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DETERMINING THE UNCERTAINTY OF THE WATER LEVEL RESIDUE OF A NUMERICAL MODEL IN THE MALACCA STRAIT

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Geographically located between the Andaman Sea and the South China Sea, the water level in the Malacca Strait is indirectly driven by the tide of the two oceans: Indian Ocean and Pacific Ocean. With use of numerical models the tidal variations should be well represented in this area. However, when the model's tidal representation is compared to the actual measurement of local coastal tidal gauges, the observed water level difference amount to more than +/- 30 cm. Based on a 15 years long time series of water level residuals (between 1992 to 2006), it is found that an annual seasonal trend in the residue may be the cause of larger and more complicated physical mechanisms that could not be properly resolved in the 2D barotropic model. For forecasting purposes, it is important to identify and quantify the seasonally varying residue of the model. This study attempts to determine the residue variation and characterize associated uncertainties by determining the daily averaged residues by unique probability distributions on monthly basis. The result of this study will provide a comprehensive error (residue) budget for the oceanographic model of the area applied in forecasting mode.

INTRODUCTION

Presently, in advance spatial and temporal knowledge of the sea state serves as important information for marine activities such as ship navigation, coastal management or offshore development. This forecasted sea state information over an entire region can be easily provided by a numerical model. However the numerical model could never perfect in representing the sea state information due to several reasons such as the assumptions made in the mathematical equations described in the model, and lack of insights to unknown phenomena or processes in the reality which could then not incorporated in the model, etc. These lead to the difference (residual) between the model representation and the reality. Therefore in order to appropriately utilize the forecast model, it is important to understand and characterize its uncertainty which arises from the variability of the residual. In this way, the users can know the risk (or uncertainty) involved when applying the forecast to facilitate the decision-making processes in the marine activities. This paper demonstrates a probabilistic approach to characterize the model residual and its associated uncertainties by fitting the residuals to a unique probability distribution. Probabilistic approaches used in uncertainty analysis and characterization have been widely applied for risk assessment studies as discussed by Chowdhury et al. [1] and for improvement of model prediction as shown by Schoups and Vrugt [2]. After the residual and its uncertainties are explicitly characterized, we can make a statistical prediction of the expected residual value with a certain confidence interval to enhance the model results.

Malacca Strait is one of the busiest shipping routes in the world. Therefore reliable forecast of the flow in the region is important for the shipping vessels or other coastal activities. Generally, water level variation can be attributed to two origins: tidal and non-tidal. Tide is induced by the gravitational forces of the celestial bodies and is deterministic. The non-tidal phenomena in this region are mostly monsoon-related. As the Malacca Strait is mainly tide-dominated, the local hydrodynamics could be described sufficiently accurate using a deterministic numerical model with the appropriate settings. After comparison of the model computation with the actual observations, the model residual can be computed. Since the actual observation consists of both tidal and non-tidal phenomena, the residual of the tidal model would actually comprise of both non-tidal water level and model error. In this paper, we do not intend to distinguish the non-tidal water level within the residual. Instead, we regard the residual as the forecast uncertainty. The residual is analyzed spatially and temporally to gain insights to the non-tidal hydrodynamic regimes within the Malacca Strait.

DATA

15 years long time series (1992 – 2006) of hourly water level data (University of Hawaii Sea Level Center, http://uhslc.soest.hawaii.edu/) at six locations along the western coast of Malaysia Peninsular in the Malacca Strait (Figure 1) would serve as observation data for residual computation.

