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Storm Surge Simulation for Hurricane Katrina using Wind-Wave-Surge Coupled process Model

바람-파랑-해일 결합모형을 이용한 2005년 허리케인 카트리나의 폭풍해일 시뮬레이션

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1. INTRODUCTION

Theory of wave-current interactions by radiation stress was introduced and developed by Longuet-Higgins and Stewart (1960). Based on momentum transfer from wave to current through the gradient of additional stresses due to excess momentum flux of wave motion. Janssen (1991) developed a wave-dependent drag relation which has enriched the theory of wind-wave interactions in the prediction of wind waves. Mastenbroek et al. (1993) investigated the wave-current interactions by studying the wave effects on the generation of storm surges with considering an additional roughness for wind turbulence due to existence of wind waves. They showed the effect of a wave-dependent drag coefficient on the generation of storm surges by exhibiting that the normal bulk law of sea surface stresses proposed by Smith and Banke (1975) underestimate the surge heights by 20% compared with those computed by wave-dependent drag coefficient. However, mutual effects between wave and current have not been fully studied yet. Tolman (1991) investigated the current effects on waves by using a third-generation model for wind wave simulation, based on the wave action conservation equation.

Choi et al. (2003) also developed the synchronous coupled model of tide-wave-surge using the quasi-linear theory of wave generation. The sea surface stresses including the interaction between wind and waves are introduced for storm surge simulation with the analytical approximation of sea surface stress for wave generation which was developed by Janssen (1991).

In this study, we attempted to reproduce storm surge and wind wave for the hurricane Katrina in 2005 by using updated atmosphere wind wave-tide/surge coupled process model. Some results of the simulation and discussion are also made for improving the hindcast experiments.

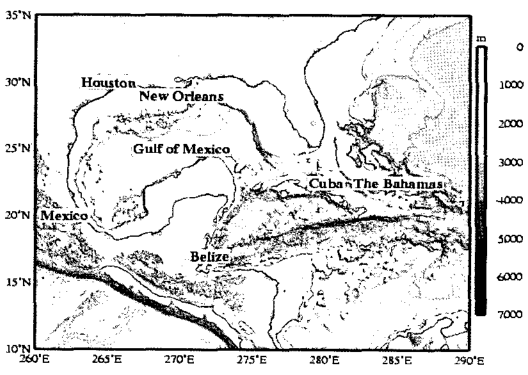

Fig. 1. Bathymetry of Gulf of Mexico

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2. EXPERIMENT

MM5 computation was carried out for simulating 2005 hurricane Katrina. Katrina's the first domain has the grid increment of 27 km, the second domain has 9 km and last domain has 3 km . Simulation is performed for mesh size of 90 x 90, and time step of 60 second. 23 vertical full-sigma levels are used from surface pressure level to 1000 hPa in all domains. The analysis period is from 00UST 27 August 2005 to 00UST 30 August 2005. The initial and lateral boundary conditions for the first domain Katrina that used NCEP and RTGSST data.

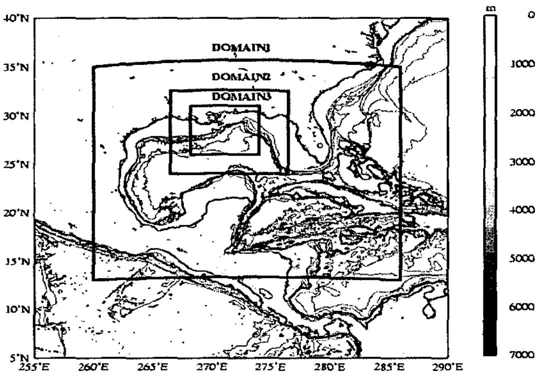

Fig. 2. Nested Domains for the Gulf of Mexico

Table. 1. Nested Domains for Simulation

	Domain1	Domain2	Domain3
Dimension	90×90	100×106	181×181
Grid size	27km	9km	3km
Simulation Time	2005/8/27~2005/8/30(for 72 hours)		
Background Data	-Meteorological data (NCEP/FNL) 1 degree resolution (http://dss.ucar.edu/datasets/ds083.2/) -Sea Surface Temperature : RTG-SST of NCEP (http://polar.ncep.noaa.gov/sst/)		
Best track	Unisys Weather data (http://weather.unisys.com/hurricane/)		

The quasi-three-dimensional ocean circulation model (POM) and WAVEWATCH III (WW3) which has been developed at the Marine Modeling and Analysis Branch (MMAB) of the Environmental Modeling Center (EMC) of the National Centers for Environmental Prediction (NCEP) are applied to simulate the tide and wind wave in the Atlantic Ocean.

