JST Basic Research Programs

C R E S T

(Core Research for Evolutional Science and Technology)

Annual Report for Research Work in the fiscal year 2006

Research Area :

High Performance Computing for Multi-scale and Multi-physics Phenomena

Research Theme

Advanced Model Development and Simulations for Disaster Countermeasures

Name of Research Director, Belonging and Title:

Keiko Takahashi, Japan Agency for Marine-Earth Science and Technology, Group Leader

§1. Outline of Research Work

This project will promote to develop the coupled model with high speed and high accuracy and make it clear the mechanisms of extremes through validation or analysis of its physical performance. The advanced coupled ocean-atmosphere model will be developed from view points of physical models of air-sea interface for high resolution simulations, advanced micro cloud physics model, cutting edge computational schemes of dynamical core and ultra high resolution simulation with high speed. In the fiscal year 2006, we have been collaborating on developing and validating those advanced component
schemes as follows. We will integrate all of results from our collaboration to show impacts of forecasting simulations with our developed coupled model in following project years. In this section, we present outline of each groups research work in this fiscal year.

Group1 promoted by Dr. Takahashi:
An ESC model, which is named by MultiScale Simulator for the Geoenvironment (MSSG), has been developed for purposed of promoting further precise prediction simulation. Not only accurate calculation or precise discritization techniques are required and but also interface physics with ultra high resolution between atmosphere and ocean play important roles for forecasting extreme events such as typhoons and heavy rain. We have improved our model MSSG due to implementation of CIP methods and a sample physical scheme for interface of atmosphere-ocean in MSSG.

Group 2 promoted by Prof. Komori:
The aims of our research are to clarify the mechanisms of water (vapor) transfer across the air-sea interface and cloud growth in the atmosphere and to develop numerical models for expressing both mechanisms. The main results obtained in this fiscal year are as follows.

(i) In order to estimate the sensible and latent heat transfer across the sheared air-water interface in a wind-wave tank, some techniques for measuring turbulent flow velocity, temperature, humidity and radiative heat intensity were developed.

(ii) The CO_2 and heat transfer rates across the air-sea interface due to rainfall were numerically estimated. The results show that the rainfall effect is globally small, but locally comparable to the wind shear effect.

(iii) Impacts of turbulence on cloud droplet collisions in mesoscale convective clouds have been investigated using the newly developed meteorological model with sufficiently high numerical resolutions to capture the in-cloud turbulence. The results have shown that the turbulence significantly promotes the collision growth and increases the amount of rainfall.

Group 3 promoted by Prof. Yabe:

We have carried out research works in fiscal year 2006 in the following aspects:

(i) Toward the establishment of high performance global numerical models for atmospheric and oceanic dynamics, we have proposed a general methodology to implement the CIP/Multi-Moment concept to the existing semi-Lagrangian/semi-implicit (SL/SI) methods. We then developed a SL/SI CIP/multi-moment global model for shallow water equations on the Yin-Yang spherical grid. The exact numerical conservativeness has been enhanced on each component grid with the computational cost remaining almost the same as the conventional SL/SI schemes. It provides a new base for constructing high accurate and high efficient global models.

(ii) We have improved the numerical code of multi-fluid dynamics for large-scale simulations of the air/water interactions. A three-dimensional domain decomposition is used for parallelization. To get higher scalability for large scale simulation, we have adopted an algebraic multi-grid (AMG) solver for the pressure Poisson equation for distributed parallel architecture. The code has been tuned on the Earth Simulator. Large scale simulations of the air/water interaction will be carried out in 2007 fiscal year.

