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Wang, Li; Decrop, Boudewijn; Lanckriet, Thijs; Breugem, Alexander

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A regional model for South East Asia in TELEMAC 2D

Li Wang, Boudewijn Decrop, Thijs Lanckriet,
Alexander Breugem
IMDC NV
Antwerp, Belgium
abr@imdc.be

***Abstract*—In this paper a TELEMAC 2D model of the Southeast Asian waters is presented, including the Andaman sea, Gulf of Thailand, South China Sea and Java Sea. The model uses boundary conditions from OSU-TPXO, whereas atmospheric data (wind and air pressure) are used from the GFS model. The results of the model are compared with the data from OSU-TPXO in order to show that the large scale tidal pattern is predicted correctly by the model. Further, the model is compared to water level observations collected by the University of Hawaii, showing that accurate results are obtained in the whole model domain. An outlook is given of further developments that IMDC will undertake in order to extend the model to three dimensions.**

I. INTRODUCTION

The Southeast Asian waters (including Andaman Sea, Gulf of Thailand, South China Sea and Java Sea) are located between the Indian Ocean and Pacific Ocean. Due to tidal transformation on the shallow areas, as well as the important influence of seasonal wind patterns in this area, the TPXO Global Tidal Solution datasets are less suited to provide boundary conditions to local models in these waters. In addition to the tides, the prevailing monsoon winds also have a direct effect on the surface water currents of the shelf region. Over the South China Sea, the south-westward monsoon prevails from November to February (winter), whereas north-eastward monsoon occurs from June to August (summer). Primary or climatological current patterns in summer and winter are shown in Figure 1. Therefore a TELEMAC-2D finite element coastal ocean model was developed to simulate the transformation of the tides from the ocean to the shelf sea.

In this paper, the South Asian Sea model is discussed. Special attention in this discussion is given to code developments that are being performed by IMDC.

This paper is set up as follows. First the model setup is described. This is followed by a description of the results of the model, which are compared to the results of the OSU-TPXO water level elevation data base, as well as to the water level observations collected by the University of Hawaii. In this section, an extension to Telemac is described, which can be used to export time series in NetCDF format. Then an outlook is given of future developments to the Southeast Asia model, as well as Telemac developments that are being performed related to these future developments. The paper is ended with some conclusions.

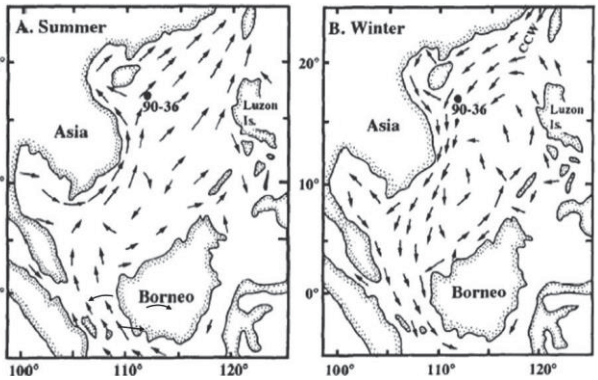


Figure 1. Primary currents during the summer and winter monsoon periods [1]

II. MODEL SETUP

This model is built on an unstructured mesh which allows to closely fit the complex geometry of numerous islands in the region and easily adjust resolution for different areas (). The resolution of the mesh ranges from 2 km to 40 km. The model consists of 49595 nodes and 94953 elements. The bathymetry used in this study comes from GEBCO (General Bathymetric Chart of the Oceans), which is freely available and has a 30-second resolution. This global grid is largely generated by combining quality-controlled ship depth soundings with interpolation between sounding points guided by satellite-derived gravity data. The bathymetric data are interpolated onto the mesh using linear interpolation. The resulting bathymetry is shown in Figure 3. The mesh is set-up in the Mercator coordinate system, but uses TELEMAC's spherical coordinates, which is needed due to the large spatial extent of the model.

The model is supplied with water level boundary conditions from the OSU-TPXO Global Tidal Solution [2] at the eastern and western model boundaries.

