Space and Earth System Modeling

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The Earth is not isolated from space and astronomical dynamics, which play a crucial role for the variability of terrestrial environment in different time-scale. However, it is not well understood yet how the evolution of terrestrial environment is related to the outside of the Earth. The objective of the Earth Simulator Project "Space and Earth System Modeling" is to advance our understanding for the variability of terrestrial environment caused by the dynamics in space. In FY 2011, we have continued the development of the several simulation models for sun-earth connection systems for cloud and global circulation in earth's atmosphere as well as solar flares, respectively.

Keywords: space weather, space climate, multi-scale, multi-physics, plasma, cloud, aerosols, solar flares, 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.

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. In FY 2011, we have continued the development of the several numerical models which will compose a space climate system simulation. They are the cloud simulation in terms of super-droplet method, the global circulation model for the study on the galactic cosmic ray and climate relation, and the magnetohydrodynamics simulation for solar flares. In the following sections, we will explain about the detail of the each particular model.

2. Simulation study on the bistability of the cloud-rain system

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 Tsuboki et al., and we call this new model the CReSS-SDM.

In 2011 FY, we started to challenge the bistability hypothesis of clouds, originally proposed by Baker and Charlson [2]. They suggested that clean/precipitating and dirty/non-precipitating atmosphere could be both stable under a certain atmospheric condition. This phenomenon is considered to occur as a result of the interaction between cloud/rain particles and aerosols, hence the CReSS-SDM is a suitable tool for addressing this open problem.

For the first step, we added three more microphysical processes into the CReSS-SDM: the Brownian coagulation of aerosols, the Brownian scavenging of aerosols by rain droplets, and the nucleation of aerosols. All of these processes play important roles in the bistability scenario.

Next, we performed a series of simulations to see how the aerosol nucleation rate affects the equilibrium state of precipitating trade-wind cumuli system. The simulations are carried out using a set-up based on the RICO composite case defined in Ref. [3] and corresponding to atmospheric state

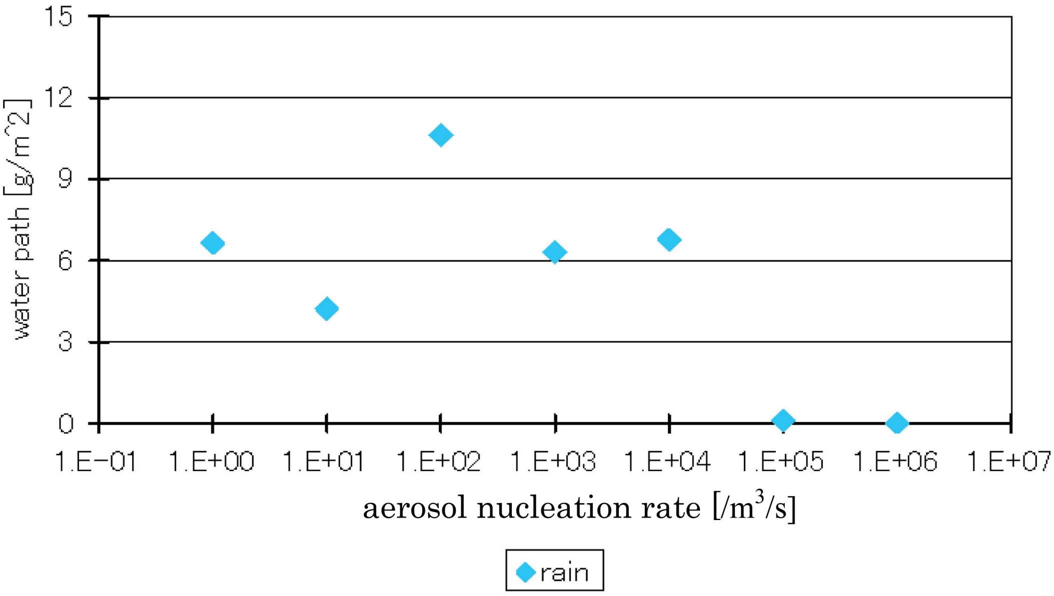

Fig. 1 Average rain water path for various aerosol nucleation rates. Rain droplets suddenly disappear when the nucleation rate is larger than 10^5 /m^3/s. This could be a glimpse of the bistability of the cloud-rain system.

measured and modeled in context of the Rain in Cumulus over Ocean (RICO) field project [4]. We compared the equilibrium states of the system for various aerosol nucleation rates. In Fig. 1 we can see rain water path suddenly goes to zero when the nucleation rate is larger than 10^5 /m^3/s. Although further careful investigations are necessary, this result may suggests the bistability of cloud-rain system.

