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Effects of Presence of Waves on Shallow Estuaries Hydrodynamics

EFFECTS OF PRESENCE OF WAVE ON SHALLOW ESTUARIES HYDRODYNAMICS

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Abstract

In this study, Dynamical COupled model for Marine environment system (DYCOM) has been developed. This system includes a 3D Hydrodynamic model, MPI TRIM3Dxyz improved in MPI version in GKSS research Center, a third generation shallow water spectral wave model, k-model which is developed in GKSS research center and a set of bottom boundary layer models, BBL developed during this research. All system integrates in Linux operating system and simulation triggered using a comprehensive Makefile. Data transfer between different modules managed using different flag files after preparation of outputs. In these paper results of one-way coupling without inclusion of BBL modules on hydrodynamic simulation of Hornum tidal inlet located in German Bight has been presented. Hydrodynamics parameters such as depth, current speed and direction also wave model results compared for 18-22 November 2002 for both stand alone models run and inclusion of their results after completion of stand alone run. Results also are compared with analytical solution using dispersion equation for following and opposite current on wave peak period due to Doppler effects. Hydrodynamic model show rapid increase in current speed for small water depth close to fall drying in ebb current inside inlet which does not take place in real situation, coupled system improves the computational results significantly. At the entrance of the inlet around sand bar decrease and increase of peak period of wave and decrease of current speed in water depth of 3 m could be seen in coupled results in compare to stand alone run. After a comprehensive comparison of the different parameters for points in different water depths and location inside and in front of the inlet, it is strongly recommended to use coupled wave-current modeling system to evaluate hydrodynamical situation in a shallow tidal inlets. Eventually some interesting points, related to influences of wave on shallow estuaries hydrodynamics, have been issued.

Keywords: Tidal inlet, hydrodynamical modeling, spectral wave modeling, coupled models

1- Introduction

Main reason of using coupled model is to be more close to real physical nature of the phenomenon. Different physical processes connect wave and current in near-shore coastal waters. Interaction between both took place at the surface and bottom of the Sea, such as radiation stress, apparent bottom roughness and Doppler shift effect..

In brief description one can categorize some of above mention phenomena in terms of wave current interaction as below.

- Current effects on wave field

Refraction and changing in wave direction due to non-stationary current field variation

Refraction and changing in wave direction due to non-stationary depth field variation

Doppler shift in spectral space propagation and dispersion relation equation

Improve bed dissipation coefficient due to wave current interaction in bottom boundary layer

- Wave effects on Current field

Improve water depth and current fields due to radiation stress effects

Apparent bottom roughness result from wave current interaction in bottom boundary layer

Improve surface stress due to wave induced form drag

2- One-way coupling

One-way coupling of wave and current fields have been considered by improving source code of both models. Each model starts as soon as receive flag file created by the other model. Complete sequence of computation takes place in two stages (figure 1-left). In the first stage both wave and hydrodynamic models has to be run independently with a specified wind field and grid resolution for N time step. Meanwhile required data resulted from wave and hydrodynamics model will be write on different files by specified time steps which going to be used in the second stage of coupling by the other one (figure 1-right) (Welsh, 1999).

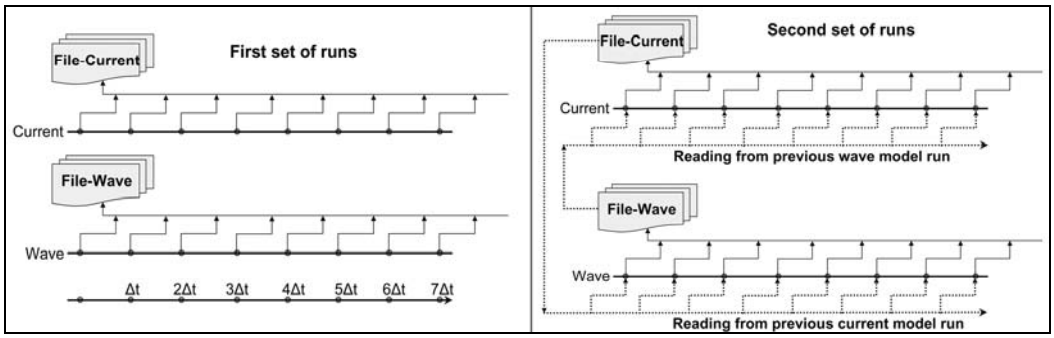

Figure 1- One-way coupling of wave and current procedure

3- Introducing coupled modeling system

DYnamical COupled Model for Marine Environment (DYCOM) has been developed for both one and two way coupling of wave and current model (Moghimi, 2005c). This system includes a 3D Hydrodynamic model, MPI TRIM3Dxyz (Eppel,2003), a third generation shallow water spectral wave model, k-model (Günther,1995; moghimi,2005b) and a BBL model developed during this research (Moghimi, 2005c) (figure 2).