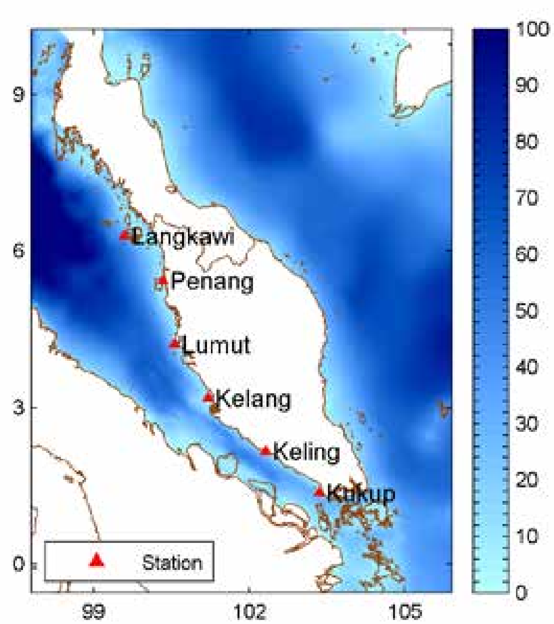

Figure 1 Location of the six coastal stations with bathymetry in Malacca Strait

NUMERICAL MODEL

Numerical model used in this study is South China Sea Model Curvilinear (SCSMC), a barotropic model covering the Malacca Strait, Java Sea and South China Sea (an area ranging from 95^o – 126^o E.L. to 8^o S.L. – 24^o N.L.), and is set up within the Delft3D modelling environment. Spatially varying grid is schematized in a way whereby the area close to the open boundaries is of low resolution of 30 to 50 km while the area of interest in the present study (coastal waters near Singapore) is of higher resolution of 5 to 10 km (Figure 2). There are eight open boundaries enclosing the model domain (Figure 2) with tidally driven forcing prescribed as water level variations by means of amplitudes and phases of the eight main tidal constituents; O_1, K_1, M_2, S_2, Q_1, P_1, N_2 and K_2. Tay et al. [3] presents details on the development, calibration and assessment of the SCSMC, whereby the model has shown overall good tidal representation in the domain including Malacca Strait.

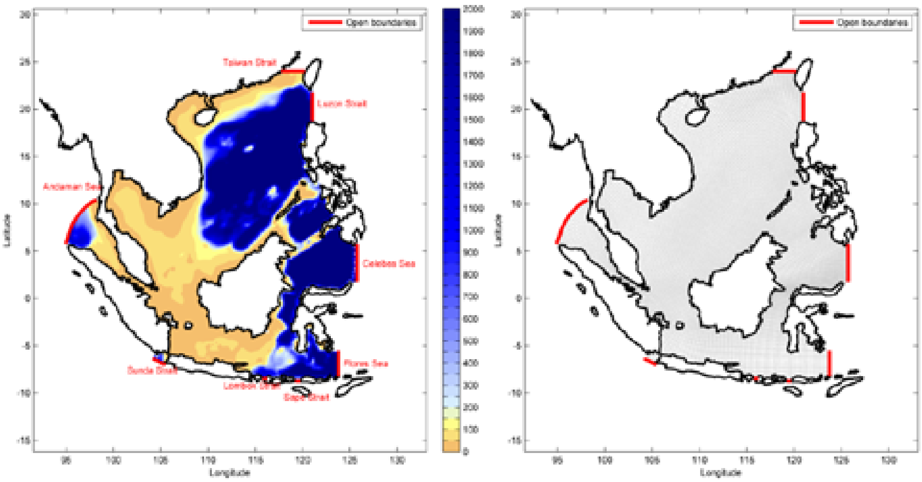

Figure 2 Bathymetry (left) and grid schematization (right) of SCSMC

RESIDUAL AND UNCERTAINTIES CHARACTERIZATION

The numerical model has been used to simulated for 15 years (1992-2006) of hourly water level and compared against recorded data at the six coastal stations over the entire period and is denoted as $WL_{computed}$. The 15 years (1992-2006) of hourly water level observed at the six coastal stations obtained from UHSLC database serve as the observations at these points and are denoted as $WL_{observed}$. The water level residual ($WL_{residue}$) at each coastal station is then trivially computed as:

$$WL_{residue} = WL_{observed} - WL_{computed} \quad (1)$$

The residual is then averaged daily and classified according to the months of a year. Figure 3 presents the boxplots of the daily averaged residual of each month for the six coastal stations over the entire 15 years, which generally shows the spread of the residual in each month. The monthly mean residual of all six stations is negative from January to April. From May till December, the northern and southern stations in the Malacca Strait are showing different residual trends. This monthly residual variation over the coastal stations illustrates the non-tidal influences of both Andaman Sea and South China Sea (on each end of the strait) on the Malacca Strait's hydrodynamic regime during different times of the year.

In our characterization of residual and its uncertainties, we apply a probabilistic approach by fitting the daily averaged residuals to a unique probability distribution on monthly basis. By assigning a probability distribution to each month of the residuals, we can explicitly characterize the residual variation including the uncertainties and make a statistical prediction of the expected residual value with a certain confidence interval for each month of each station.

The daily averaged residuals of each month are attempted to be fitted to the following nine probability distributions (normal, three-parameter log-normal, three-parameter Gamma, two-parameter exponential, three-parameter Weibull, smallest extreme value, largest extreme value, logistic, and three-parameter log-logistic) using the statistical software Minitab.

