Using open source software
to simulate estuarine hydrodynamics

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Abstract: The use of open source softwares helps users learn the internal structure of numerical models. However, open source softwares usually require linking to auxiliary programs for data preprocessing, post-processing, and visualization. The users also have to understand the problem thoroughly, and may at times modify the source code so that the model could better represent the natural mechanisms. An example of simulation hydrodynamic and morphological change of Tra Khuc estuary (in Vietnam) with XBeach [1] (a 2-D hydrodynamic modelling program) is presented, which will illustrate simple techniques we may apply when using open source programs for modelling shallow flow processes. XBeach is inherently a model for coastal hydrodynamic with dune erosion without modelling the river flow. In order to simulate the effect of river flow to hydrodynamic process and morphological change at the river mouth, we consider the implementation of the inflow boundary by editing XBeach program code and handling time scale and morphological factors. A test case is done with the 2005 flood, where the model results an irregular pattern of bathymetry change. Model calibration and validation is not addressed in this study.

Keywords: estuarine hydrodynamics, numerical simulation, modelling, open source software, Tra Khuc estuary, XBeach.

1. Overview

The application of hydrodynamic modelling softwares in the field of coastal and river engineering is ubiquitous nowadays. Several well-known consultant companies or agencies have released their proprietary software packages, which have proven their reliability for many real-world applications. Most of those softwares includes easy-to-use graphical interface and various tools, together with technical training / support offered by the company.

From the perspective of researching or academic training, however, the use of such proprietary software packages has major drawbacks. Aside from a substantial price for the product, as for proprietary software programs, access to the code is impossible. This is a real shortcoming, as the best way to gain insight in the model is to accompany the theoretical equations with the program code.

Since 1980's, the advent of open source software licensing has allowed more scientific and engineering codes to be available online, including hydrodynamic simulation codes. Examples range from 2-D wave models (Swan [2]), 2-D flow model (AnuGA [3]) to 3-D models for oceanic waters (ROMS [4]) or CFD application (OpenFOAM [5]). Unlike proprietary software suites with graphical dialogs, plotting and visualization tools, etc. which can guide user through the whole modelling process, open source programs tends to be a collection of source code files which needs to be compiled before running. Besides, programs rely heavily on text-based input/output files and we have to integrate with auxiliary (usually also open source) programs or self-written code to preprocess or visualize outputs, that we can think of a multi-stage process with a collection of open source softwares.

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In this paper such a chain of programs include XBeach – an open source 2-D simulation code initially designed for modelling hydrodynamic phenomena in storms, Saga GIS tool [6] for topographic interpolation, Octave [7] - a matrix calculation tool similar to Matlab, and `gfortran` – the Fortran compiler. Additional tools can be used for plotting (e.g. Gnuplot [8]) or text processing (e.g. `awk` [9]) (Figure 1). Within XBeach there are various modules: parameters, bathymetry and grid construction; initial conditions, boundary conditions, calculation in each time step for wave, flow, morphological change, and output specifications.
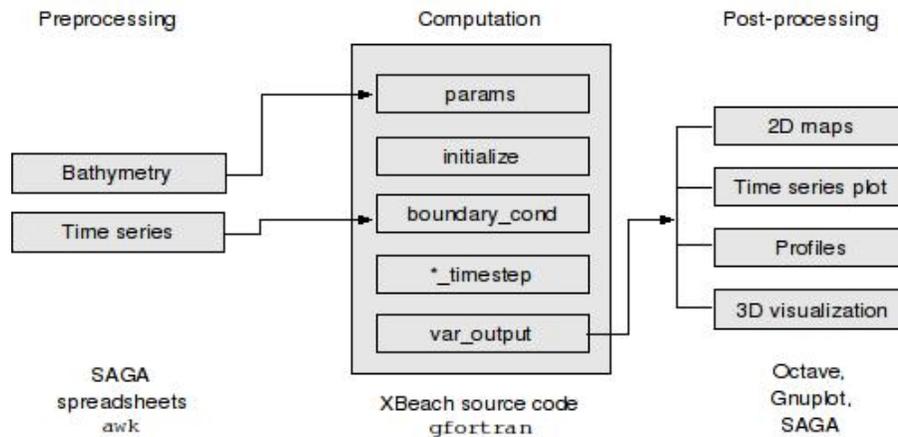

