Numerical studies on dynamic response of interactive system between atmosphere and ocean

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A coupling system of MM5 and POM using Stampi with different kinds of parallel computer is proposed and comparative numerical simulations of mesoscale wind induced by topography around East Sea/Sea of Japan are carried out. The results are as follows: 1) Strong horizontal conversion is induced by high mountain Pekdoo at its leeside. 2) The conversion winds at lee of high mountain are not clear in monthly and yearly mean NCEP-reanalysis because of coarse resolution of 1.86 degree by 1.86 degree. But Wind conversion is well simulated at atmosphere and ocean coupling system. And the conversion area of lee side of mountain is also agreed well with observed data of NSCAT launched in satellite ADEOS. 3) The surface ocean current is well correspondent with wind direction, induced by high mountains. And small different wind field information lead the different of particle distribution in numerical experiments of particle distribution on ocean surface.

Key words : MM5, POM, coupling of Atmosphere and ocean, Mesoscale circulation, lee wave

1. Introduction

Unexpected ocean pollution accidents by oil tank or nuclear accident around ocean give natural environment huge damage in long time and especially nuclear power plants grow up around East Sea/Sea of Japan.

Radioactive contaminants emitted from nuclear power plants due to a nuclear accident, fall down not only to the ground but also to the sea surface. Then, radioactive contaminants on the sea disperse by ocean current and infect the sea environment. Thus, it is important for the prediction of weather, ocean current and pollutant circulation to couple an atmospheric model with an oceanic one. Coupling system of atmosphere and ocean with differential calculation of several computers is proposed [1]. And the coupling system gives good performance in meso-beta scale ocean circulation. And by this coupling system, wind information is important factor to evaluate ocean circulation and oceanic dispersion in Shimokita area, Japan [2].

Mesoscale atmospheric circulation associated with the influence of topography have been studied [3,4,5]. The results of studies are that the horizontal scale of topography is one of important factors in the mesoscale circulation. Especially, the anabatic airflow induced by periodic topography depends on the horizontal scale of the topography and that a maximum is reached when a horizontal scale is about 100 km. In the case of a small horizontal scale, turbulent diffusivity is fundamentally important for the local wind[6]. In this respect we expect that Pekdoo mountain with about 100km width and 2km high in Northern part of Korean peninsular gives great influence on formation of mesoscale circulation. We will forcus on the formation of mesoscale circulation induced by Pekdoo mountain with several wind information. And also show the movement of ocean surface associated with atmospheric wind calculated by numerical simulations with several different conditions.

The purpose of this paper is to use the coupling system using Stampi with different kinds of parallel computer and to reveal the variation of wind and ocean current generated by Pekdoo mountain.

2. Model description

a) Atmosphere model

Mesoscale atmospheric dynamic model used in this study is MM5. The model is developed by Penn. Stat Univ. /NCAR which is well known as one of the famous atmospheric community models. MM5 is a

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three-dimensional, non-hydrostatic, primitive equation model with a pressure-following vertical coordinate. All model variables are governed by three-dimensional advection-diffusion equations. A second-order turbulence closure model is used to calculate the turbulence diffusion terms in the prognostic equations. The ground surface heat budget equation coupled with a soil-layer heat conduction equation is used to calculate the ground surface temperature. The solar and atmospheric radiations are parameterized in terms of the cloud amount and the air temperature.

The lateral boundary condition is a radiative condition of Orlanski-type to prevent reflection of gravity waves at the boundaries. For the same reason, the top boundary condition by Klemp-Durran type is employed in the model ⁷⁾. At the bottom of air layer, the Monin-Obkhov similarity theory is applied. The model is initialized with the numerical forecast data from Japan Meteorological Agency. The data are interpolated to the finer model grid.

b) Ocean model

An ocean model used in this study, is Princeton Ocean Model(POM). The model was institutionally developed and applied to oceanographic problems in the Atmospheric and Ocean Science Program of Princeton University, the Geophysical Fluid Dynamics Laboratory of NOAA ⁸⁾.

The prognostic variables of the model are the free surfaceη , Potential temperature T, Salinity S(hence densityρ), velocity components U,V and W and turbulence energy and length scale. The numerical scheme has a split time step, an external mode, which solves the vertically integrated momentum equation, and an internal model, which solves the three-dimensional momentum equations.

