed directly. In shallow water, the gravitational effects that can be measured from the satellite are too small to be reliable. In coastal area of the Gulf of Thailand, the local high resolution survey data have been used. It is useful, in particular for constructing detailed bathymetry for local or nested models.

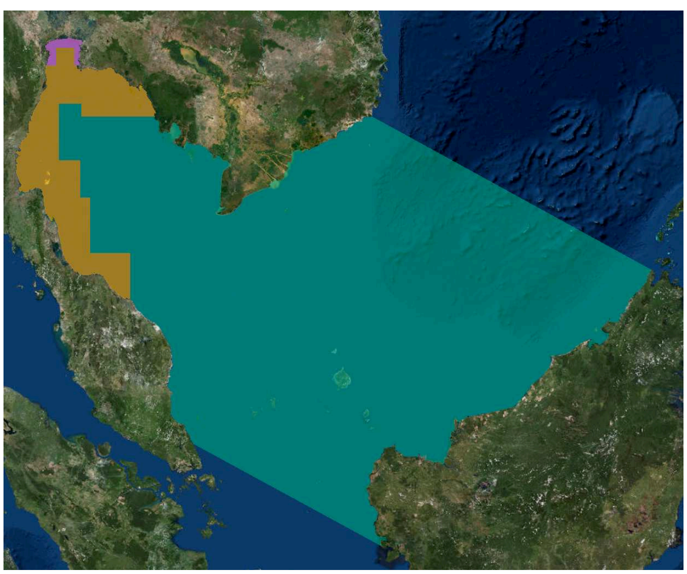

Fig. 5 The bathymetric data used for hydrodynamic and wave models

System Architecture

The early warning system based on Delft-FEWS. It has open interfaces to input data and supports a wide range of input data formats. As such, by using Delft-FEWS, data from a wide range of monitoring stations and forecasting agencies can be made accessible in one place. Delft-FEWS deployed in a client-server based architecture, with a central server running tasks and clients accessing through the internet or intranet. The users can monitor data feeds, produce model forecast at regular intervals / forecast cycles, view the measurement data and run specific tasks. The tasks will also be scheduled with certain time interval to allow automatic running of workflows. Delft-FEWS configured to manage data prior to presentation or prior to feeding this data into the forecasting models, the modelling framework applied to run the hydrodynamic and wave forecasts (in this system both models are not dynamically coupled), the post-process of model output and the export of these forecasts (Fig. 6). An example of WRF-ROMS meteorological forecast imported by Delft-FEWS as shown in Fig.7
The early warning system consists of the following functionalities:

- Automatic import of real time data feeds provided to the system
- Pre-processing of meteo-data (forecasts) before using it in the hydrodynamic and wave models
- Execution of the hydrodynamic and wave modelling framework
- Visualization of measurement data and forecasts
- Exporting of forecasts in various format
- Dissemination of forecasts (e.g. internet, intranet)