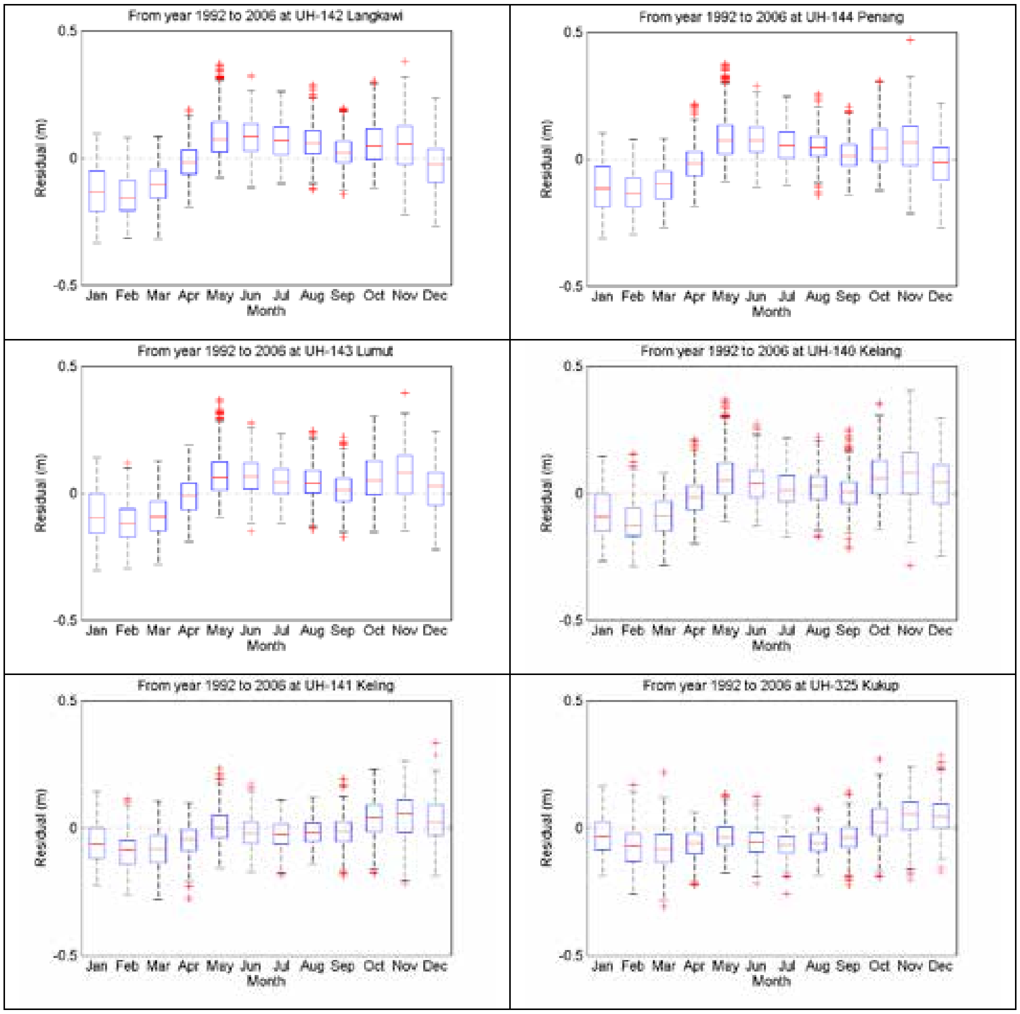

Figure 3 Boxplots of the daily averaged residual of each month for the six coastal stations over the period from 1992 to 2006

RESIDUAL AND UNCERTAINTIES PRESENTATION

A best fitted probability distribution for each month of each station has been established to characterize the corresponding residual and its uncertainties in the earlier section. Based on the probability distribution parameters determined, an upper- and lower-bound of the monthly residual can be drawn to form a monthly residual band of a typical year. For the present study, this band is constrained by the 2.5th and 97.5th percentile of the particular distribution. Figure 4 and Figure 5 show the monthly residual with an uncertainty band at Langkawi and Kukup for a typical year. This residual band could then be interpreted as the deviation of the model forecast from the actual water level with a probability of 95 percent.

In order to provide spatial overview of the model uncertainty, the spatial variation of the residual standard deviation in the Malacca Strait can be projected from each of the coastal stations. Figure 6 presents the spatial uncertainty of the model during January and July which each represents the Northeast and Southwest monsoon, respectively. The overall standard deviation of July is lower than that of January. As mentioned earlier, the Northeast monsoon has known to have greater regional wind intensity than the Southwest monsoon. It should be noted that wind-induced water level is not simulated in the presented numerical model, therefore the standard deviation is of the residual is much greater during January than July.

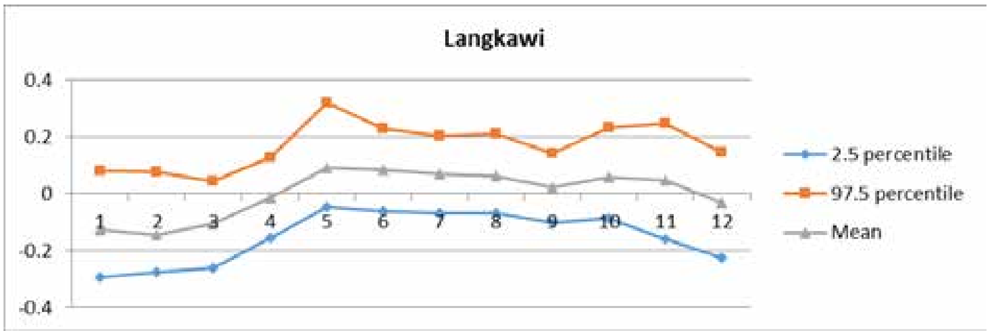

Figure 4 Monthly residual with uncertainty band described by the 2.5th and 97.5th percentile at Langkawi