Figure 1: Workflow of various stages, modules and open source programs involved

We discuss various issues arising in hydrodynamic simulation with open source programs. Starting from raw data we process to obtain the input for the model. On the other hand, from nature we identify the physical mechanism to be modelled, and adjust the program code (if necessary) to correctly reflect the natural system. Specified output can be obtained either through postprocessing the output or through further coding. For the topic, we will focus on implementation aspects to get simulation result (no calibration and validation are addressed in this study).

2. The modelling problem

The Tra Khuc river in Vietnam flows into the South China Sea, with frequent floods in rainy season. The tidal scheme is non-uniform semi-diurnal, with an average tidal range of 1.3 m. The average wave height is 1.5 m.

Tra Khuc estuary exhibits a spit-bar morphological pattern (Figure 2). In [10], the variation of estuary pattern is analysed both in short term (seasonal) and long term (from 1995 to 2005). During the flood season in 2005, discharge of the Tra Khuc river had remarkably altered the bathymetry of the inlet [11]. For this flood simulation we identify the major dynamic factor to be the river flow. The tidal water level acts as a seaward boundary, with considerable influence within the system. Wave is not a major influencing factor, and is represented by a stationary wave field (uni-directional). Effect of the wind is neglected. Our objective is to simulate the flow pattern and corresponding change in sea bed at the inlet. The time scale for simulation should be typically the entire period which time series data is available, although some techniques may be applied to reduce the computation effort.

Figure 2: Google Map image of Tra Khuc river inlet featuring the extent of modelling domain. Only part of the grid is shown for the sake of clarity

3. Bathymetry and grid

Raw bathymetry data contain in two files, in XYZ format, measured in two different field surveys before (Aug-2005) and after the flood season (Feb-2006). The spatial extent of data is approximately 11 km × 6 km. The data points contains elevation of sea bed, stretching 1.5 km seaward and river floodplain, up to 9 km landwards. The elevation generally ranges from -15 m up to 10 m.

Based on the elevation data collected, a Cartesian grid for the model was set up with with 213 × 95 grid cells, sized 50 m × 50 m. The *x* axis is pointing to the West (landwards), nearly perpendicular to the shoreline. A cell size of 50 m is coarse compared to sizes of the geomorphological features of the estuary (barriers, trenches), which are are at the order of 100 m. However, for preliminary calculation it would suffice. A detailed run would require a grid size of 25 m or less.

Saga was used to generate the elevation matrix of the calculation grid. First the XYZ file is transformed into a point-figure file with elevation as the property of each point. This point-figure layer, in turn, is the input for Saga to make a grid (raster map). In order to do so we applied an interpolation algorithm, such as B-spline. Grid points which are far from sample points are filtered out with a high elevation, e.g. +15 m. The resultant grid is saved as an ASCII file whose file name to be declared in the variable `depfile`.

4. Hydrodynamic boundaries

XBeach model is designed initially for modelling impact of waves on the shoreline, without any river flow. By introducing a river discharge, we have to set up the upstream flow boundary and accounting for the influence of the inflow water to the system. This boundary is built based on the "transparent" boundary type (by setting the program parameter `back` = 0), and will be assigned as the corresponding water level (*zs*) measured at Tra Khuc bridge (from 1-Aug-2005 until 31-Dec-2005). The boundary is imposed on the

