MOPS - A Morphodynamical Prediction System on Cluster Computers

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Abstract. The simulation of morphodynamical processes with a 3D model requires high horizontal and vertical resolution at least in some parts of the model domain. In particular, all areas with steep bathymetry gradients like tidal rivulets or shipping channels require highly resolved simulations. Since it is not feasible to run the total model domain with the same high resolution everywhere, this problem calls for a multiply nested approach. Still, the amount of grid points necessary for a multiply nested simulation is enormous. Since in shallow areas the influence of wave action on the bottom shear stress becomes important a wave model particularly suitable for shallow water is coupled to the hydrodynamics. The integrated system is implemented on a Linux cluster using the MPI library. Performance results for different types of model coupling are presented.

Key words: hydrodynamics, wave model, hierarchical nesting, cluster computing, morphodynamics

Topics: Large Scale Simulations in CS&E, Parallel and Distributed Computing, Cluster Computing

1 Introduction

In the light of a possible sea level rise due to climate change coastal engineers are interested in estimates of the impact of such a change on coastal protection works like dikes. This motivates the development of a model system integrating a current module, a wave module, and a morphodynamical module. Fig. 1 symbolizes the physical processes involved. Besides tidal motion the main driving force for currents is the stress executed by wind on the surface. This stress is also a main driving force for the generation of waves. Waves and currents also interact, and both are responsible for a stress force acting on the bottom. When the bottom is allowed to change (erosion and/or deposition) and when this change is fed back into the dynamical system the process is called morphodynamics.

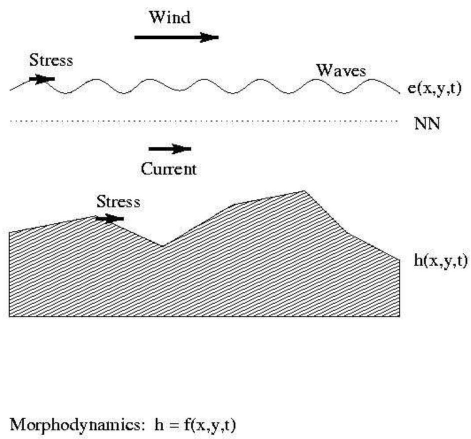

Fig. 1. Physical processes involved in a morphodynamical prediction system.

This morphodynamical prediction system (MOPS) is still in development. In particular the morphodynamics part is still missing. But the most important prerequisites for estimating a reasonable bottom shear stress to be used for morphodynamical processes are a coupled current and wave model.

2 Component Models

The hydrodynamical model used is based on TRIM3D from Casulli and co-workers in Trento, Italy ([1]). It is a finite difference model discretized on a staggered Arakawa-C cartesian grid. Optionally it allows inclusion of baroclinic and non-hydrostatic terms, which are both not relevant for the cases presented here. We have extended the original model to allow for a focused view on the area of interest. The focus is realized by a set of hierarchical grids with increasing refinement (usually by a factor of 2), where the boundary conditions of the finer grids are provided by the results of the next coarser grid. For our test application to be described later a staggering level of 4 was used with horizontal resolutions varying from 800 to 100 m. The flow of information is still one-way from coarse to fine. A two-way nesting providing part of the unresolved coarse grid terms by fine grid results would constitute a major improvement and is on the to-do-list. A further extension of TRIM3D was its parallelization for distributed memory systems. A domain decomposition with explicit message passing using the MPI-Library was chosen.

The wave model is a spectral model especially adapted for applications in shallow waters with strong bathymetric gradients ([2]). It solves an equation for energy density taking into account wave generation by wind and non-linear dissipation effects due to wave breaking. Wave model and current model interact in two ways. On one hand water depth and current velocity influence the wave period, while on the other hand wave energy can also be transferred to currents by terms called radiation stress. This effect occurs primarily in shallow water with strong energy gradients and can lead to significant long shore currents. Certainly, the effect is strongest during strong wave periods like storms.

3 Test Case

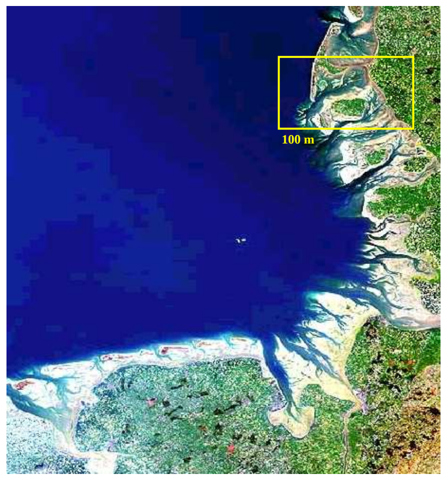

Fig. 2. German Bight with yellow rectangle indicating the location of the finest grid.

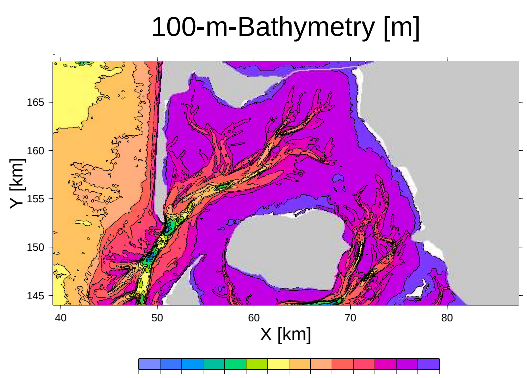

Fig. 3. Bathymetry of the 100 m resolution grid.