The physical process included in the model are the Coriolis force (using a spatially varying Coriolis coefficient), tidal boundary forces and bottom friction using the Manning equation. The model uses atmospheric pressure and wind velocities to take the atmospheric influence into account. Atmospheric data is used from the GFS model [3]. This data has a time interval of 3 hours and a spatial resolution of 0.5

Figure 2. Computational mesh of the Southeast Asia model

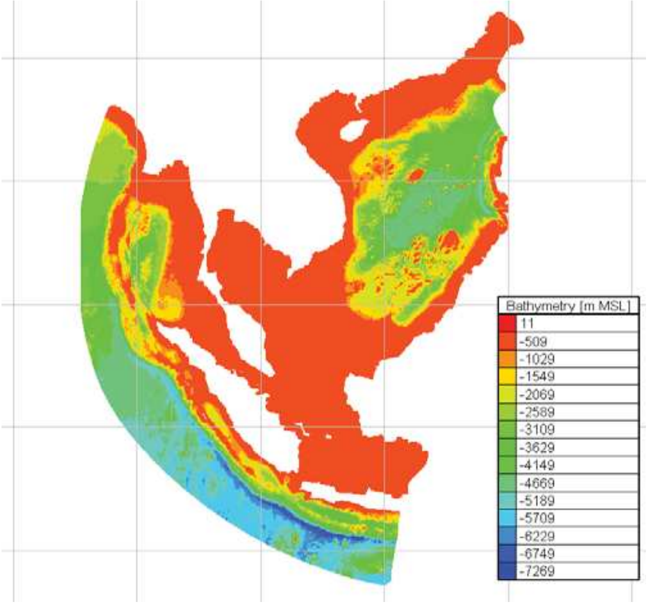


Figure 3. Bathymetry of the Southeast Asia model.

degrees. The resolution is sufficient to resolve the influence of the seasonally occurring monsoon periods. However, during extreme conditions such as typhoons, higher resolution wind data is needed. The wind drag coefficient from the British Admiralty is used. This drag coefficient is wind-speed dependent, with higher drag coefficients during higher wind velocities. A time step of 200 s is used.

The model is calibrated against tidal amplitude and phases at 60 tidal gauges over the model domain [4]. The model calibration is performed by adjusting the bed roughness and the wind drag coefficient using a multiplication factor as a calibration coefficient.

III. MODEL RESULTS

A. Tidal flow

First, the tidal flow is validated by performing a simulation without wind influence and atmospheric pressure gradients. The simulation had a duration 30 days with an additional spin-up period of 7 days, which is sufficient to distinguish the main tidal components. The results of the model are compared with those from OSU-TPXO as well as with those from water level measurements.

The model results are shown in Figure 4 to Figure 7. These figures shown the tidal amplitude as well as cotidal maps for the K1, M2, S2, M4, M6, N2 and O1 tidal components from the model results as well as those components from OSU-TPXO.

The model results compare generally well with those from OSU-TPXO. In the South China Sea, the tide is diurnal (a decreased M2 amplitude in combination with a larger K1), whereas in the rest of the domain, the tide is semi-diurnal (with larger M2 components). The transition between the diurnal and semi diurnal tides is predicted well by the TELEMAC model. There is an amphidromic point in the South China Sea, whose location is predicted well by the model (Figure 5).

B. Time series comparison

Time series of the water levels observation collected by the University of Hawaii [4] are used to compare with time series extracted in the model. This dataset containing hourly water level measurements spans many years and is freely available for download from http://uhslc.soest.hawaii.edu/data/rqh. Reconstructed (tide-only) time series from harmonic analysis were used, which were obtained by means of harmonic analysis using the UTide package.

In order to easily obtain time series from TELEMAC, a module was developed that writes time series in NetCDF format. Each station is exported to a separate NetCDF file. This module uses bi-linear interpolation inside a triangle. It is possible to specify different output periods, each within a different time interval, which must be an integer multiple of the time step in the model. All variables defined the parameter “VARIABLES FOR GRAPHIC PRINTOUTS” in the cas file are exported to the NetCDF files. In case of TELEMAC 3D, a profile is written for each location, containing all vertical nodes.

The module uses an input file called “coordinates.txt”, which contains the following information:

- Number of output periods and number of output points
- Start time, end time of each output period in seconds since the start of the model) and output interval (in seconds)
- x and y coordinates, station id and station name of each output location

An example of the coordinate file is shown in Figure 8.