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cells where the stream channel presents (Figure 3), instead of the whole land boundary as specified default by XBeach. Another assumption is that the boundary is perpendicular to the river section, so that the inflow only contains the u component (along x axis).
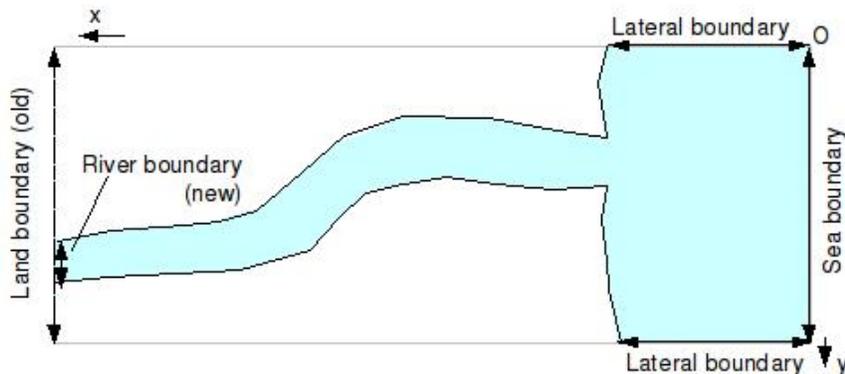

Figure 3: Schematized boundary layout of the problem

Due to the lack of tidal data, we use wxTide [12] to generate the tidal water level time series for Da Nang, near the study site. The tidal water level, also from 1-Aug-2005 until 31-Dec-2005), is corrected to the same datum used by the river stage, and is imposed on the seaward boundary (as the model area is not large we neglect the difference between tidal water level at two lateral boundaries.

The wave climate collected from 1966 – 1980 shows that from August to December the predominant wave direction moves from NE to SW. For this study we only consider regular wave with root-mean-square wave height of 1.7 m, entering from SE (angle = 135° w.r.t. North).

5. Time scale

The time frame chosen for simulation is based on the problem itself and the data available. Time series of measured flow is from 1-Aug-2005 until 31-Dec-2005. Very high water was measured on 30-Sep, 10-Oct, 11-Oct, 25-Oct, 1-Nov, 17-Nov, and 14-Dec. All these floods should be taken into account for the morphological change of Tra Khuc inlet, expanding the simulation time up to at least 3 months. Thus from the practical aspect we may want to divide the simulation into different runs. At the end of each run, the bed elevation data is stored for the next run. There is an overlap between two successive runs (Figure 4, in which runs are denoted by shaded rectangles), since a start-up time period (~ 2 days in our case) is required to bring the system from stationary state into motion.

As a convention for time series data, the temporal zero starts at 1-Sep-2005 19:00. By doing so we can use a common time series for all runs, whereas computation time of XBeach is reset to zero at the beginning of each run.
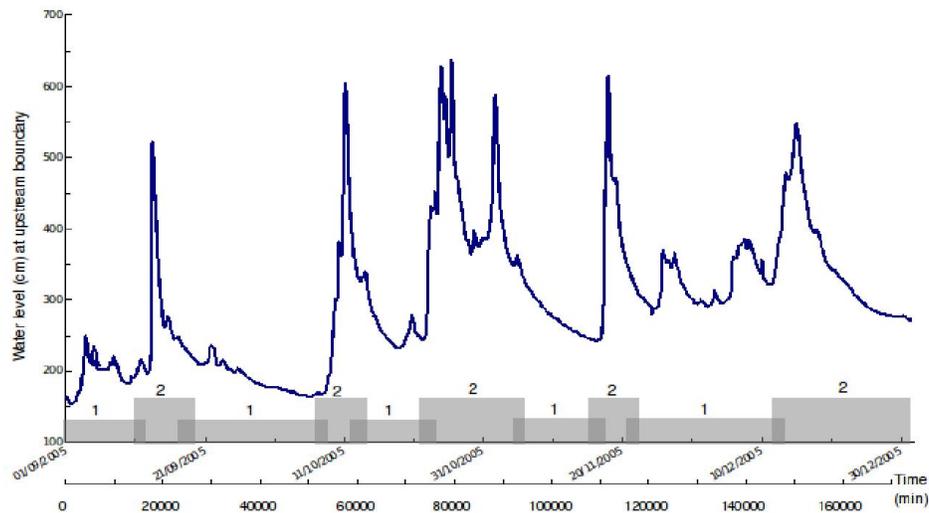
Figure 4: Different runs for the whole simulation

To save the running time, a "morphological factor" (`morfac`) is used [1], assuming that the change in bed level is much slower compared to the variation in water level or discharge. Thus hydrodynamic calculation is performed with the "compressed" flow time series (with fewer time steps), allowing the morphological to change as in "real time" (enlarged by `morfac` times). In this simulation, `morfac` = 60, which implies that a second in calculation is corresponding to a minute in reality. Thus in the input time series the time values equals to 1/60 that of measured at gauge.