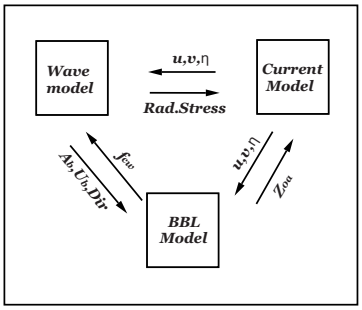

Figure 2- DYCOM system data flow

4- Case study

Wave and hydrodynamics simulation performed for Hoemum inlet located in German Bight located inside North Sea (figure 3). DYCOM model outputs within 5 days from 17 to 22 November in 2002 have been presented.

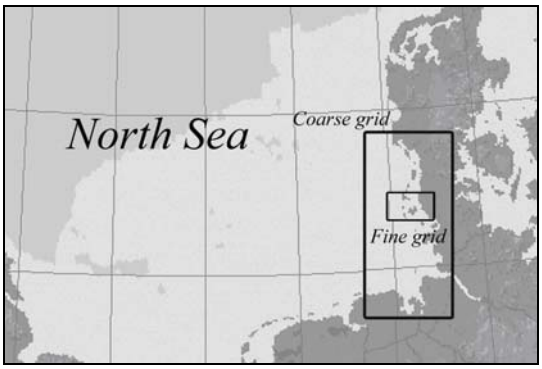

Figure 3-German Bight geographical location

Integration of governing equation has done with internal time step of 10 and 60 seconds for wave and flow models, both with 400 meter geographical resolution for the fine grid. Information exchange of models has chosen 30 minutes to take into account variation of tide and climate changing conditions.

In order to investigate wave and current conditions within simulation period, results for both models recorded for some points inside and outside of Hoemum inlet (figure 4).

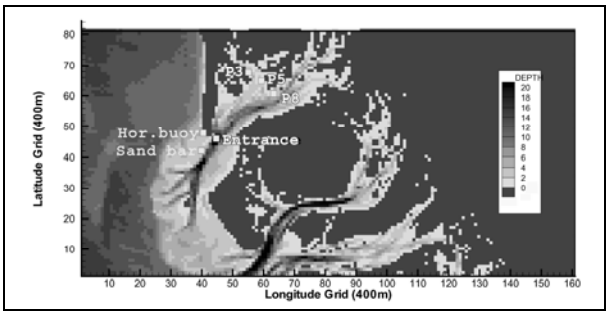

Figure 4- Bathymetry and selected points Inside and out-side of Hournum inlet

5- Stand alone models vs. one-way coupled system

Wave and current coupling even without taking into account interaction inside bottom boundary layer can affect both model results tremendously. Results of DYCOM system for current filed including radiation stress from wave model have been presented in compare with stand alone current model results, in order to evaluate performance of models separately. Results of wave model in stand alone state have been compared against one-way coupling results which is included water level variation and current field effects from flow model.

Figures 5, 6 illustrate time series of wave and current parameters from 18 to 22 November 2002 at Hoemum inlet (location in figure 4) in stand alone and one-way coupled mode of DYCOM system. Significant wave height for both states is the same anyhow some improvement of wave height within 21 to 22 November due to coupling of models is a regarded issue. Also significant wave height reduction during ebb tide resulted from one-way coupled system show better accordance with measurements in compare to stand alone wave model outputs.