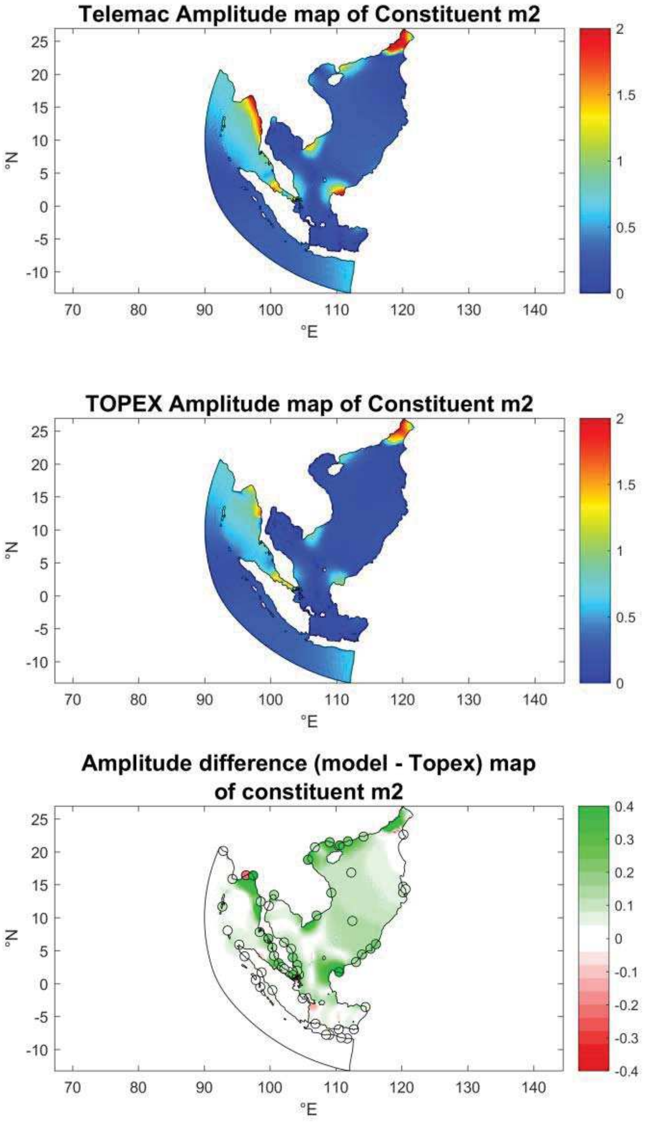


Figure 4. Comparison of the amplitude of the M2 component between OSU-TPXO and the Southeast-Asia model.

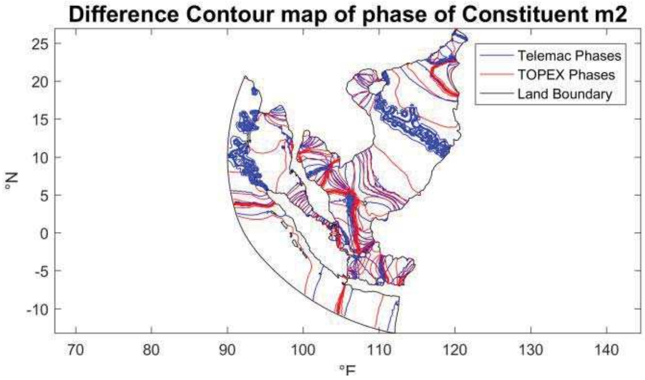


Figure 5. Cotidal maps comparing the phase of the M2 component between OSU-TPXO and the Southeast-Asia model.

