High Performance Simulation of Extremes with Multi-scale and Multi-physics Schemes

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1. Outline of Research Work

Social request and expectation for forecast severe extremes with high accuracy will be getting strong in climate change such a global warming. It is widely accepted that the most powerful tools available for forecast/assessing future weather/climate are fully coupled ocean-atmosphere models. 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. Especially, the advanced coupled ocean-atmosphere model will be develop from the three points of view of clear physical models of air-sea interface and cloud, cutting edge computational schemes of dynamical core and ultra high resolution simulation with high speed. Each of themes will be promoted by Prof. S. Komori, Prof. T. Yabe and Prof. F. Xiao and K. Takahashi. In addition, forecasting urban weather/climate will be performed as important simulation experiments with the developed model. This theme is promoted by Prof. Ashie through collaboration with above groups. In this fiscal year, six months were mainly spent to accomplish original arranges of each group, and organic systems for a joint research was constructed with the inauguration of the projects.

2. Content of Research Work

<u>Development non-hydrostatic atmosphere-ocean coupled model for forecasting weather disasters with high accuracy</u>
Keiko Takahashi, Japan Agency for Marine-Earth Science and Technology

In this group, the following themes were promoted in this fiscal year and results are shown as follows.
(i) Validation of sensitivity of the bulk method used in exchanging fluxes through the interface between atmosphere and ocean is one of most important issues for weather/climate projection. Especially, it is still unclear whether conventional schemes are able to present realistic physics of the interface in ultra high resolution simulations. We have performed preliminary experiments in order to validate impacts of physical performance. Changing horizontal/vertical resolution in those simulations, volume of fluxes has been changed. It suggests that selection of schemes and condition of resolution might give strong impact on the accuracy of forecasting weather or projecting climate. This research has been promoted under the collaboration with Prof. Komori.
(ii) Excellent computational accuracy on the sphere was obtained by using the CIP method known as a highly accurate advection scheme and a semi-Lagrangian scheme. The benchmark experiments were done, and the high accuracy was verified. This theme has been promoted under the collaboration with Prof. Yabe and Prof. Xiao.
(iii) Urban canopy model (UCSS), which has been developed by Prof. Ashie, was introduced to the ESC model (:global/regional non-hydrostatic atmospheric-oceanic coupled model). Implementation has been completed; in addition, basic experiments have been performed to validate its physical performance. Comparable results with ordinal model experiments were obtained.

<u>Model Development of Heat- and Mass-Transfer through the Sea Surface and the Collision Growth of Cloud Droplet</u>
Satoru Komori, Kyoto University

Research topics of our group are the heat- and mass-transfer through the sea surface and the collision growth of cloud droplets. We aim to investigate those phenomena and develop models of them for more accurate predictions of weather disasters. We have obtained the following two results in this fiscal year.
(i) We have prepared the wind-wave tank for reproducing the temperature- (sensible heat) and water vapor- (latent heat) transfer through the air-water interface. We have also

prepared experimental apparatus, such as the newest infrared thermography camera, wind meter and heat- and moisture-analyzer, for the laboratory measurements being carried out in the next fiscal year. We have already succeeded in finding a provisional experimental condition by trial and error.

(ii) There is a growing consensus that the collision growth of cloud droplets can be increased by turbulence. However, the turbulence effect is not considered in the present atmospheric models. We have developed a collision kernel model based on the data from direct numerical simulations (DNS) of particle immersed 3-dimensional turbulent flows. Figure 1 shows the collision kernels normalized by the collision radius and local shear rate, in an isotropic flow with turbulent Reynolds number (Re_λ) of 44. The predictions of our collision kernel model (solid line) agree well with the DNS results (solid circle). This indicates that our model can accurately predict the collision kernels in turbulent flows. We have implemented our collision kernel model into LES (Large-Eddy Simulation). Figure 2 shows the time evolution of a particle size distribution. Broken line shows our LES prediction and the solid line shows the DNS result. We can conclude that the LES with our developed collision kernel model can predict the particle collision growth in turbulent flows.