Variable vertical kinematic viscosity and vertical diffusivity are calculated by the Mellor-Yamada level 2.5 turbulence closure model ⁹⁾. And horizontal friction viscosity coefficient is calculated by Smagorinsky shear parameterization ¹⁰⁾. The horizontal viscosity coefficients depend on the grid size and velocity gradients.

Time differencing is explicit and implicit in horizontal and vertical directions, respectively. Time integration is divided into a two-dimensional external mode and a three-dimensional internal mode. The external mode uses a short time step based on the Courant-Friedrichs-Lewy (CFL) condition calculated from free surface gravity wave speed, and internal mode uses a long time step based on the CFL condition calculated from the internal wave speed.

c) Dispersion model

We use a numerical dispersion model for the verification of influence of mesoscale atmospheric circulation induced by topography on ocean surface current. The transportation of ocean surface particle is simulated by the trajectories of a large number of marker particles from release points.

The location of a particle for a sequential time step a with time interval of Δt is determined from

$$L_{t+\Delta t} = L_t + V\Delta t + \delta d \qquad (8)$$

$$(L = x, y, z^*, \quad V = u, v, w)$$

where, L , V and d are the location of particles, the velocity of current and the diffusivity of each direction (x, y, z) , respectively. No buoyancy is considered in the present simulations.

The second term on the right-hand side represents the advection of a particle due to the ocean current, and the third term the diffusion of a particle due to turbulence. In this study, the diffusion due to turbulence calculated for every step is expressed by a random displacement whose standard deviation is defined by $\sqrt{2\,\Delta t\,K_i}$ with a mean of 0.

d) Coupling of models

Although common MPI is communication-passing library between process elements in a parallel computer, Stampi used in this study can pass protocol messages not only between internal processes but also between external process in different parallel computers. Stampi is based on the MPI2 specification, and it realizes dynamic process creation to different machines and communication between spawned one within the scope of MPI semantics. Stampi distinguishs internal communication and external communication and then change to suitable communication protocol automatically.

Main features of Stampi are as follows: (1) an automatic switch function between external- and internal communications,(2) a message routing/relaying with a routing module, (3) a dynamic process creation, (4) a support of a communication with Java applets. Indeed vendors implement MPI libraries as a closed system in one parallel machine or their systems, did not support both functions; process creation and communication to external machines. But Stampi support both functions and enables us distributed parallel computing.

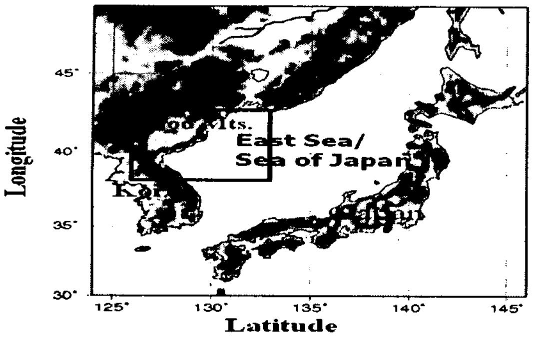

Fig.1 Topography of atmospheric model domain. Rectangular means target area of this study and Pekdoo mountains with 2km high is located at northeastern part of this area.

3. Design of numerical experiments

The simulations were carried out to examine the interaction between atmosphere and ocean using Stampi are listed in Table 1.

Model / Item	MM5	POM
Grid number (x × y × z) Grid interval	200×200×23 10 km	197 × 229×16 10km(about)
Integrated time step	15 second	INT : 20 second EXT : 5 second
Initial condition	GPV data from JMA	Pre-calculation data (10 years integration)
Boundary condition	Radiation	Orlanski scheme

Table 1. Specification of numerical simulation. EXT and INT mean external mode and internal mode integrated time

The topography of the model domain is shown at Fig.1. The horizontal atmospheric domain covered in 2000×2000 km^2, was represented by mesh of 200×200 grid elements with a resolution of 10km. The atmosphere was simulated up to 10km high and divided into 23 layers with higher resolution near the ground surface and progressively less resolution. The ocean domain includes the East Sea/Sea of Japan, which is covered by 1.12×10^5 km^2. The sub-polar water and Tsushima current occupy northern and southern regions, respectively. The ocean model covers an area from 33°N to 52°N in latitude and from 126.30°E to 142.30°E in longitude. The ocean model has 197 × 229 grids with 10km interval, horizontally.

A realistic bottom topography (not shown) is introduced by taking up to 20 levels in the deepest part using the ETOPO5 global depth data. The vertical grid intervals with sea temperature, salinity and current velocity points at the center of grid intervals are closer near the sea surface than that near the bottom of sea.