The test bed for the combined system was the Hörnum tidal basin between the islands of Sylt, Amrum and Föhr in the German Bight. Four nested grids with horizontal resolutions of 800, 400, 200, and 100 m were used. Fig. 2 shows a satellite picture with the position of the finest grid indicated by the yellow rectangle. The coarsest grid was driven by data from the BSH (Bundesamt für Seeschifffahrt und Hydrographie). Simulating time was a period of two years from November 1999 to October 2001, which also includes a heavy storm (*Anatol* on 3rd and 4th of December 1999). Fig. 3 shows the bathymetry of the finest grid and in Fig. 4 the typical surface velocity pattern at maximum ebb tide is presented. Very strong currents in the main tidal channel can be seen as well as strong crosswise currents over the shallows at the southern tip of Sylt.

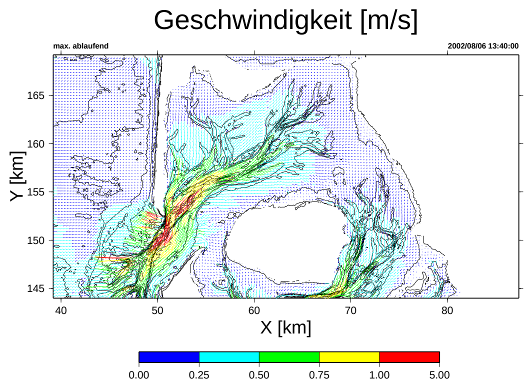

Fig. 4. Surface velocity vectors at maximum ebb tide.

4 Timing Results

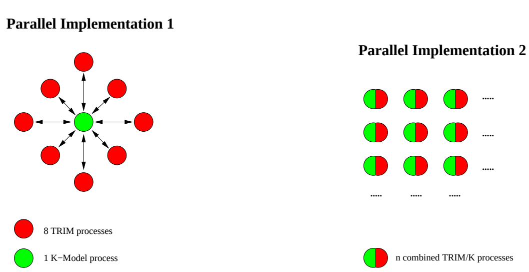

Fig. 5. Parallelization patterns. Left: Original version with sequential K-model. Right: Fully parallelized system.

In a first setup for the model system the wave model was still not parallelized. Therefore, it was placed on a separate processor on the Linux cluster with a total

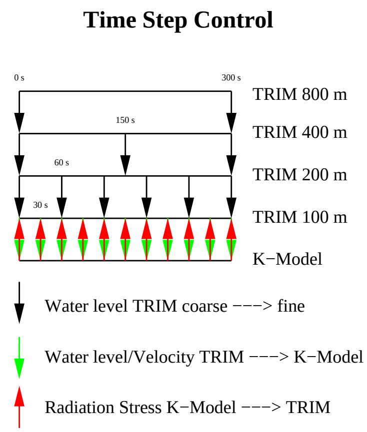

Fig. 6. Time step control of the coupled system. The arrows indicate data exchange.

of 64 2.4 GHz Intel Xeon processors (Fig. 5, left panel). Fig. 6 shows the timing of the model system with data exchange directions and positions in time. It turned out that the wave model was the bottle neck of the system. When run on the finest grid it took 3 times longer than real time. On the other hand the current model when run in fully nested mode on 8 processors was about 8 times faster than reality. Since the latter timing was considered to be feasible in terms of total CPU time for the whole simulation period the wave model was adapted to a much coarser 400 m resolution on the finest grid domain in order to give approximately the same CPU demands. This required a lot of interpolation back and forth, which is certainly not ideal. Nevertheless, the system was run stably and produced reasonable results giving estimates of the wave energy flux on the coast line (which is the relevant parameter for coastal engineers).

In the meantime the model system has been migrated to another Linux cluster consisting of 24 nodes with 2 dual-core 2.2 GHz Opteron processors on each node. Fig. 7 shows performance results for a 24-hour simulation of the hydrodynamic code alone. Interestingly the Opteron cluster shows super-linear speedup as long as only one processor per node is used. This is probably a cache effect. The more processors are used the smaller the individual sub-problems become fitting more easily into the cache. Comparing the results for 24 processors but using 2 processors per node instead of 1 shows a significant drop in efficiency. This could be an indication of competition among several processors on limited resources on a node.

In the next stage of development the wave model was parallelized with the same domain decomposition approach as the current model (Fig. 5, right panel). The coupling can now be much tighter (data exchange every time step), and the synchronization is just a question of defining the sub-domains in order to achieve load balance. Now the wave model can also be designed in a multiply nested way, but it turned out quickly that now the computing time increases by

NP	NPN	CPU	S	E
1	1	7312	1.00	1.00
3	1	2335	3.13	1.04
6	1	1147	6.37	1.06
12	1	572	12.78	1.06
24	1	264	27.70	1.15
24	2	323	22.64	0.94
48	2	235	31.11	0.65
96	4	153	47.79	0.50

Fig. 7. Timing results for the Opteron cluster. *NP* is the number of processors used, *NPN* denotes the number of processors per node utilized, *CPU* is total CPU time in seconds for a 24-hour simulation, S is the speedup, and E the efficiency.

approximately a factor of 10. Running the coupled and fully parallelized system on a much larger number of processors is not really a solution since then the sub-domains become very small increasing the communication overhead. Therefore, it is still a matter of research how to apply this system optimally on a cluster computer. One solution might be to keep on running the wave model on the coarser grids only. Another solution could be to switch on the wave model only in situations where the coupling has significant influence on the results. As it turned out from the two years simulation period only strong wind events create strong enough waves to be of importance for the currents and bottom shear stresses. Most of the time the differences between runs with or without waves were negligible.

5 Conclusions and Outlook

In conclusion it was shown that a coupled system of current and wave prediction results in a gain of quality of the results. It still needs to be shown that the inclusion of a morphodynamic sub-module benefits from these results. Furthermore, the CPU requirements of the fully nested system for both currents and waves are prohibiting for routine forecasts. There still needs to be found a way to simplify the approach without loosing too much of forecast skill.

References

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