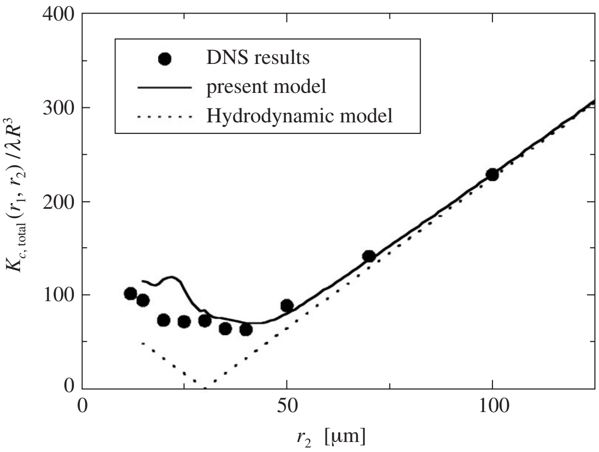


Fig. 1 Collision kernels in a turbulent flow with $Re_\lambda = 44$.

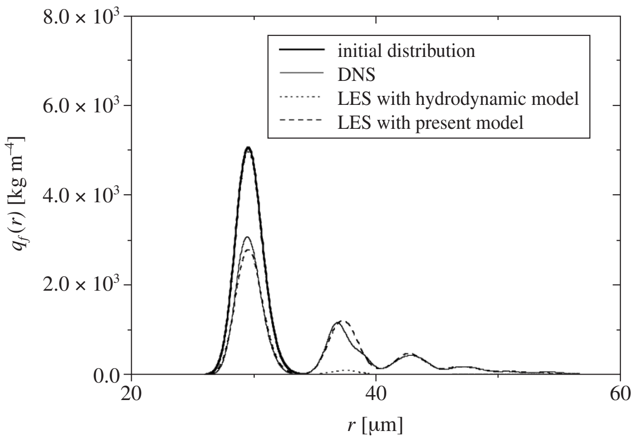


Fig. 2 Particle size distributions at t/Te = 40 in a turbulent flow with $Re_\lambda = 44$.

Development of dynamical core with multi-modal concept and high order accuracy

Takashi Yabe and Feng Xiao, Tokyo Institute of Technology

In our group, the following research theme are studied in this project,

(1) Development of the dynamic cores for atmospheric and oceanic models

(2) Numerical modeling for air/water interactions.

In this fiscal year, we have carried out research works in fiscal year 2005 in the following aspects and obtained the results as follows,

- Following the CIP/Multi-Moment concept, we have proposed a single-cell high order interpolation reconstruction by using only two types of moments, i.e. the volume integrated average (VIA) and the point value (PV).
- A more efficient and practical way to evaluate the numerical fluxes has been developed by sampling the semi-Lagrangian point-mapping of the PV variable, which makes the multi-dimensional computations much more efficient compared to the original CIP-CSL advection schemes. A 3rd order algorithm has been devised and proven.
- The proposed scheme has been implemented on the latitude/longitude grid and the Yin-Yang grid.
- We have parallelized the numerical code of multi-fluid dynamics for large-scale simulations of the air/water interactions.
- We have developed three dimensional fluid dynamics code with CIP scheme on Soroban grid system. Using the code, surface representation of falling water droplet was simulated with high resolution.

Development of Disaster Predictive Model to Solve Urban Scale Meteorology and Climate

Yasunobu Ashie, Building Research Institute

In this research group, the UCSS model developed by the Building Research Institute, in which the effect of buildings

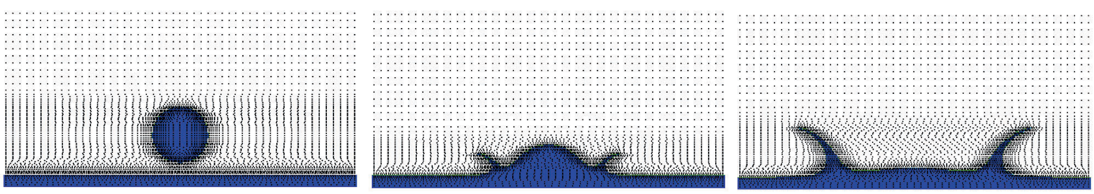
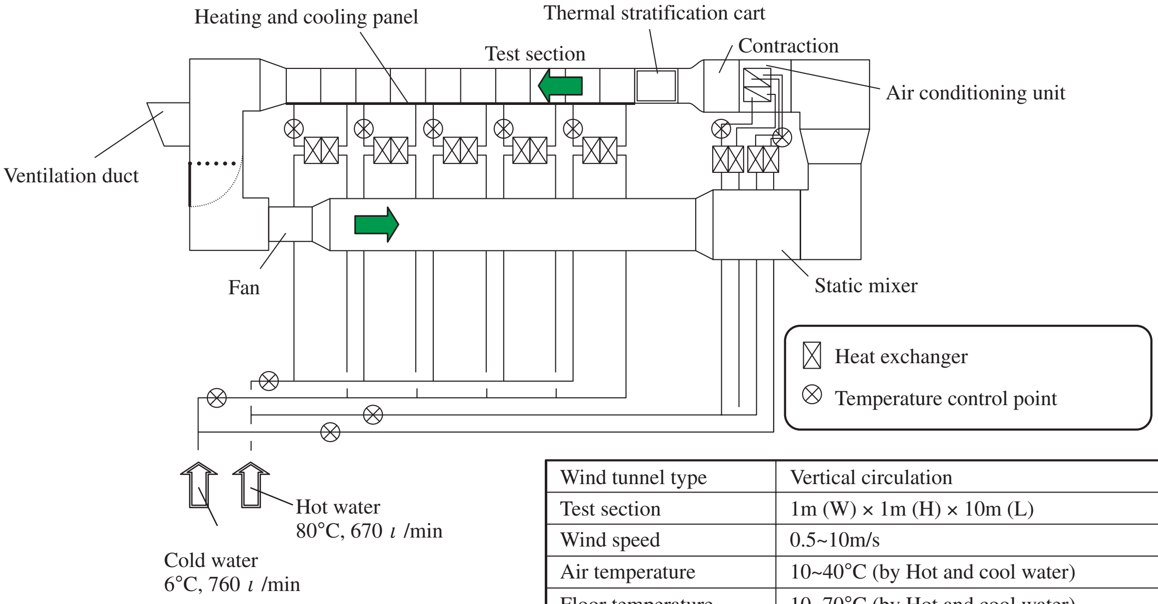