A difficulty when modelling river flood with XBeach is that too rapid variation of water level upstream may cause instability within the model. To eliminate this effect we expand the calculation time period with a scale of 2. Figure 4 shows the high flood time using this scale (2). Consider this as a time expansion for flow modelling, where two seconds in flow simulation correspond to a minute in reality. A function was written to transform between the computation time and real time.

6. Data post-processing and discussion

XBeach is able to produce 2-D maps containing spatial quantities (elevations, velocity) during the simulation, and we can visualize the result with Octave/Gnuplot. The velocity field of the system (Figure 5) shows two cases with low and high river discharge, and the change in shoreline shape can also be figured out. Through simulation, a bar breaching occurred, which actually not (field survey showed that the inlet gap only widened and deepened [10]). In addition, the change in bed level compared to the initial bathymetry (at t = 0) is shown in Figure 6, where we can see extreme deepening of the inlet. This is due to the abnormally rapid flow near the left bank of the river. Thus for a better simulation, the parameters of the river part as well need to be adjusted.

Improper choice of morphological parameters also lead to emergence of a large bar, which strongly blocks the wave propagation into the estuary (Figure 7). Consequently, the flow through the shallow gap is fast (~1.6 m/s), with no presence of inflow to the river. Although unrealistic, the simulation proves the capability of XBeach in handling rapid flow, wetting/drying, steep bathymetry slope without numerical instabilities, given a cost in computation time.
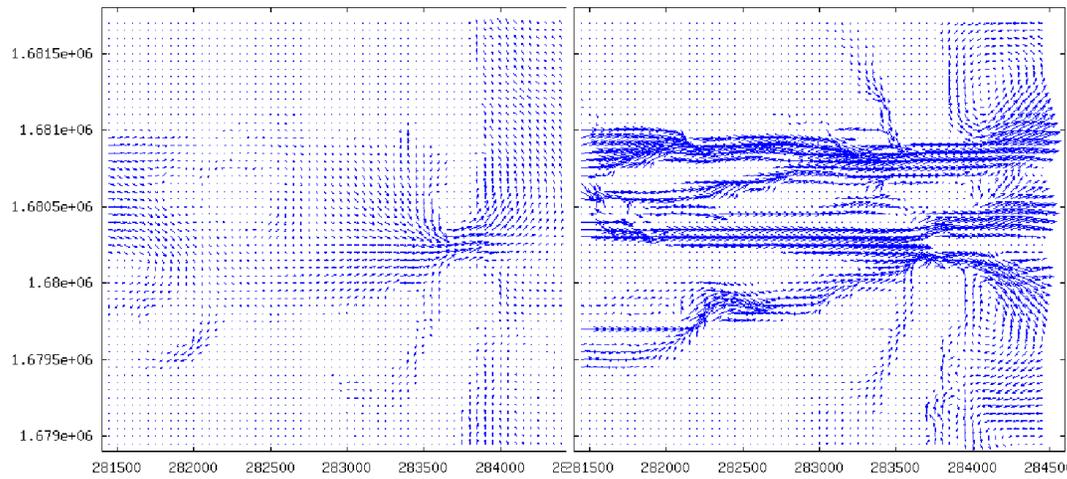
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Figure 5: Velocity vector plots at t = 15480 minutes and t = 174250 minutes
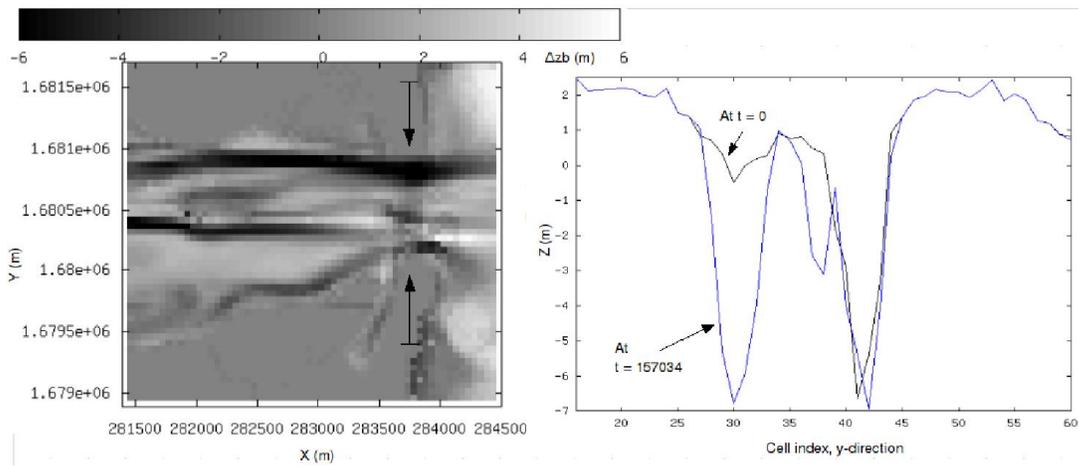