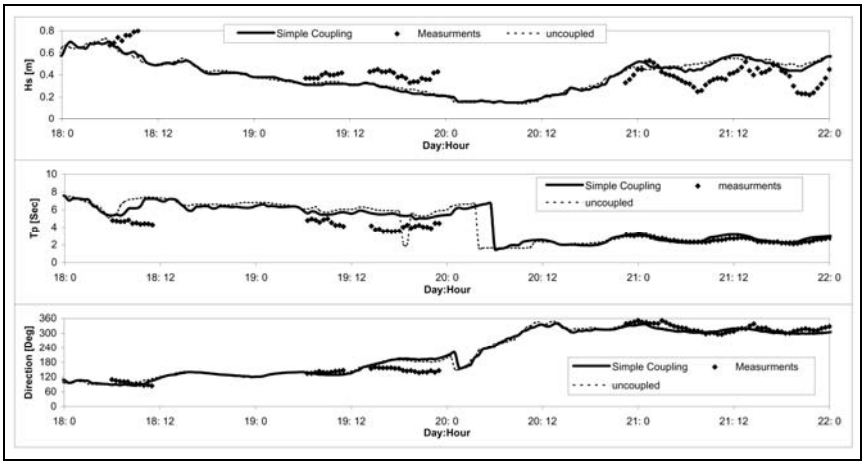

Figure 5 time series of wave parameters from 18th to 22th November in Hoemum (location in figure 4) up: significant wave height, middle: peak period, and down: mean wave direction; thick lines: one-way coupling, narrow lines: uncoupled and dots: measurements.

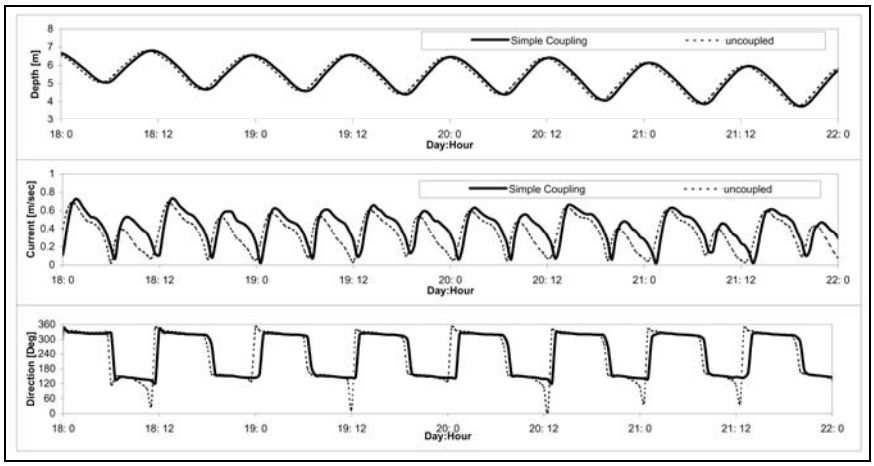

Figure 6 time series of current parameters from 18th to 22th November in Hoemum (location in figure 4) up: water depth, middle: current velocity, and down: current direction; thick lines: one-way coupling, narrow lines: uncoupled.

The peak period of waves from coupled model is less than stand alone model results. This reduction, cause to better accordance between one-way coupled model and measurements.

Resulted water depth from one-way coupled and stand alone model are similar. Better accordance existed between results of current velocity from flood to ebb. Improvement of current direction is another important point in compare of DYCOM and stand alone model results, in the other hand coupled model cause to elimination of existed jumps in measures of current direction.

Figure 7 illustrates time series of wave and current parameters on 18th November in Sand Bank (location in figure 4). Significant wave height for stand alone model and coupled produced similar results, but significant difference is visible in resulted wave peak period above mentioned methods.

Considered dispersion relation $\omega = \sigma \pm kU$ with in positive mark is for following and negative for opposing current and assuming typical wave period around 8.5 seconds, table 1 could be given from models result and dispersion equation.

Differences in magnitude of peak periods in various states in relation with current velocity can be justified by calculated results from dispersion relation. This simple test could proof that difference in amount of period is because of Doppler shift effects (Moghimi, 2005b).

Table 1 - Comparison of Wave parameters inside different current situations from model and dispersion relation

	Opposing current		Following current	
	Uncoupled	Coupled	Uncoupled	Coupled
U(m/sec)	-0.9	-0.7	0.95	0.55
Depth(m)	3	3	2.2	2.2
σ(1/sec)	0.739	0.739	0.739	0.739
Tp_wave_model(sec)	9.8	9.3	6.9	7.8
Tp dispertion eq(sec)	10.2	9.25	7.03	7.58

In figure7, presenting wave and current specifications in Sand Bank point, a complete similarity existed between one-way coupled and stand alone models for wave height and direction; also for water depth and current direction but one could see tremendous improvement of results for wave peak period and current velocity due to Doppler shift effects and radiation stress respectively.