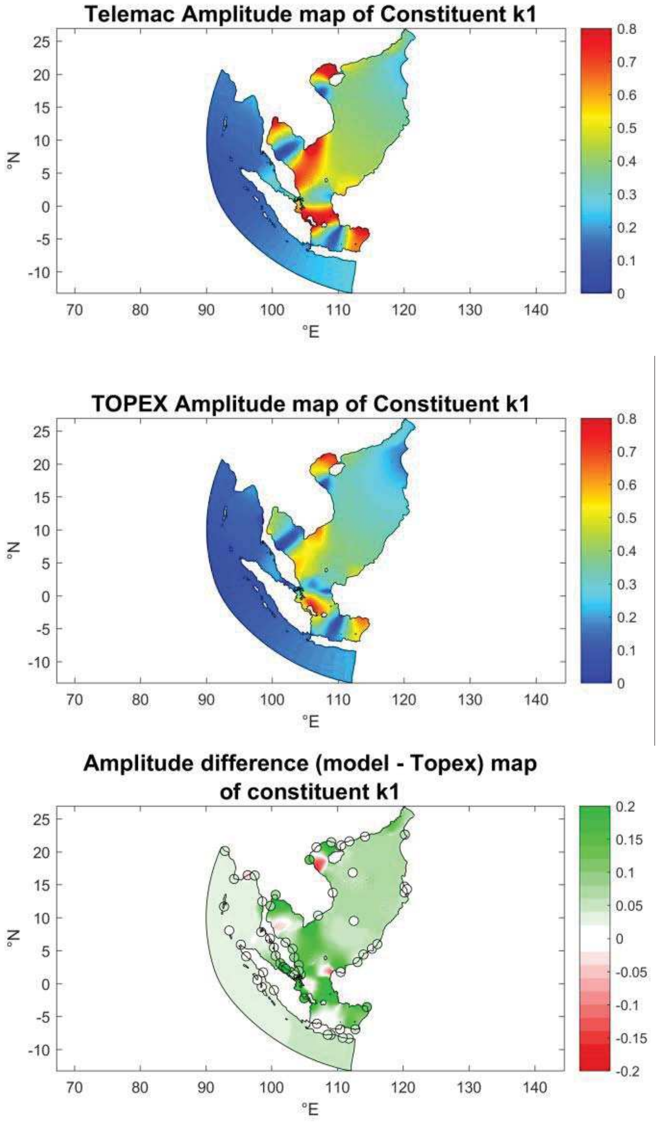


Figure 6. Comparison of the amplitude of the K1 component between OSU-TPXO and the Southeast-Asia model.

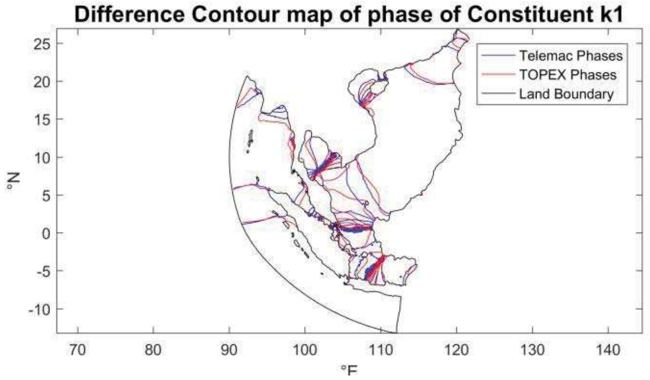
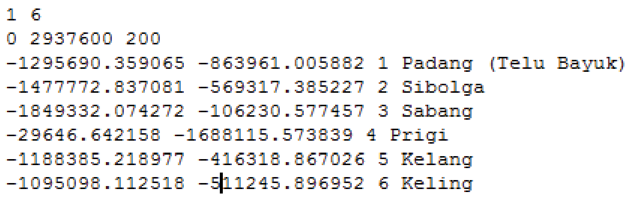