Fig. 3 Simulation results of surface of a water droplet (dot points are corresponding to grid points on Soroban grid system).



Wind tunnel type	Vertical circulation
Test section	1m (W) × 1m (H) × 10m (L)
Wind speed	0.5~10m/s
Air temperature	10~40°C (by Hot and cool water)
Floor temperature	10~70°C (by Hot and cool water)
Cart	20steps (by Electric heater)

Fig. 4 Thermally stratified wind tunnel.

are considered in estimating urban climatic change, is to be coupled with the ESC model. In this fiscal year, the thermally stratified wind tunnel was used to check the thermal characteristics of the urban canopy layer, and measurement data was achieved to verify numerical models. In addition, wind tunnel's measurement system was upgraded by introducing 1) a new wind velocimeter system using cold wire and hot wire probes, 2) a high speed camera for the visualization of thermal flow. With this upgraded measurement system, air temperature and wind velocity in and above the urban canopy layer can be measured for the thermally stratified flows and for building arrangement with a wide range of aspect ratios.

3. Formation of Research Work

<u>Research Director or Main Research Collaborator, and Items of Research</u>

Keiko Takahashi,
Items of Research:
- (i) Development of non-hydrostatic atmosphere-ocean coupled model
- (ii) Development of advanced simulation techniques for forecasting extremes

Satoru Komori, Department of Mechanical Engineering. Kyoto University,
Items of Research:
- (i) Modeling of the heat- and mass-transfer through the sea surface
- (ii) Modeling of the collision growth of cloud droplets

Takashi Yabe, Department of Mechanical Engineering and Science, Tokyo Institute of Technology,
Items of Research:
- (i) Development of the dynamic cores for atmospheric and oceanic models
- (ii) Numerical modeling for air/water interactions

Yasunobu Ashie, Building Research Institute,
Items of Research:
- (i) Development of advanced urban model for estimating urban climatic change
- (ii) Assessment for projection of future urban disaster

災害予測シミュレーションの高度化

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高精度の災害予測に対する社会的な要請と期待は大きく、これに応える最も有望な手段の一つとして、大気、海洋、陸面過程を総合的に表現する気象、気候の数値モデルを用いた災害予測シミュレーションの確立がある。本プロジェクトは、地球シミュレータを最大限に活用できる高速・高精度の災害予測を可能とする数値シミュレーションコードを開発し、災害予測の精度向上へ寄与することを目指すものである。

本プロジェクトは、高精度の災害予測シミュレーションへのアプローチとして、超大規模シミュレーションによる予測技術、実験室の実験を基盤とする物理過程モデリング技術、高精度・高安定な数値計算技術の確立を柱として、それらの応用課題として、都市型気象、気候に代表される局所的予測シミュレーションを挙げている。

本17年度のプロジェクトの発足から6ヶ月は、本格的なプロジェクトの稼動へ向けた準備期間と位置づけ、各課題の研究を遂行するとともに、各課題のテーマと課題間にわたる共同研究テーマについても協議のもと整理し、有機的な共同研究体制を構築する。