Group4 promoted by Dr. Ashie:

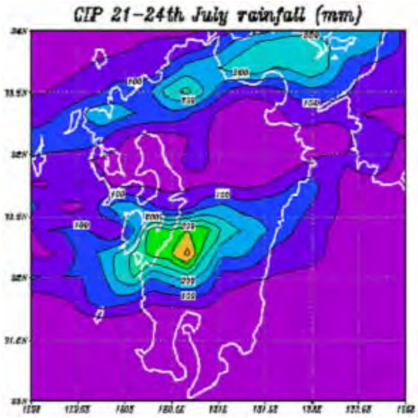
In this research group, urban meteorological model verified by thermal wind tunnel test, is to be coupled with the ESC model to simulate heavy rain fall phenomena related to urban disasters. The accuracy of the meteorological model on urban heat island phenomena will be checked in next year.

§2. Content of Research Work

Group1 promoted by Dr. Takahashi:

Following results were obtained due to improvements of the coupled atmosphere-ocean simulation code: MSSG which include implementation of CIP methods, a sample physical scheme for interface of atmosphere-ocean and turbulence and heating transfer models with urban scale of $O(10)$m.

▪ The heavy rainfall in Kyushu during July 20-25, 2006 was simulated with the CIP-CSLR scheme. 20-km global model of MSSG. A 108-hour simulation shows a much improved rainfall in Kyushu area in comparison with the second-order finite deference scheme. No negative vapor is confirmed in the model run.



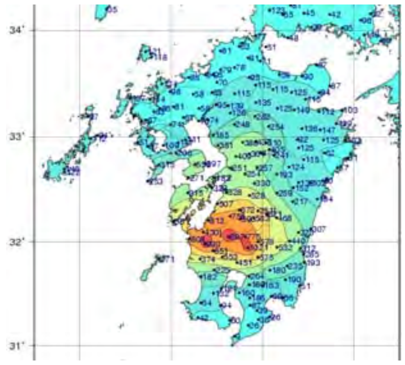


Fig.1. Distribution results of heavy rain from simulation results with 20km horizontal resolution and CIP-CSLR scheme.

Fig. 2. Observational data presented by Fukuoka District Meteorological Observatory.

- Validation experiments for forecasting tracking and strength of typhoons have been promoted the coupled atmosphere-ocean simulation code: MSSG. The following figure shows results from real time simulation for 72 hours forecasting of SHANSHAN in 2006. Each colored circle presents every 12hours initial points of the lowest pressure in Japan and tracking traces results from the initial points are shown as the lines with the same color. Those results suggest that our approach will enable us to simulate them with further accuracy.

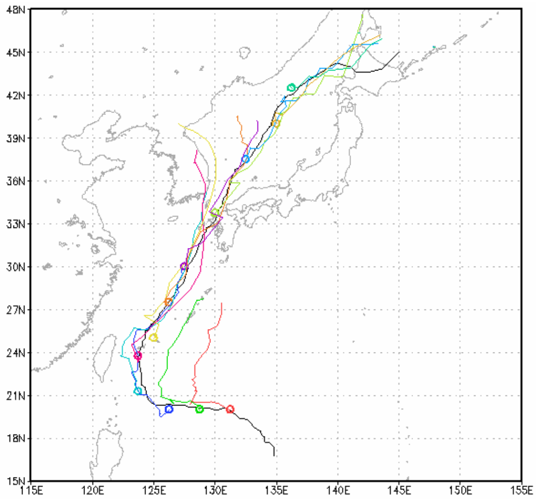


Fig3. Real time simulation results of 72 hours forecasting tracking and strength of SHANSHAN in 2006.

Group 2 promoted by Prof. Komori:

The aims of our research are to clarify the mechanisms of water (vapor) transfer across the air-sea interface and cloud growth in the atmosphere and to develop numerical models for predicting the water transfer and cloud growth.