Figure 8 shows time series of wave and current parameters on 21st November at P3 point (see in figure 4). Depth of this point is about 0.78 m and selected because of highly variation of water depth due to tide around 1.5 m; so that wet and dry conditions are happening for this point in each tidal cycle.

Besides accordance of wave height and direction; rapid increase of current velocity for stand alone model could be seen. This kind of unrealistic increasing is due to jet velocity for thin layer of water with a very small discharge which produces large velocity which can not be happened in nature. Using one-way coupled model removes this vague result significantly. According to (Wolf, 1999), simultaneous measurements of wave and current in different locations and depth are the only way for comprehensive investigation.

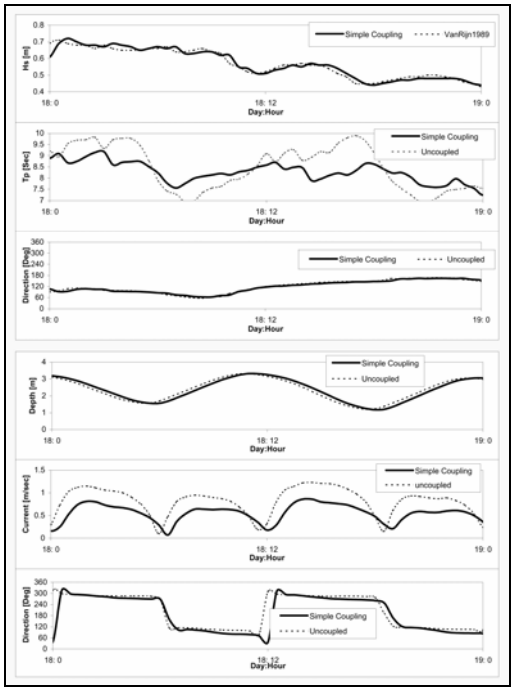

Figure 7 time series of wave and current parameters of 21st November in sand bank (location in figure 4) top: significant wave height, second from top: peak period, third from top: mean wave direction, forth from top: water depth, fifth from top: current velocity and bottom: current direction; thick lines: one-way coupling, narrow lines: stand alone.

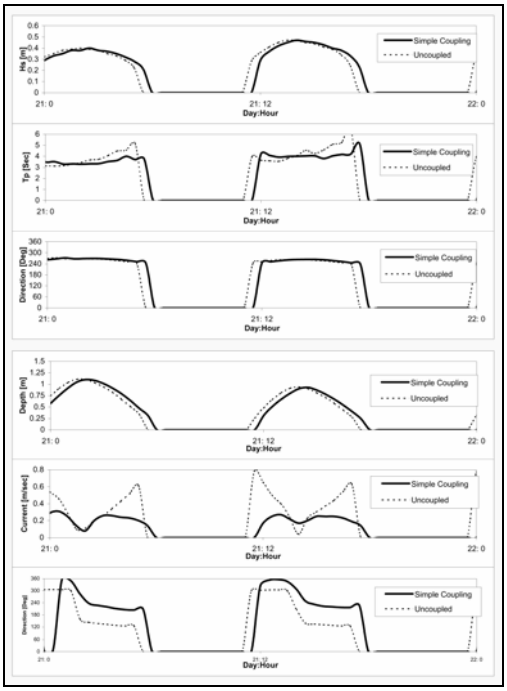

Figure 8 time series of wave and current parameters of 21st November in P3 (location in figure 4) top: significant wave height, second from top: peak period, third from top: mean wave direction, forth from top: water depth, fifth from top: current velocity and bottom: current direction; thick lines: one-way coupling, narrow lines: stand alone.

6 Conclusions

In spite of lack of measurements in this current research application of simple strategy for coupling wave and current model could prevent some obvious errors and improve both wave and current models outputs. This improvement especially takes place in highly variable tidal environment exposed to wind waves or swell in the estuaries area. Significant change of peak period of wave model in opposing and following current situations which also lead to wave blocking condition has been investigated with stand alone and one-way coupled models in compare to dispersion equation for some points which shows reasonable behavior of coupled system in compare to stand alone model results. Regarded to the results for points with different depth and geographical position, it seems that the significance of using coupled models in shallow areas are noticeable, however the survey that shows how much are variations effective on results improvement needs widespread simultaneously measurements for wave and flow in coastal shallow areas. Improving unrealistic current velocity increasing for falling dry points in ebb condition using one-way coupled model system is another important advantage of this modeling system which recommends use of coupled model especially in shallow water environment.

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