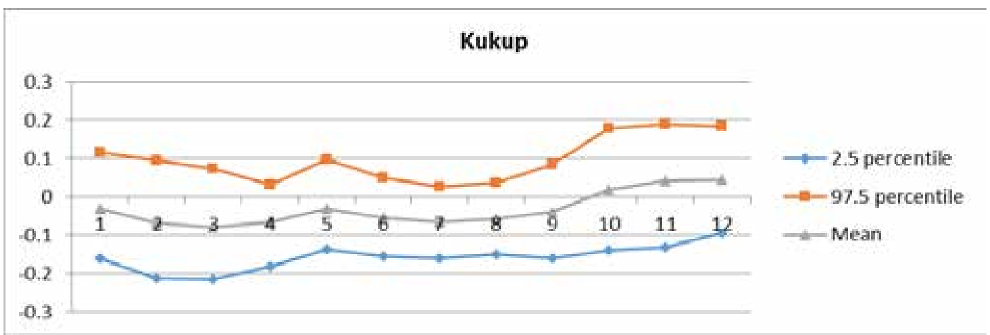

Figure 5 Monthly residual with uncertainty band described by the 2.5th and 97.5th percentile at Kukup

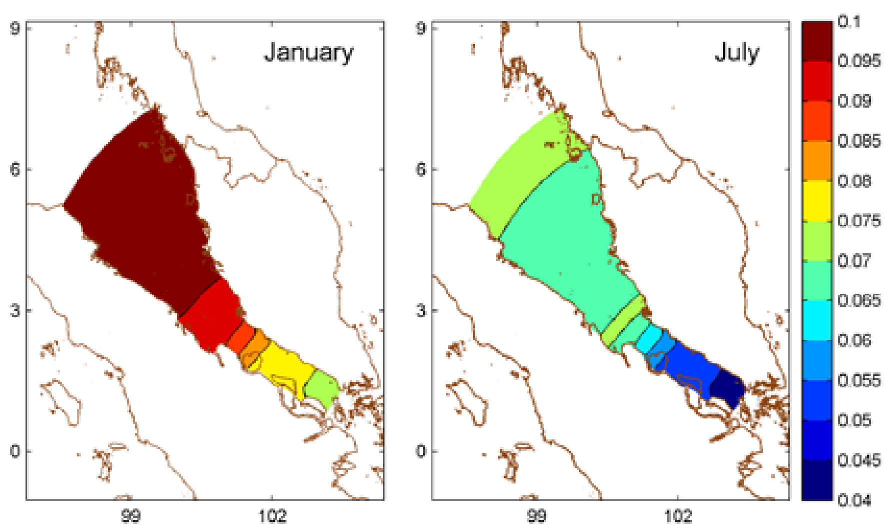

Figure 6 Spatial residual standard deviation projected from the coastal stations in Malacca Strait during January (left) and July (right)

CONCLUSION

Using computed water level of a well calibrated numerical tidal model as water level forecast in the Malacca Strait, the 15 year long residual is determined by subtracting forecast water level from actual measurement for six coastal stations in the strait. By classifying the residuals into 12 months for all 15 years at each station, a seasonal trend of the residual over a year at all six coastal stations has been observed. The monthly mean residual of all six stations is negative from January to April. From May till December, the northern and southern stations in the Malacca Strait are showing different residual trends. This monthly residual variation over the coastal stations illustrates the non-tidal influences of both Andaman Sea and South China Sea (on each end of the strait) on the Malacca Strait's hydrodynamic regime during different times of the year. This result provides us insights to the source of residual and its uncertainties in a physical sense, and also highlights the significance of characterizing the residual and its uncertainties to enhance the model results. The residual and its uncertainties of each station are characterized using a probabilistic approach by fitting them to a unique probability distribution on monthly basis.

After explicitly characterizing the residual and its uncertainties, this study presents a monthly mean residual of the forecasted water level at specific locations in the Malacca Strait in a typical year. This monthly mean residual is also accompanied with its upper- and lower-bounds and together, they show the range of residual values within the 95 percent probability for each month. For the overall spatial distribution of the model uncertainties, the residual standard deviations of all six coastal stations are interpolated and projected to represent the model uncertainties in the Malacca Strait for January and July, with each representing the Northeast and Southwest monsoons, respectively.

ACKNOWLEDGEMENT

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