Space and Earth System Modeling

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Solar and astronomical dynamics as well as volcanic activity is widely believed to play a crucial role for the variability of Earth's environment system at different time-scale. However, it is not well understood yet how the evolution of Earth's system is related to the outside as well as the interior of the Earth. The objective of the Earth Simulator Project "Space and Earth System Modeling" is to advance our understanding of the variability of the Earth's system caused by the dynamics in space and the deep interior of the Earth. In FY 2010, we have continued the development of the several element models for space-earth environment system for the nucleation of aerosol, cloud, the acceleration of energetic particles, respectively. Moreover, we began a new simulation study of global climate variation depending on cloud droplet size in terms of the global circulation model.

Keywords: space weather, space climate, multi-scale, multi-physics, plasma, cloud, aurora, nucleation, aerosols, particle acceleration, Earth Simulator

1. Introduction

Earth's environment is not isolated from the outside of the atmosphere as well as from the interior of the solid earth. In fact, the several evidences indicate that there is clear correlation between the climate variation and sunspot activity. Also it is widely believed that giant volcanic eruption may impact the worldwide climate. However, the mechanism whereby the solar activity may affect the climate is not well understood yet. It is also a great issue for the study of geological history to reveal how the surface environment and the deep-interior of the Earth interact to each other.

Earth Simulator Project "Space and Earth System Modeling" was established in order to understand the mutual relationship between the surface environment and the activity in space and the interior of the Earth. In FY 2010, we have continued the development of the several element models which will compose a space climate simulation system. They are the molecular simulation of aerosol nucleation, the cloud simulation in terms of super-droplet method, the particle simulation of energetic particle acceleration, respectively. Moreover, we began a new simulation study of global climate variation depending on cloud droplet size in terms of the global circulation model, CFES (Coupled model For the Earth Simulator). In the following sections, we will explain about the detail of the each particular model.

2. A General Circulation Model Study of the Effect of Changes in the Size of Cloud Droplets on Surface Air Temperatures

The purpose of this study is to investigate the influence of changes in size of cloud droplets may give to the earth surface air temperature, using a coupled atmosphere-ocean general circulation model, called CFES (Coupled model For the Earth Simulator). In the present study, CFES was spun up for 100 years with a default size of cloud droplets. The control experiment afterward was run for 10 years further without changing the diameter of cloud droplets (control run). Two sensitivity experiments were performed for 10 years by suddenly making the diameter of cloud droplets half (half run) and double (double run). Figure 1 shows time series of global, monthly mean surface air temperatures where control run is black curve, half run blue curve, and double run red curve. The global, monthly average surface air temperature decreases about three degrees K within eight years when the diameter of cloud droplets is halved. On the other hand, the surface air temperature increases about three degrees within eight years when the diameter of cloud droplets is doubled. Interestingly, the cloud amount does not uniformly increase over the globe but it decreases in some regions when the diameter of the cloud droplet is halved. Also, the amount of clouds does not always increase in the region where the temperature largely decreases.

We are currently analyzing the results in detail.

3. Micro-Macro Interlocked Simulation of Cloud Formation and Precipitation

Although clouds play a crucial role in atmospheric phenomena, the numerical modeling of clouds remains somewhat primitive. We have developed a novel, particle-based, probabilistic simulation scheme of cloud microphysics, named the Super-Droplet Method (SDM), which enables accurate numerical simulation of cloud microphysics with less demanding cost in computation [1]. The SDM is implemented on the Cloud Resolving Storm Simulator (CReSS), which is a well-established cloud-resolving model developed by K.Tsuboki et al., and we call this new model the CReSS-SDM.

In 2010 FY, we have incorporated more detailed and advanced microphysical processes into the CReSS-SDM. For checking the reliability of the CReSS-SDM, we have simulated a field of shallow convective maritime clouds using the so-called