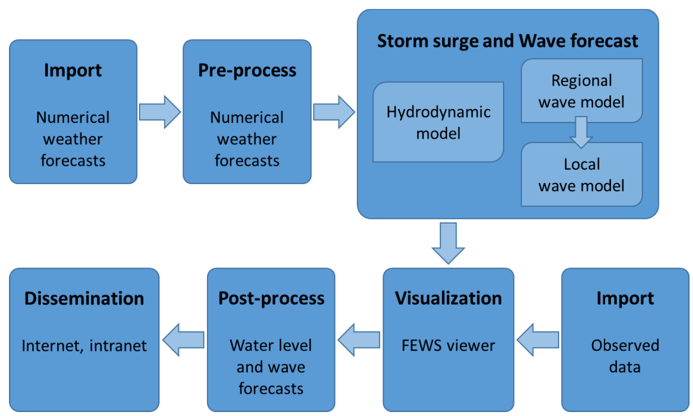

Fig. 6 An overview of the early warning system workflow

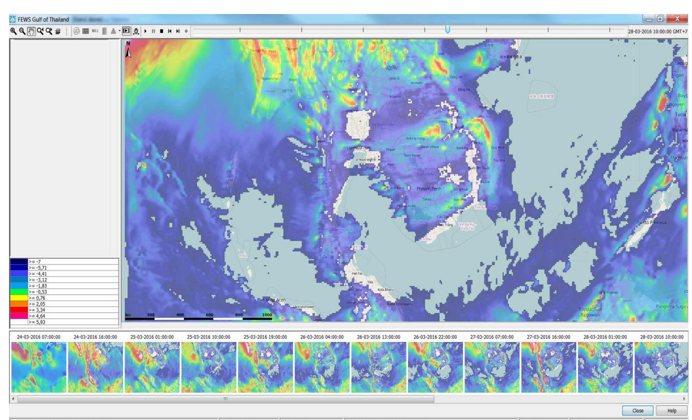

Fig.7 WRF-ROMS meteorological forecast imported by Delft-FEWS

Model Validation

The hydrodynamic and wave models were setup based on an event that has high surge and wave height in March 2011. By using Delft3D FM with input data of GFS reanalysis data and tidal constituents from TOPEX/Poseidon. The results of Delf3D FM compared with the observed data 16 stations from Marine Department, Thailand and 1 station from the University of Hawaii Sea Level Center (UHSLC). As the simulated water level results, the model has a good agreement with observed data with the average root mean square error is 15 cm and the average correlation coefficient is 0.90 Fig.8 illustrates an example of the good agreement between observed and simulated water level, tide and surge at Ko Lak station, Prachuap Khiri Khan province.

SWAN model was setup for the Gulf of Thailand, forced by ERA-interim winds and used ERA-interim wave parameters as boundary conditions. Due to the limitation of the observed data, the simulated wave height was compared with 13 locations ERA-interim wave height. The comparison of ERA-interim data and SWAN simulation results reveal a generally good agreement for significant wave height, mean wave period and mean wave direction. Fig.9 shows an example of the comparison of significant wave height, mean wave period and mean wave direction at 10.5°N latitude and 99.75°E longitude.

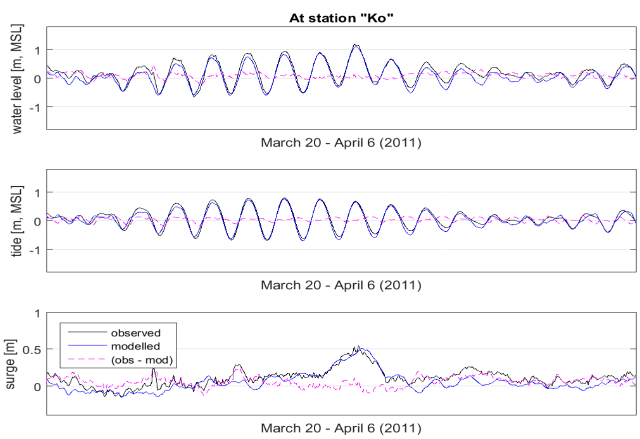

Fig. 8 Comparison of Delft3D FM at Ko Lak station

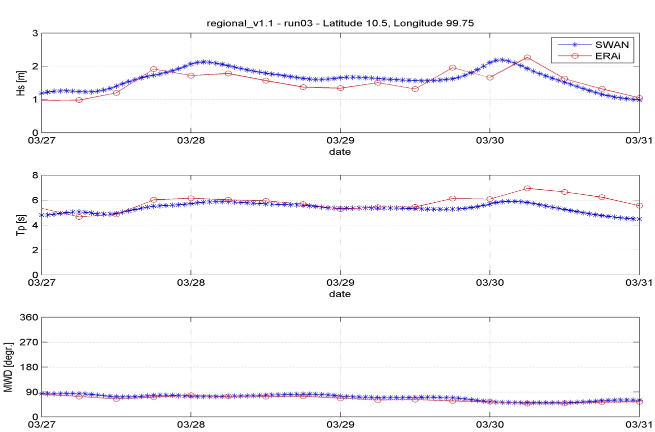

Fig. 9 Comparison of SWAN model at 10.5°N latitude and 99.75°E longitude

CONCLUSIONS

The Gulf of Thailand has experienced already 6 severe storm surges due to tropical cyclone since 1952. The combined effect of surge, tide, water level and wave can worsen the situation as it can increase the strength of the surge causing a larger coastal flooding and damages. In the past, the absence of real-time monitoring systems makes it difficult to provide information and warning people in the coastal area. Prediction of the storm surge by numerical models become a popular tool nowadays, it can provide the good estimation. The development of an operational forecasting system is also important for human life and properties in the coastal area.

According to this study, the overall Delf3D FM hydrodynamic model and SWAN wave model performance is sufficient to forecasting for the Gulf of Thailand. Delft-FEWS system also provides flexibility to adjust data format, link the models and presentation of data and model output. This helps the forecasting system become more efficient, stable and robust. The storm surge forecasting system is being implemented in the Gulf of Thailand aiming at the integration of meteorological data with simulation models to provide storm surge forecasts more in advance. This system will be useful for the decision making for coastal management and early warning procedures to protect and reduce the losses in the Gulf of Thailand.

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