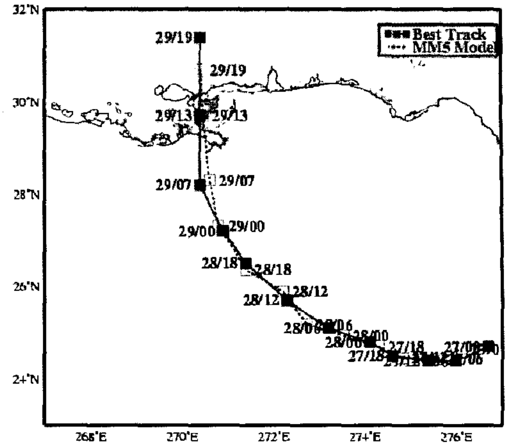

Fig. 3. Hurccane Track by Unisys and Track Simulated by MM5 Bogussing

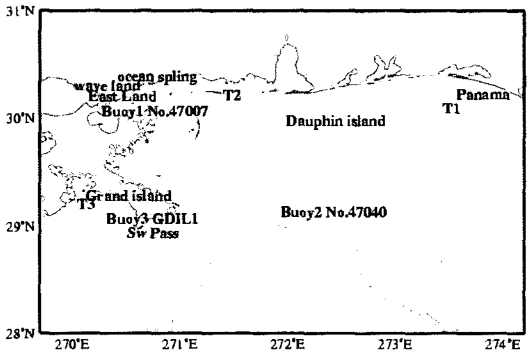

Fig. 4. Buoy station and Water level gauge position

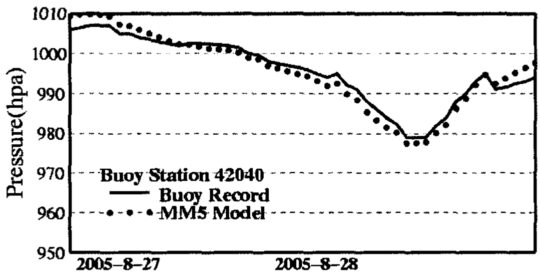

Fig. 5. Time Series of the Surface Atmospheric Pressures Observed at Buoy Station 42040 and Calculated at Model Domain3

The quasi-three-dimensional model was computed by the horizontal grid size of 100 arc-second (about 3,000m) and the external and internal time step of 0.5 and 10s. The water depth data. was composed by EOTOPO 5min, ETOPO 2min and GEBCO 1min as shown Fig. 1. The model computed in major 8 constituents (M_2, S_2, K_1, O_1, N_2, K_2, P_1, Q_1) separately and they can compose for real time simulation.

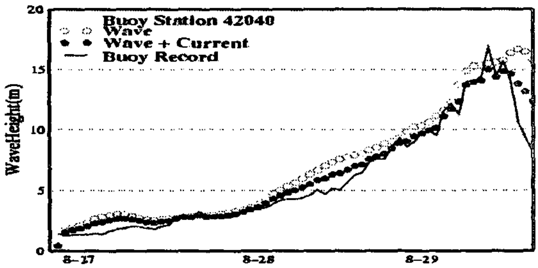

Fig 6. Comparisons of Each Calculated Wave Height with Buoy Station Records (NOAA Buoy 42040)

3. PARALLEL COMPUTATION METHOD

We developed coupling program to collect and distribute the exchanging data with the parallel system. Three models and coupler are executed at same time, and they calculate their own jobs and pass data with Parallel Linux Cluster system. Fig. 2 shows the nesting system and model application. The first domain is used for the atmosphere model. The middle region indicates the second domain used for the atmosphere model nesting from the first domain. The smallest region is used for computations of atmosphere, wave and current in the hurricane Katrina .

The essential function of the coupler is to repeatedly transfer data, such as atmospheric pressure and wind speed, to other models that need this data as a boundary forcing term. The coupler must also do additional, computationally significant work, such as interpolate the data onto a different grid. The moving averaging gridding method was hired for interpolation between each model. The Multiple Program Multiple Data (MPMD) method programming was performed to couple the models. The coupler and each models united by the separated group, and they calculated by the group unit. Also they passed message when exchanging data in the system. The coupler and the master nodes of each model communicate the signal at each models time step and they exchange the data every 120-seconds of the model time that is the least common multiple time of the atmosphere model, the wave model and the ocean model.