The effects of rainfall on the scalar transfer across the air-sea interface were investigated. The scalar transfer due to rainfall is considered to be promoted by the following two factors, namely, the scalar transfer by surface renewal motions generated beneath the sea surface due to the impinging droplets on the water surface and the transfer between raindrops and atmosphere during the falling process of raindrops. The former contribution was estimated using the empirical expression between local momentum flux of rainfall and heat (or mass) transfer coefficient together with meteorological data such as rainfall momentum flux given by precipitation data set. On the other hand, global partial pressures of CO_2 in atmosphere and ocean near the sea surface were used to estimate the latter contribution to mass transfer. Atmospheric and wet-bulb temperatures near the surface were used for estimating heat transfer, although we were forced to assume that the temperature difference between sea surface and bulk water is constant. The rainfall effects were quantitatively compared with the effect of wind shear. The results show that the global effects of rainfall on scalar transfer between atmosphere and ocean are less than 5%, compared with the wind shear effect. However, the contribution of rainfall is locally big in the tropical region and the rainfall effect reaches about 35%. In summary, the rainfall effect is significant for the local scalar transfer between atmosphere and ocean.

As for the impacts of turbulence on cloud droplet collisions, there is a growing consensus that collision growth rate of cloud droplets can be increased by in-cloud turbulence. In order to investigate the turbulence impacts, we performed numerical simulations of orographic convective clouds over a mountain. In the simulations, we used the collision model which we had developed to predict the collision frequency in turbulence. The simulation results have shown that the particle collision growth is dramatically promoted by turbulence. They have also shown that the total amount of rainfall over the mountain is increased by as much as 20%. This means that failure to treat the turbulence effect on droplet collision growth leads to significant errors in local weather predictions.

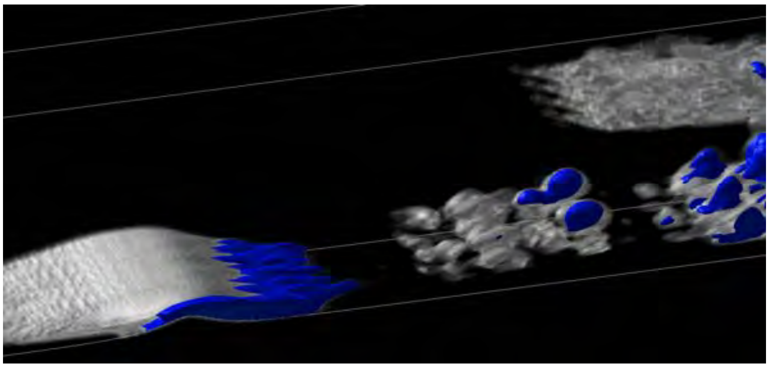


Fig.4. Volume rendering of water content. (The water content of large droplets ($r>100\,\mu$ m) is greater than 0.1 g/m3 in blue region.)

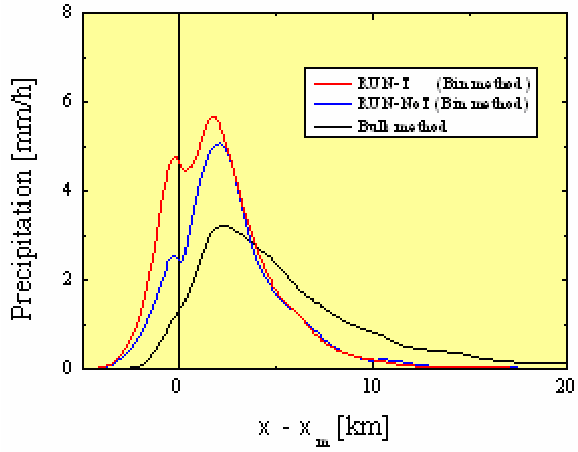


Fig.5. Spanwise- and time-averaged rainfall rates over the mountain.