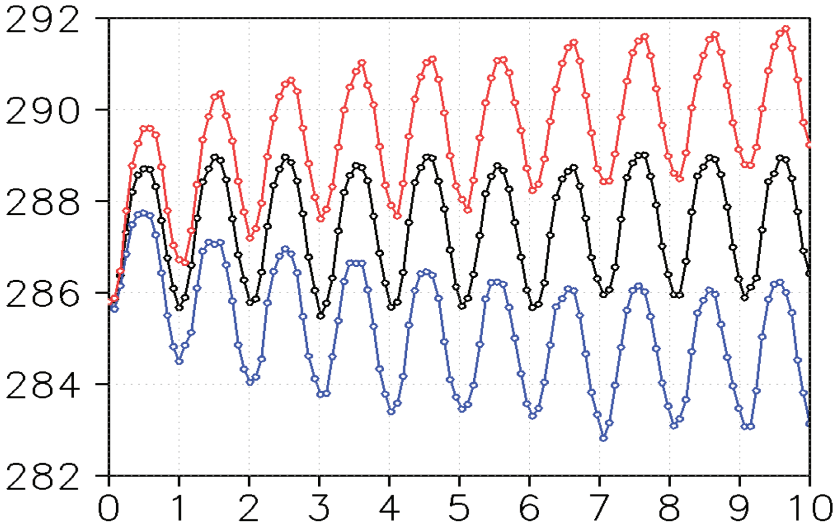

Fig. 1 Time series of global mean T2 (two meter air temperature) where control run is black curve, half run blue curve, and double run red curve. The unit of X-axis is year, and that of Y-axis K, respectively.

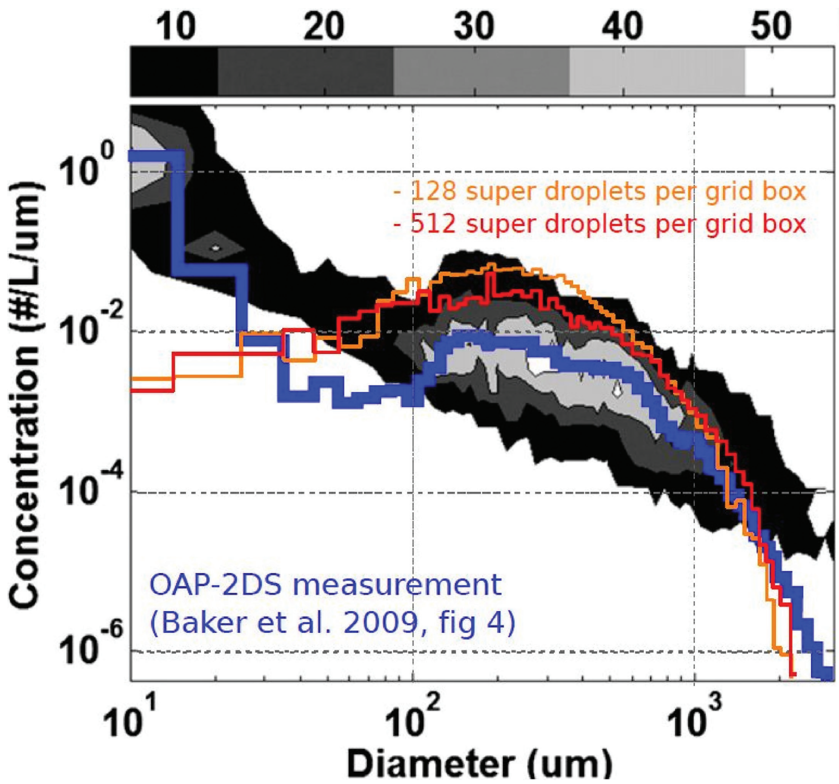

Fig. 2 Comparison of the CReSS-SDM output with the OAP-2DS instrument which measures sizes of drizzle and rain drops. The spectra in the 30 um - 3 mm range seem almost quantitatively comparable.

RICO set-up [2]. Model results are compared with simulations employing bulk treatment of cloud microphysics as well as with aircraft observations of cloud-droplet size spectrum during the RICO experiment [3]. As a result, we found a good agreement of the CReSS-SDM and the actual measurement (Fig.2).

Concurrently, to further accelerate the computation, we are constructing a general mathematical framework for a certain type of the Micro-Macro Interlocked Simulation, which is based on the mathematical idea that a Macro variable could be a set of coordinates on a certain invariant manifold embedded in the phase space of the Micro model. The possibility to apply this framework to the cloud simulation is also under investigation.