Initial and boundary conditions is important factors in numerical simulations. Initial conditions of atmospheric model for the simulation are based on the large-scale re-analysis grid point data given by JMA. The atmospheric model is initialized at 1200UTC on 1, January 1997. Initial data used in the ocean model are based on World Ocean Database 1998 (WOD98), which is produced by National Oceanographic Data Center. And the database contains observed and standard level profile data with variable resolution. The variables such as temperature and salinity are interpolated from seasonal mean values with 1° × 1°grid interval. And wind stress, which is calculated by MM5, is used in surface wind stress at ocean model.

After about 5 years of ocean model integration, upper ocean above 500m depth repeats almost same seasonal changes except for some small scale variables related to the eddy activities in the surface layer. Lateral boundary condition of atmosphere model is revised by re-analysis grid point data every 6 hours.

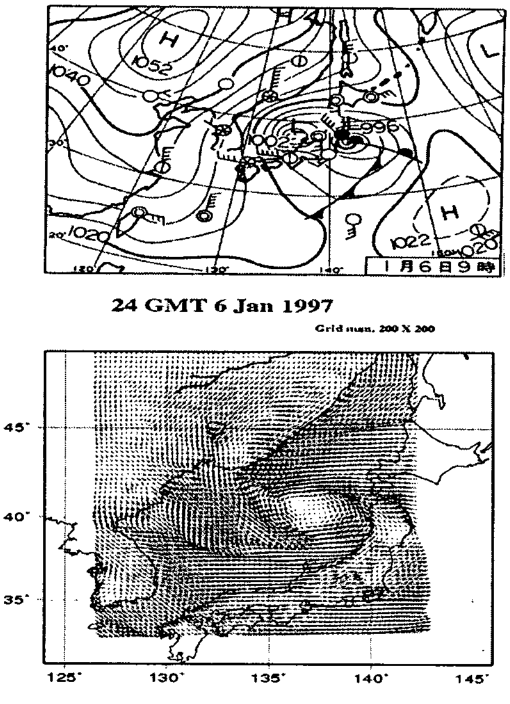

Fig.2. Synoptic chart (left panel) provided by JMA at 0099JST on 1 January 1997, and surface wind vectors (right panel) calculated by

Lateral boundary condition of POM in this study is adopted by Smagorinsky radiation condition, because this scheme well decreases the unexpected turbulence developed around lateral boundary of numerical model.

4.Results

a) Physical respect

Simulation period is 30 days from 1,January 1997 to 30 January 1997. Because we essentially focus on the influence of topography on wind formation and ocean current, this study is adopted on the case from 1 to 6 January 1997. Figure 2 is synoptic chart (left panel) published by JMA and wind field (right panel) from coupling system at 6 January 1997, respectively.

The low-press move northeastern part of East Sea/Sea of Japan and develop with time. This condition often occurs to develop the meso-scale circulation induced by topography and distribution of land/sea. And observation synoptic chart agree well with wind field distributions and location of low pressure of MM5 simulation.

We have important two points in this combination experiments. The one is the influence of topography on surface current and surface wind. And second point is that an up-welling current, induced by strong surface wind, can be simulated in this coupling system. In respect to the former, we focus on wind field around Pekdu Mountain (127°E 42°N) and on water current near the Vladivostok(132.5°E, 43°N). Pekdo Mountain, which is the highest mountain in the North Korea, is in up-wind area in the winter season. A convergence area due to topographical influence is appeared around the lee of High Pekdu moutain. This convergence is well simulated by MM5 (Fig.2.). The area with weak wind velocity under 6m/s can be seen from coast line of Hamhung to 200× 200km area. These patterns of wind are observed at 9,18 and 24, January 1997 (not shown)

We also use the NSCAT(NASA Scatterometer) wind, which is a kind of satellite data, for verification of wind calculated by numerical model. The NSCAT carried by the Advanced Earth Observing Satellite (ADEOS) was the first high temporal resolution device for direct measurement of wind over the ocean. Fig.3 is high resolution NSCAT wind and sea surface temperature in 5, January 1997. This is observation data by satellite. Observed wind flows along thick arrow in figure and figure also shows a convergence zone more clearly near the leeside of Pekdoo Mountain. More topographically influenced wind patterns are formed in the East Sea/Sea of Japan creating a strong convergence area. And position and strength of the conversion wind field agree with these calculated by coupling system.

Fig.4 shows surface wind field provided by monthly mean NCEP re-analysis at January 1997.