Figure 7. Cotidal maps comparing the phase of the K1 component between OSU-TPXO and the Southeast-Asia model.



```
1 6
0 2937600 200
-1295690.359065 -863961.005882 1 Padang (Telu Bayuk)
-1477772.837081 -569317.385227 2 Sibolga
-1849332.074272 -106230.577457 3 Sabang
-29646.642158 -1688115.573839 4 Prigi
-1188385.218977 -416318.867026 5 Kelang
-1095098.112518 -511245.896952 6 Keling
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Figure 8. *Example of an input file for generating NetCDF output*

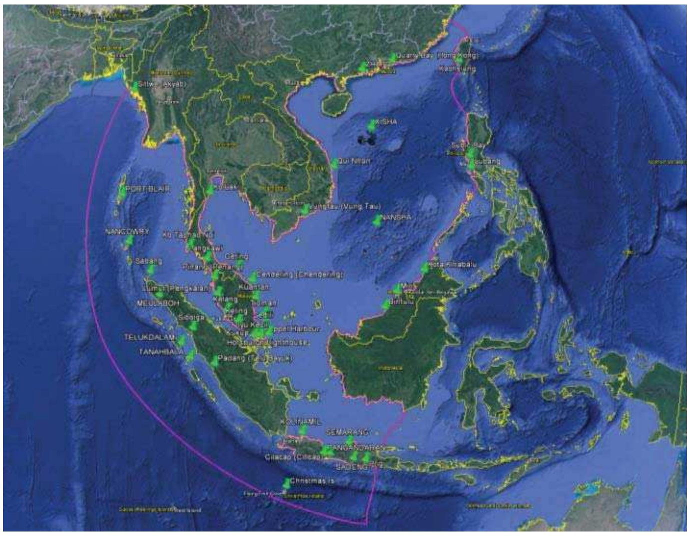

Figure 9. *Location of UHSLC research-quality hourly tide stations (green pins)*

The time series at Lumut in the Malacca Strait and at Kuantan in the South Chinese Sea (see Figure 9) are shown in Figure 10 and Figure 11. These figures show that the model predicts the water levels due to the tide well, in areas with a predominantly semi-diurnal tide as well as in areas with a diurnal tide.

C. *Influence of the monsoon*

The model is run for two different periods: the summer period (July to September), during which the North-eastern monsoon occurs in the South China Sea, and the winter period (December to January) during which the South-western monsoon occurs. These monsoons are important, because they lead to wind setup and set-down in the South China Sea and the Strait of Malacca, leading to a net flow in the Singapore Strait.

In order to test the model performance during wind, the meteo-induced water level anomaly is plotted for the model results as well as for the measurements in Figure 12 and Figure 13. The anomaly was obtained by performing an harmonic analysis on the data. The reconstructed signal obtained from the harmonic analysis was subtracted from the real time series in order to obtain the anomaly.

In general, the model is capable of predicting the trends in the water level anomaly in the observations. The model clearly shows peaks in the anomaly in the South China Sea in winter. This peak is somewhat overestimated by the model due to remaining frequency content. The summer monsoon setdowns around August 8th and September 15th are captured by the model.

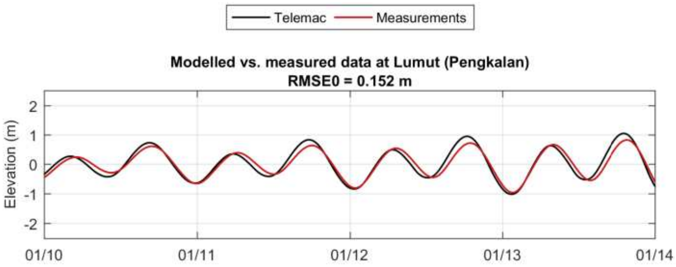

Figure 10. *Time series of the water levels in Lumut (located in the Malacca Strait. There is a clear semi-diurnal pattern.*

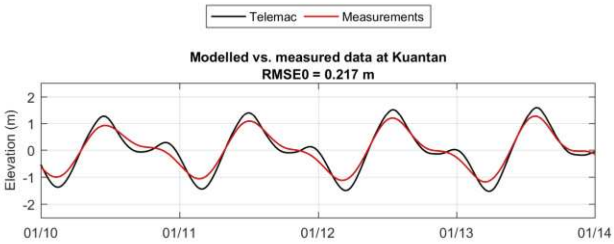

Figure 11. *Time series of the water levels in Kuantan (located in the South China Sea). There is a clear diurnal pattern.*

IV. OUTLOOK

Apart from predicting water levels, the model is also intended to obtain flow velocities. Unfortunately, it is not possible to test the performance of the model due to the lack of available velocity data in the area. In deep areas, wind driven flows have a strong three dimensional character, because the wind influence is mainly limited to the top of the water column. In order to apply TELEMAC 3D for such a model, IMDC is currently performing two developments, which are described briefly below.

A. *Three dimensional nesting*