4. Super-diffusive Transport of Energetic Ions Associated with a Coronal-mass-ejection-driven Interplanetary Shock

We have performed collisionless shock simulations using a one-dimensional hybrid particle-in-cell method to investigate the energy spectra of the differential intensity around the quasi-parallel shocks [4]. This work is necessary to estimate the precipitating flux of energetic particles on Earth's surface. The system size is sufficiently large (200,000 ion inertia length) in order to eliminate the unphysical effect caused by the upstream boundary. The obtained spectra of the differential intensity have the shape of the power-law with exponentially falling off in higher energy as predicted in previous simulations, however, the power-law indices and e-folding energy do not depend on the shock parameters, the shock Mach number (7.1-11.7) and the shock angle (10-40 degree). The power-law index is 0.9~1.1. This number is close to the prediction by the standard diffusive shock acceleration theory but is a little harder than the predicted value (1.0). The e-folding energy linearly increases in time for all runs. Figure 3 schematically summarizes the time evolution of the energy spectrum observed in the quasi-parallel shock region. Moreover an additional acceleration process is also observed in the present runs and this additional acceleration process suggests that the index is modified from 1.0. One of the reasons for these independent profiles on shock parameters is that the pitch angle distribution in the upstream region shows similar profiles in each run.

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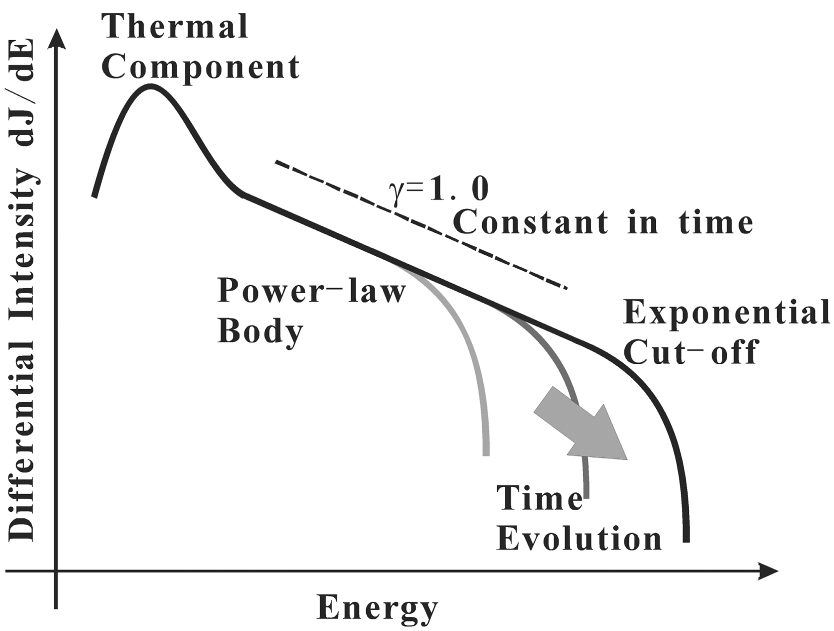

Fig. 3 The schematic illustration of the energy spectrum observed around the quasi-parallel shock. The spectrum consists of three components, thermal component in lower energy, power-law body with the index of 1.5, and exponential falling in higher energy.

宇宙・地球表層・地球内部の相関モデリング

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地球環境システムは内部（地殻、マントル、コア)、表層（大気海洋）および外部（宇宙）が互いに影響を及ぼしながら変動進化する相関システムである。本プロジェクトは地球環境の大規模変動と宇宙及び地球内部ダイナミクスの関係を探るために、先進的な相関モデルを開発する目的で 2009 年度より開始された。本プロジェクトでは、特に宇宙線と雲の関係に注目しその物理的関係を定量的に解明するため、ミクロスケールからマクロスケールに至る様々な物理過程を可能な限り第 1 原理に基づいてモデル化すると共に、それらのモデルを総合した包括的な宇宙地球システムモデルを構築することを目指している。2010 年度は、エアロゾルの核形成に関する分子シミュレーション、超水滴法を利用した積雲成長シミュレーション、プラズマ中の高エネルギー粒子加速過程のシミュレーションについてそれぞれ発展させた、さらに、大気海洋結合全球循環モデルを用いて銀河宇宙線の影響によって生成されると考えられている雲凝結核の変化による気候変動に関するシミュレーション研究を新たに開始した。

キーワード : 宇宙天気, 宇宙気候, マルチスケール, マルチフィジックス, プラズマ, 雲, オーロラ, 核形成, エアロゾル, 粒子加速, 地球シミュレータ