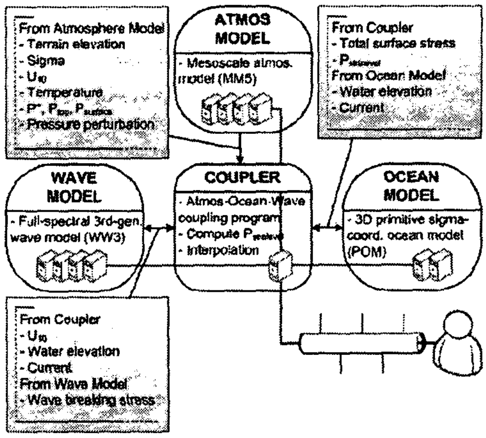

Fig. 7. Structure of the Synchronous Coupled Wind-Wave-Surge Model

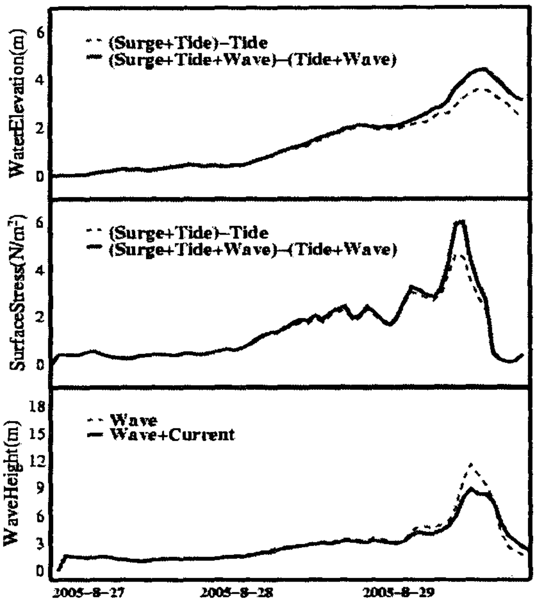

Fig. 8. Comparisons of Calculated Water Elevation, Surface Stress and Wave Height at the Wave Land (Dot: Non-coupled, Line: Coupled)

4. SIMULATION RESULTS

Fig. 8 shows the surge residual elevations without wave effect and considering 2 way interaction between wave and surge for the period 0000 UTC 27 August to 00 UTC 30 August 2005 from the storm surge model simulation. Wave height of coupled model results are less than non-coupled model, and surface stress in coupled model are lager than non-coupled model results. Water elevation of coupled model is lager than non-coupled model results. In this study, it is confirmed that high wave condition makes high whitecap wave dissipation resulting in high water level elevation. Moreover, high water level elevation makes water depth deeper. As wave energy flux is conserved, deeper water makes results in smaller wave height. Also reduced wave may affect current and water elevation.

5. CONCLUSIONS

Numerical hindcast of the storm surge caused by hurricane Katrina were performed by using the parallel computing system of coupled wind-wave-current model which consists of meso-scale atmosphere model (MM5), hydrodynamic model (POM) and the full spectral third-generation wind-wave model (WW3). An additional sea surface stress, the whitecap wave breaking stress, were introduced to consider the effects of energy transfer from wind to current through wave breaking in the air-sea interaction system. The conducted hindcast of storm surge in this study clearly showed the importance of energy transfer path via whitecap dissipation of wind waves in the generation mechanism of mean current in the extremely shallow water. The major results obtained in this study are summarized as follows :

(1) An additional shear stress for mean current, which is the shearing stress caused by surface roller of whitecap breaker was defined to take the following effects into account. Wave breaking energy dissipation rate in the wind wave energy flux equation can be used for evaluation of the total amount of wave energy changing into mean current. Enhancement effects of wave breaking dissipation of shoaling waves due to increasing of wave steepness.

(2) High wave condition makes high whitecap wave dissipation resulting in high water level elevation. High water level elevation makes water depth deeper. Deeper water makes high wave condition. This cycle may be constructed in the case of neglected wave-current interaction.

(3) Through comparisons between the results with consideration of influence of wave wind and the results without consideration of influence of wave wind, it is confirmed that the water elevation is increased and the mean wave period is shortened in the simulation including consideration of influence of wave wind. In detailed, energy loss in the wave affect additional rising of water elevation, it is shown that rate of energy loss is increased as rising water elevation.

In this study, nevertheless, the discussing merits and demerits of both modeling is difficult, because the coarse grid is used as 3km in wave model on a level with grid size of atmosphere model and dissipation in the shallow water is not well represented in the modeling WW3. In the further work, therefore, those problems can be solved. Also it is desirable to incorporate bottom boundary physics of wave and current in two-way coupling mode. Experiments for baroclinic condition are also being considered.

REFERENCES

Choi, B.H., Eum, H.M. and Woo, S.B., 2003. Modeling of coupled tide-wave-surge process in the Yellow Sea, Ocean Engineering, 30, 739-759.

Janssen, P.A.E.M., 1991. Quasi-linear theory of wind wave generation applied to wave forecasting, J. Phys. Oceanogr., 21, 1631-1642.

Kim, K.O. 2005. Coastal Ocean Model with Consideration of Meteorological -Oceanographic Mesoscale Interaction, Doctor thesis, Tokyo University.

Longuet-higgins, M.S., and Stewart, R.W., 1960. Changes in the form of short gravity waves on long waves and tidal currents, J. Fluid Mech., 8, 565-583.

Mastenbroek, C., Burgers, G. and Janssen, P.A.E.M., 1993. The Dynamical Coupling of a Wave Model and a Storm Surge Model through the Atmospheric Boundary Layer, J. Phys. Oceanogr., 23, 1856-1866.

Smith, S.D. and Banke, E.G., 1975. Variation of the sea surface drag coefficient with wind speed, Quart. J. Roy. Meteor. Soc., 101, 665-673.

Tolman, H.L., 1991. Effects of Tides and Storm Surges on North Sea Wind Waves, J. Phys. Oceanogr., 21, 766-781.

Tolman, H.L., 2002. User manual and system documentation of WAVEWATCH-III version 2.22, MMAB.