Group 3 promoted by Prof. Yabe:

(i) To establish numerical dynamic cores of adequate accuracy and efficiency for atmospheric and oceanic models, we have been making use of the CIP/multi-moment finite volume method as the fundamental framework. The underlying concept of multi-moment provides a guidance for us to construct robust and accurate numerical schemes with a great flexibility. In the last year, we have devised a general framework that works well with any existing semi-Lagrangian/semi-implicit to enhance the numerical conservativeness. A conservative moment, namely the volume integrated average (VIA), is included as the new model variable that is put forward in time as well at every time step. As an implementation, we developed a SL/SI CIP/multi-moment global model for shallow water equations on the Yin-Yang spherical grid. The point values are updated through the conventional semi-Lagrangian/semi-implicit procedure, but with the interpolation reconstruction built in terms of both the point value and the volume integrated average. The VIA is predicted by a flux-based finite volume formulation. Thus, the exact numerical conservativeness is exactly guaranteed on each component grid with the computational cost remaining almost the same as the conventional SL/SI schemes. Fig.1 shows the Benchmark test of a zonal Rossby-Hauwitz wave. The numerical result is competitive to that from a spectral model with higher spatial resolution. Our study has established a general methodology for incorporating the numerical conservation in the non-conservative schemes.

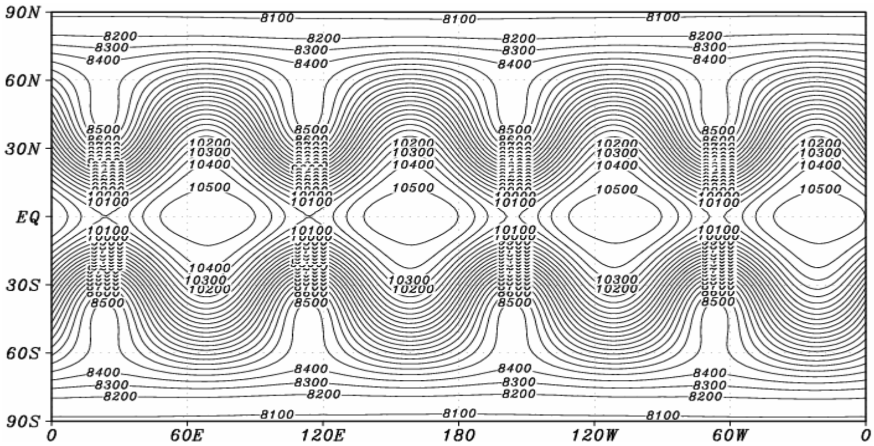


Fig6. .Rossby-Haurwitz wave after 14 days with a 1.875□ ＊ 1.875□ resolution by the SL/SI CIP/multi-moment finite volume method.

(ii) Reliable numerical parameterizations of the fluxes across the air/water interface are essential in the simulations of the coupling between atmosphere and ocean, and depend heavily on the understanding of the turbulent transfer over free interface. In order to clarify the turbulent structure and the mechanisms concerning the material and energy transfer across the air/water interface, direct numerical simulation of the air/water interactions has been planed as a part of the project. We have improved and tuned our numerical model for the parallel computation in the last year. An algebraic multi-grid method has been introduced as a new iterative solver for the Poisson equation. To get higher parallelization efficiency, the whole code has been re-written for 3D parallel partitioning. The new version of the code has much better parallel scalability and efficiency and is well suited for large scale simulations.

Group4 promoted by Dr. Ashie:

In this research group, the UCSS model developed by the Building Research Institute, in which the effect of buildings are considered in estimating urban climatic change, is to be coupled with the ESC model. In this fiscal year, thermal stratification wind tunnel test for the research on thermal characteristics in and above the urban canopy layer, coupling model of radiation and convection in urban canopy layer, revision of thermal model considering the thermal characteristics of urban canopy layer were carried out. Figure 1 shows the abstract of thermal stratification wind tunnel test of urban canopy, and an example of temperature distribution around urban canopy is shown in Figure 2.