3. Influence of cloud droplet size to climate

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 (GCM), called CFES (Coupled model For the Earth Simulator). The last year, we conducted a set of 10-year simulations with different cloud droplet sizes. This year,

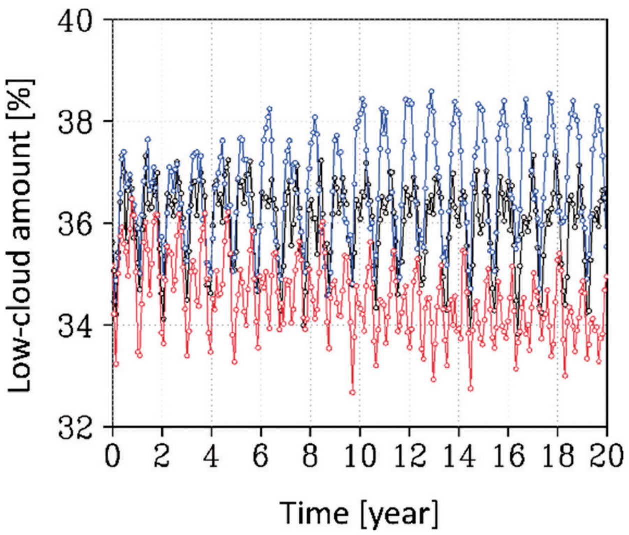

Fig. 2 Time series of monthly-global mean surface air temperatures. Black curve is for the control run, blue the half run, and red the double run.

we continued the simulations for 10 more years in order to get more reliable statistics. First, CFES was spun up for 100 years with a default size of cloud droplets. The control run afterward was run for 20 years further without changing the diameter of cloud droplets (control run). Two sensitivity experiments were performed for 20 years by suddenly making the diameter of cloud droplets half (half run) and double (double run). The global mean surface air temperature decreased 3.7 K in the half run and increased 3.7 K in the double run within 20 simulation years. The cross section of a cloud droplet increases with r^2, where r is the droplet radius, while the number density of cloud droplets decreases with r^{-3}. This explains the colder (warmer) climate for the half (double) run.

There are some feedback processes in the climate system. Figure 2 shows the time series of global and monthly mean low cloud amount. The low cloud amount increases in the half run while it decreases in the double run. The low clouds are known to cool the earth's surface temperatures [5]. While the mechanism is not clear, yet, the changes in low cloud amount is a positive feedback and enhances cooling and warming induced by the droplet size change.

4. Predicting the onset of solar flares

Solar flares and coronal mass ejections are the most catastrophic events in our solar system, and they sometimes impact the terrestrial environment and our infrastructure. Although these solar eruptions are widely believed to be driven by magnetic energy stored in the solar corona, what triggers their onset remains poorly understood. Hypotheses for the trigger mechanism include the emerging flux model, which proposed that the small magnetic flux emerging onto the solar surface may lead to the solar eruptions. However, what kind of the emerging flux is capable to trigger the eruptions is unclear. This severely limits our capacity to predict the occurrence of solar eruptions and forecast space weather. In this study, we systematically survey the nonlinear dynamics caused by emerging fluxes in terms of three-dimensional (3D) magnetohydrodynamics (MHD) simulations, and find that there are two different types of small magnetic structures triggering the solar eruptions.

The first type of magnetic structure causing flares is called the opposite polarity type, in which the small magnetic bi-pole opposite to the major magnetic polarity in an active region drives the solar eruption as shown in Fig. 3 A-C. The second type is called the reversed shear type, in which the cancellation of magnetic shear on the polarity inversion line may cause the onset of eruption (see Fig. 3 D-F). We have compared the simulation results and the data of Hinode solar observation satellite, and found that major flare events can be classified into these two types. These results suggest that solar flares are predictable if we can measure the detail structure of small magnetic field triggering solar eruption [6].