In order to be able to prescribe three-dimensional open boundary conditions (for example obtained from an oceanic model such as HYCOM), a module was developed that reads boundary data (water level, three-dimensional velocity profile data and three-dimensional tracer data) from an ASCII file. The ASCII file contains the following information:

- Header line containing the text "OBCFILE3D"
- Number of boundary points in the file
- Node number of the boundary points
- Data for each time step consisting of :
    - Time (in seconds since the start time of the model)
    - Water level data (one value per node)
    - U-velocity profile data (first all values)
    - V-velocity profile data (format as for U-velocities)
    - Tracer profile data (format as for U velocities; only in case a tracer is used in the model).

The data are read, and then are interpolated linearly in time. The velocity data can be added to the water levels and velocities from OSU-TPXO, thus combining the influence in case this is necessary. In this way, space and time varying boundary conditions can be read in TELEMAC without the need for a user to do any FORTRAN programming.

B. GOTM for TELEMAC 3D

GOTM [5] is an open source 1DV turbulence model, specially aimed at oceanic applications. It contains different turbulence models typically used in oceanography, such as the Mellor-Yamada [6] model, and the KPP [7] model. GOTM is especially designed to be easily coupled to other models. The advantage of using GOTM over the existing turbulence models in TELEMAC is that the turbulence models are more suited to use in oceanography.

Presently, a coupling between GOTM and TELEMAC 3D is developed, such that the turbulence models in GOTM can be used to calculate the vertical mixing. Apart from that, it is the intension to use the equation of state from Unesco [8] within GOTM, rather than the linearized equation of states currently available in TELEMAC.

V. SUMMERY AND CONCLUSIONS

In this paper, a TELEMAC 2D model was presented for the Southeast ocean sea including the South China Sea, the Andaman sea, the Gulf of Thailand and the Java Sea. This model was compared with data from OSU-TPXO and with water level observations. This comparison shows that the model delivers good results predicting the diurnal tide in the South China Sea and the semi-diurnal tide in the rest of the model domain. An overview is given of the TELEMAC developments at IMDC, which are considered useful in order to perform three-dimensional ocean modelling.

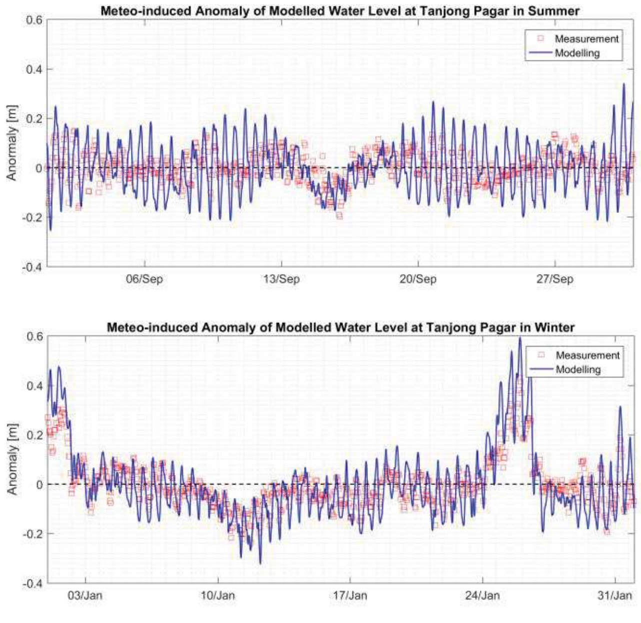

Figure 12. Meteorological water level anomaly in Tanjong Pagar (located in the Singapore Strait). Top: during the summer (North-eastern Monsoon). Bottom: during the winter (South-eastern monsoon).

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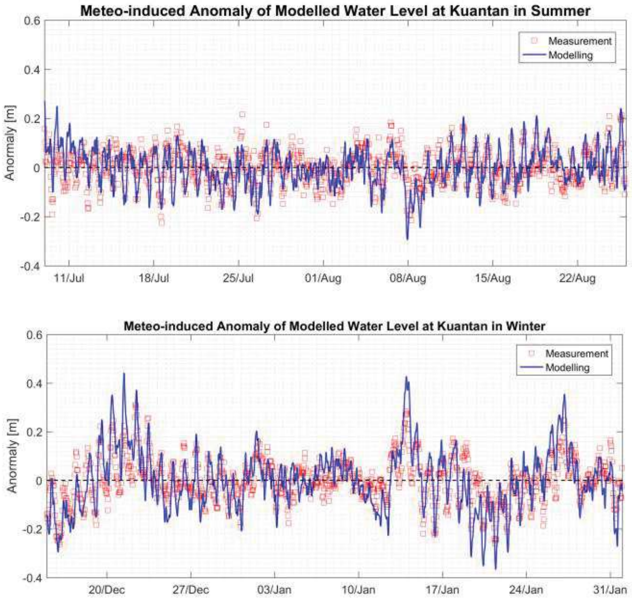

Figure 13. Meteorological water level anomaly in Kuantan (located in the South China Sea). Top: during the summer (North-eastern Monsoon). Bottom: during the winter (South-eastern monsoon).