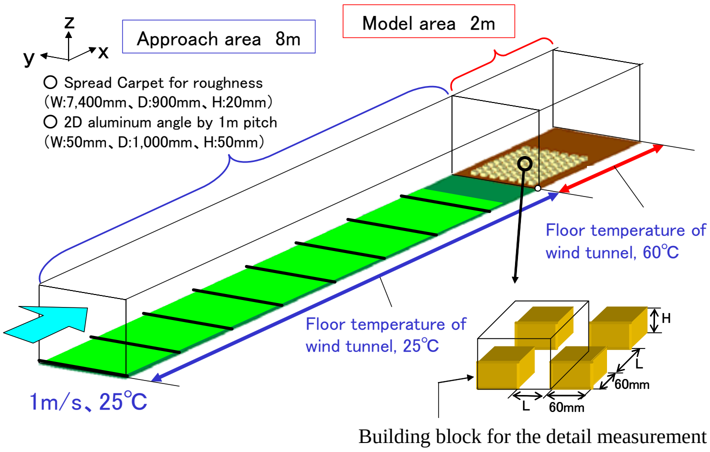


Fig.7. Abstract of the experiment of urban canopy using thermal stratification wind.

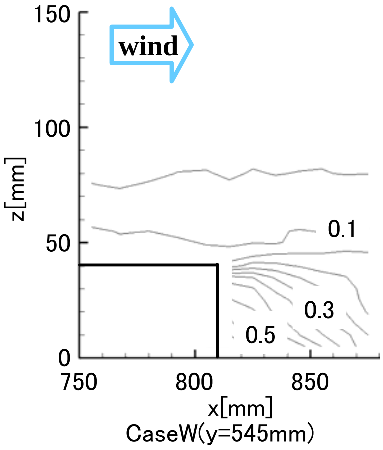


Fig.8. Example of Air temperature distribution around urban canopy.

§3. Formation of Research Work

Group promoted by Dr. Takahashi:

	Name	Organization	Title	Period
○	Keiko Takahashi	Japan Agency for Marine-Earth Science and Technology	Group Leader	2005.10-
	Peng Xindong	Japan Agency for Marine-Earth Science and Technology	Research Scientist	2005.10--
	Mitsuru Ohdaira	Japan Agency for Marine-Earth Science and Technology	Research Scientist	2005.10-
	Takeshi Sugimura	Nagoya University	PhD student	2005.10-
	Takeshi Adachi	Mitsubishi Heavy Industries, LTD.	special adviser	2005.10-
	Koji Goto	NEC cooperation	company staff member	2005.10-
	Mitsuhiro Fuchigami	NEC Information Systems Co.	company staff member	2005.10-

Group promoted by Prof. Komori:

	Name	Organization	Title	Period
○	Satoru Komori	Kyoto University	Chief Research Engineer	2005.10-
	Ryoichi Kurose	Kyoto University	Associate professor	2006.4-
	Yasumasa Ito	Kyoto University	Assistant professor	2005.10-
	Takanori Imashiro	Kyoto University	PhD student	2006.4-
	Ryo Onishi	Japan Agency for	Research Scientist	2005.10-

		Marine-Earth Science and Technology		

Group promoted by Prof. Yabe:

	Name	Organization	Title	Period
○	Takashi Yabe	Tokyo Institute of Technology	Professor	2005.10-
	Feng Xiao	Tokyo Institute of Technology	Associate professor	2005 .10-
	Yoichi Ogata	Tokyo Institute of Technology	Assistant professor	2005.10-

Group 3 promoted by Dr. Ashie:

	Name	Organization	Title	Period
○	Yasunobu ASHIE	Building Research Institute	Chief Research Engineer	2005.10-
	Mark Matheson	Building Research Institute	Supporting Priority Research Engineer	2006.4-
	Vu Thanh Ca	Building Research Institute	Visiting Researcher	2005.10-
＊	Takaaki Kono	Building Research Institute	CREST researcher	2005.10-
	Toshio Abe	Building Research Institute	Supporting Priority Research Engineer	2005.10-
＊	Hongbin ZHANG	Building Research Institute	CREST researcher	2006.10-
	Takaaki TOKAIRIN	Building Research Institute	Supporting Priority Research Engineer	2006.4-

§4. Publication of Research Results

（4－1） Publication of Thesis (The original Work)

① Number of Publications (0 times-Domestic, 15 times-International)

② Detailed Information of Thesis

Keiko Takahashi, Xindong Peng, Ryo Onishi, Mitsuru Ohdaira, Koji Goto, Hiromitsu Fuchigami and Takeshi Sugimura, Impact of coupled Non-hydrostatic Atmosphere-Ocean-land model with high resolution, High Resolution Numerical Modeling of the Atmosphere and Ocean, K. Hamilton et al. (Eds.), Springer, New York, (in press).