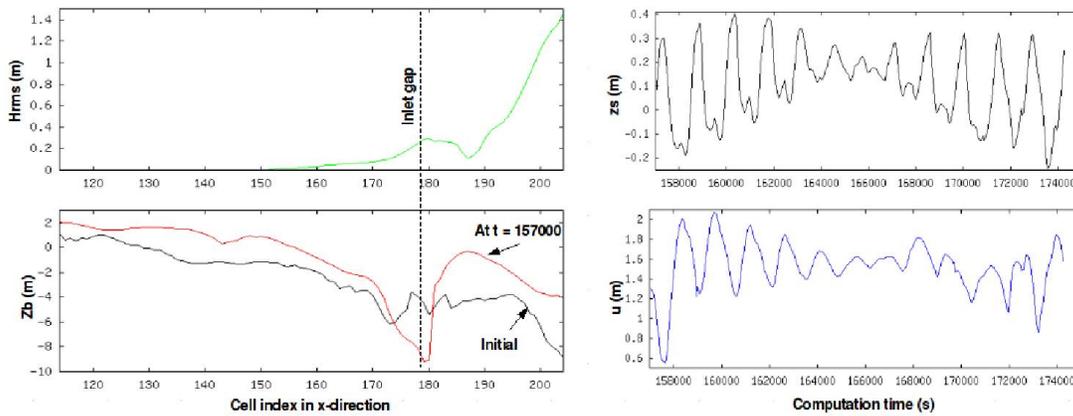Figure 6: Simulated change in bed elevation compared to initial bathymetry

Figure 7: Wave height and bed level along the inlet profile (left). Tidal water level and velocity at the inlet gap (right)

7. Conclusions

This study illustrates another migration in XBeach program design from a climatic viewpoint (long-term wave effect on morphodynamics) to short-term events (aside modelling impacts of hurricanes). The simulation of rapid-changing flows requires shorter time step which is computationally expensive, and longer start-up time in case we run for different stages. We had attempted to solve the problem by dividing into successive runs.

The fact that open source programs such as XBeach lack output visualization is a major drawback, as currently the quality of our plots is not sufficient for real projects. On the other hand, the text input and source code files proves to be very powerful to extend the functionality of the XBeach program (specifically multiple runs, flow time series, and additional boundary condition).

After a promising effort on experiment of XBeach with actual data [13], the problem of Tra Khuc estuary has been solved in more details on GNU/Linux operating system. We believe that the implementation of modelling entirely with open source tools is viable. It is promising to serve as a supplement material for a training course in coastal hydrodynamics or environmental CFD.

Acknowledgement

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