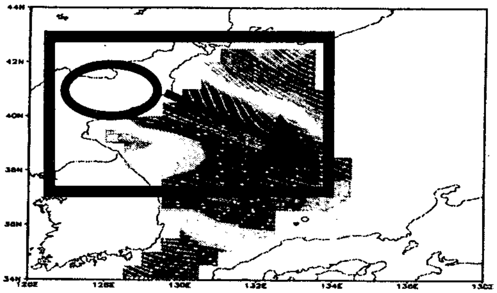

Fig.3. Surface wind analyzed by NSCAT. The thick arrow indicate the direction of wind flow and thin arrows and colors mean velocity and intensity of wind, respectively.

Target area is crossed by rectangular line.

North-westerly is predominant wind in target area. The conversion of wind at lee side of Pekdoo mountain does not occur in re-analysis data. This is great discrepancy of coupling system. NCEP re-analysis data is generally used in operation of prediction system of sea current. But this re-analysis data is not expressed mesoscale atmospheric circulation at leeside of Pekdoo mountains. Thus, in order to reveal the influence of this atmospheric mesoscale circulation on sea surface current, we also carried out numerical experiments of prediction of ocean current with different atmospheric data. One is wind data calculated by coupling system and the other is wind data of monthly averaged re-analysis data provided by NCEP.

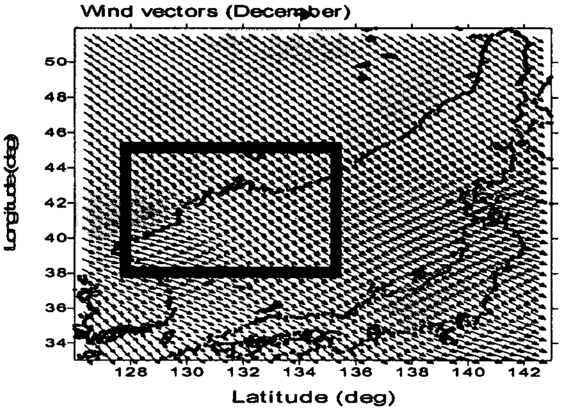

Fig.4. Wind vectors of monthly mean at January 1997 of NCEP re-analysis data. Rectangular is target area

Fig.5 is magnification of sea surface current at target area. The direction of sea surface current in Exp-comb tends to converge around lee side of Pekdoo mountains. The other hand, sea current in Exp-mean directly moves from west to east. Namely, sea surface current conversion at lee side of Pekdoo Mountains is clearer at Exp-comb than Exp-mean. This discrepance of sea surface current is caused by difference of mesoscale wind of two experiments. Thus the surface current is influenced on variation of surface wind and precise surface wind information is important to prediction of surface current movement.

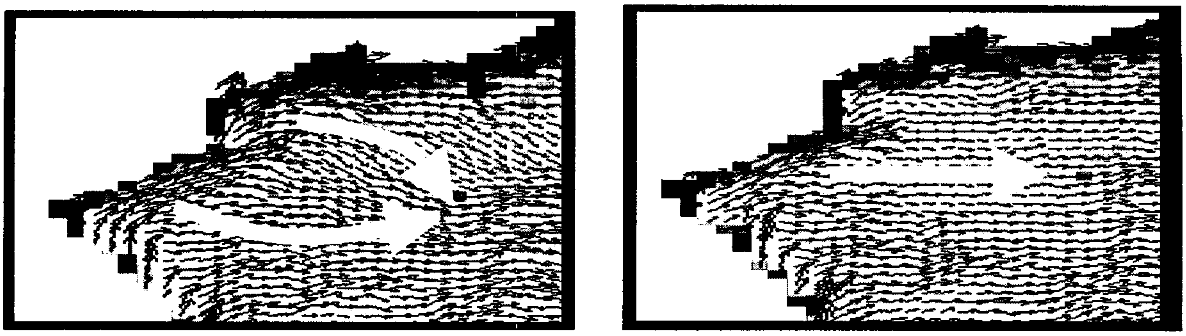

Fig.5 Sea surface current and sea surface temperature around lee-side of Pekdoo Mountain calculated by Exp-comb and Exp-mean

In order to show how influence of surface wind on ocean pollution, particles dispersion experiments were also carried out. Figure 6 shows particles distribution under Exp-comb (gray particles) and Exp-mean(dark particles) at 6,30, and 60 days after release. Cross is location of release point. We will find little difference between particles distribution of two experiments at 3 days after release. But after 60days, there is large discrepancy of particles distribution. This is mean that the coupling system between atmosphere and ocean well respond the influence of atmospheric condition to prediction of ocean current. Namely the variation of low/high pressure system is well expressed in coupling system. Thus it can say that this coupling system is one of the prediction systems of ocean current and ocean pollution at emergency.