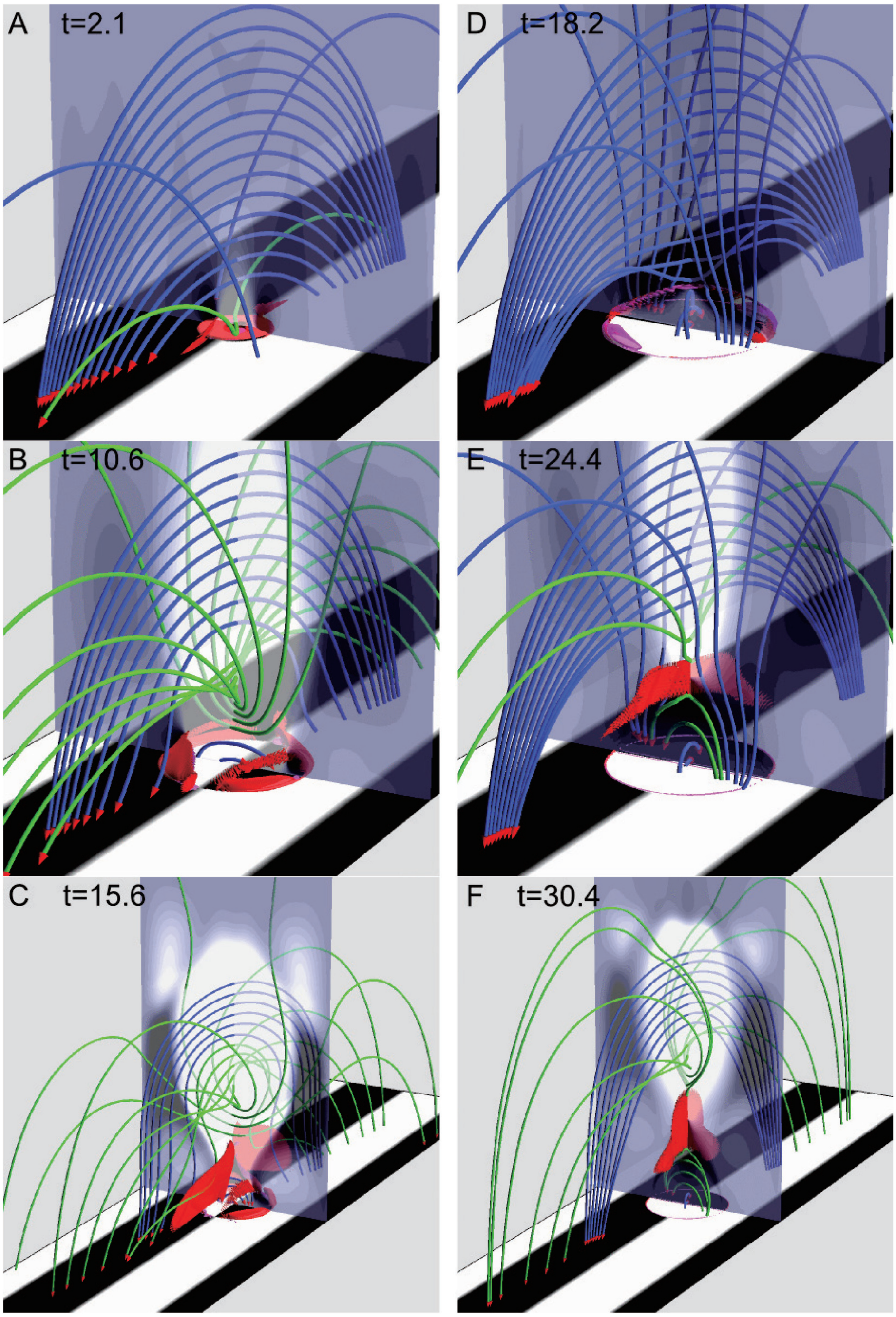

Fig. 3 Typical results of solar flare simulations for the two different scenarios: The left column [panels A–C] and the right column [panels D–F] are for the opposite polarity type and the reversed shear type scenarios, respectively.

References

[1] S. Shima, K. Kusano, A. Kawano, T. Sugiyama, and S. Kawahara, The super-droplet method for the numerical simulation of clouds and precipitation: a particle-based and probabilistic microphysics model coupled with a non-hydrostatic model, Quarterly Journal of the Royal Meteorological Society, Vol. 135, 642, pp.1307–1320, 2009.

[2] M. B. Baker and R. J. Charlson, Bistability of CCN concentrations and thermodynamics in the cloud-topped boundary layer, Nature, Vol. 345, 142-145, 1990.

[3] M. van Zanten et al., Controls on precipitation and cloudiness in simulations of trade-wind cumulus as observed during RICO, J. Adv. Model. Earth Sys., http://cavern.atmos.colostate.edu/~rames/ojs224/index.php/JAMES/article/view/56/118, 2010.

[4] R. Rauber et al., Rain in Shallow Cumulus Over the Ocean - The RICO Campaign, Bull. Amer. Meteor. Soc., Vol. 88, pp. 1912-1928, 2007.

[5] S. Manabe and F. R. Strickler, Thermal equilibrium of the atmosphere with a convection adjustment, J. Atmos. Sci., Vol. 21, pp. 361-385, 1964.

[6] K. Kusano, Y. Bamba, et al., Magnetic field structures triggering solar flares and coronal mass ejections, submitted to The Astrophys. J., 2012.

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太陽及び宇宙空間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及び太陽活動と地球環境の関係に注目し、それらの理解と予測を目指したシミュレーション研究を実施している。2011 年度はその結果、以下の３つの成果を得た。①超水滴法を利用した積雲成長シミュレーションにより雲降水システムが雲核生成率に対して双安定状態を持つことを示唆する結果を得た。②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を実施し、雲核数の変化による平均粒径の変化が地球表面温度に大きな影響を与えることを見出した。③地球環境に大きな影響を与える巨大太陽フレアの発生が２つのタイプに分類できることを見出すと共に、フレア発生の予測可能性を示した。

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 , エアロゾル , 太陽フレア ,
地球シミュレータ