Xindong Peng, Feng Xiao and Keiko Takahashi, Conservation constraint for quasi-uniform overset

grid on sphere, Quarterly Journal Royal Meteorology Society. (2006), 132, pp. 979-996.

R. Onishi, K. Takahashi and S. Komori, Large-Eddy Simulation for Particle Collision Growth in Turbulent Flows， Trans. JSME ser. B, Vol.72 No.722, pp.2441-2448 (2006)

R. Onishi and S. Komori, Large-Eddy Simulation for Particle Collision Growth in Turbulent Flows, Trans. JSME ser. B (in press）

R. Onishi, H. Takagi, K. Takahashi and S. Komori, Turbulence Effects on Cloud Droplet Collisions in Mesoscale Convective Clouds, Proc. of Fifth International Symposium on Turbulence, Heat and Mass Transfer(THMT5) (2006).

S. Komori, N. Takagaki, R. Saiki, N. Suzuki and K. Tanno, The Effects of Raindrops on Interfacial Turbulence and Air-Water Gas Transfer, Transport at the Air Sea Interface-Measurements, Models and Parameterizations, Springer Verlag (2007)

Y.Ogata, T.Yabe and K.Odagaki: An Accurate Numerical Scheme for Maxwell Equation with CIP-Method of Characteristics, *Comm. in Comput. Phys.* **Vol.1**, No.2, 311-335 (2006)

Takashi Yabe , Kazuya Chinda, Tomohiro Hiraishi: Computation of surface tension and contact angle and itsapplication to water strider *Computers and Fluids* in print (2007) appeared in web page.

K.Takizawa, T.Yabe, Y.Tsugawa, T.E. Tezduyar, H.Mizoe: Computation of Free-Surface Flows and Fluid Object Interactions with the CIP Method Based on Adaptive Meshless Soroban Grids *Computational Mechanics* in print (2007) appeared in web page.

Y.Ogata, H.N. Im and T.Yabe: Numerical Method for Boltzmann Equation with Soroban-grid CIP method *Comm. in Comput. Phys.* , in print (2007) appeared in web page.

S.Ii and F.Xiao: CIP/multi-moment finite volume method for Euler equations: a semi-Lagrangian characteristic . J. Comput. Phys., **222**, 849-871 (2007).

X.Li, D.Chen, X.Peng, F.Xiao, X.Chen: Implementation of the semi-Lagrangian advection scheme on a quasi-uniform overset grid on a sphere. *Advances in Atmospheric Sciences*, **23**, 792-801 (2006).

F.Xiao, X.Peng and X.Shen: A finite volume grid using multi-moments for geostrophic adjustment. *Monthly Weather Review*, **134**, 2516-2526 (2006).

F.Xiao, R.Akoh and S.Ii: Unified formulation for compressible and incompressible flows by using multi integrated moments II: multi-dimensional version for compressible and incompressible flows. *J. Comput. Phys.*, **213**, 31-56 (2006).

Yasunobu ASHIE and Takayuki TOKAIRIN: Examination of Building Heights for Various Building Types in Tokyo 23-wards - Utilizing Airplane Laser Measurement Data -, Journal of SHASE, No.115, pp.51-54, 2006.10

（4－2） Patent Application

① Cumulative Number

1) Patent Applications in the fiscal year 2006 (Domestic- 0 Cases, Oversea- 0 Cases)
2) Cumulative number of Patent Applications for the research period of CREST (Domestic-0 Cases, Oversea- 0 Cases)
3) Details for this fiscal year
   a) Domestic Application (0 cases)
   b) Oversea Application (0 Cases)