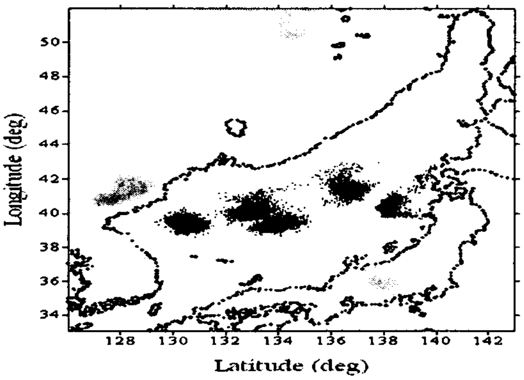

Fig. 6. Particles distribution of Exp-con(gray particles) and Exp-mean(dark particles) at 6,30, and 60 days after release. Stat mean the location of release point.

b) Computational respect

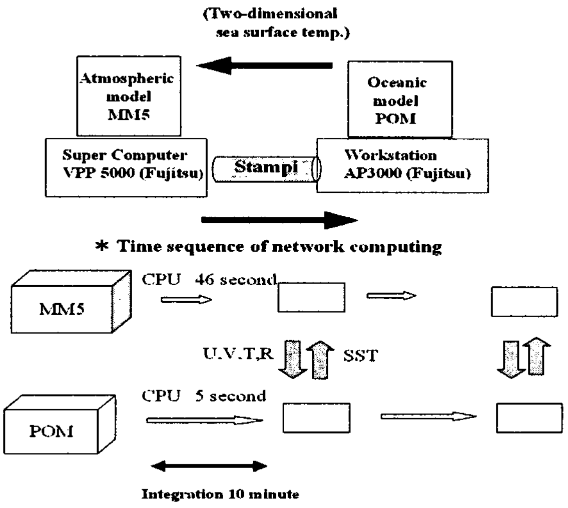

Fig.7. (a) Computational architecture of combination system and (b) the flow chart of data transportation between atmospheric and oceanic models.

In General, a prediction system between atmosphere and ocean is carried out by a successive combination of model codes. In this study, to acquire quick responses, simultaneous calculations system of MM5 and POM are proposed.

The atmospheric values are calculated on a vector-parallel computer using highly vectorized MM5. The ocean current is predicted by a scalar-parallel computer, which shows high performance for the computational dynamics code. The communication library, Stampi, performs the data exchange between both mode on the parallel computers connected by network. The outline of computing system is shown in Fig. 7.

The CPU time used in calculation of this combination system decreases 18% comparison with that of system without Stampi. Although data transmission time between two computer architectures increase a little CPU time, this combination system shows good performance to almost real time simulation of interaction between atmosphere and ocean.

5. Conclusion

The coupling between atmosphere and ocean model has physical and computational difficulties for short-term forecasting of weather and ocean current. In this research, a combination system between high-resolution meso-scale atmospheric model and ocean model has been constructed using a new message-passing library, called Stampi, for finding the relation between mesoscale atmospheric circulation induced by topography and sea surface current.

We applied this combination system to predict sea surface current at East Sea/Sea of Japan in winter season. The results are as follows:

1)Strong horizontal conversion is induced by high mountain Pekdoo at its leeside. 2) The conversion winds at lee of high mountain are not clear in monthly and yearly mean NCEP-reanalysis because of coarse resolution of 1.86 degree by 1.86 degree. But Wind conversion is well simulated at atmosphere and ocean coupling system. And the conversion area of lee side of mountain is also agreed well with observed data of NSCAT launched in satellite ADEOS. 3) The surface ocean current is well correspondent with wind direction, induced by high mountains. And small different wind field information lead the different of particle distribution in numerical experiments of particle distribution on ocean surface. 4) Coupling system shows higher performance computing (about 18% in calculation speed) by distributing the atmospheric and the ocean dynamics calculations to the vector-parallel computer (VPP) and the Scalar-parallel computer (AP3000). And coupling system makes us carry out parallel calculations of combination system without parallelization skill to model code. And it realizes dynamic process creation on different machines and communication between spawned one within the scope of MPI semantics.

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