Space and Earth System Modeling

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Solar activities may seriously impact terrestrial environment as well as our infrastructure in different manners. However, our predictability of solar activities and the influence upon the earth is substantially hindered, because the evolution mechanism of solar activities and the causal relationship between the solar variation and the climate change are not yet well understood. 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 including the sun. In FY 2014, we have continued the development of the several simulation models for space weather and space climate, respectively, for the prediction of solar eruption as well as for understanding the influence of cloud microphysics onto the variability of weather and climate.

Keywords: space weather, space climate, multi-scale, multi-physics, plasma, cloud, aerosols, solar flares, solar eruptions, snowball earth, Earth Simulator

1. Introduction

The solar activities influence the terrestrial environment and the social system. However, the mechanism whereby the solar activity may affect the climate is not well understood yet. Although giant solar eruptive events such as solar flares and coronal mass ejections (CMEs) may seriously impact the infrastructure of satellite, power grids, and communication facilities, our capability to predict the onset of solar eruption is limited. Therefore, the improvement in the predictability of solar activities and our understanding of the sun and earth connection is crucially important not only from scientific point of view but also from the social and economic aspects.

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 including the solar activities. In FY 2014, we have continued the development of cloud simulation in terms of super-droplet method, and the magnetohydrodynamics (MHD) simulation for solar eruptive events. In the following sections, we will explain about the detail of the each particular model.

2. Bifurcation analysis of the stratus-to-cumulus transition of maritime shallow clouds

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 demand on computation [1]. The SDM is implemented on the Cloud Resolving Storm Simulator (CReSS), which is a widely used cloud-resolving model developed by Tsuboki et al. [2], and we call this new model the CReSS-SDM.

In 2014 FY, we continued our study on the stratus-to-cumulus transition of marine stratocumulus using the CReSS-SDM. The simulations are carried out on an idealized meteorological system in which aerosols are formed continuously, which is constructed by modifying the set-up based on the RICO composite case [3]. In this time we applied the actually measured value of the sea surface temperature, instead of 5K higher one which we adopted in the previous study to accelerate the transition. We confirmed that the stratus-to-cumulus transition induced by the aerosol nucleation rate also occurs for this more realistic atmospheric condition. We also investigated the time evolution of the aerosol size distribution to its final steady state (Fig. 1). Through a comparison with the actually observed aerosol size distribution during the RICO campaign, we estimated the formation rate of 30nm size aerosols as ca. $10^{-3}/cm^3/s$. It is found that Hoppel gap disappeared from the simulated aerosol size distribution, which suggests the importance of aqueous phase chemistry for understanding the aerosol-cloud interaction.

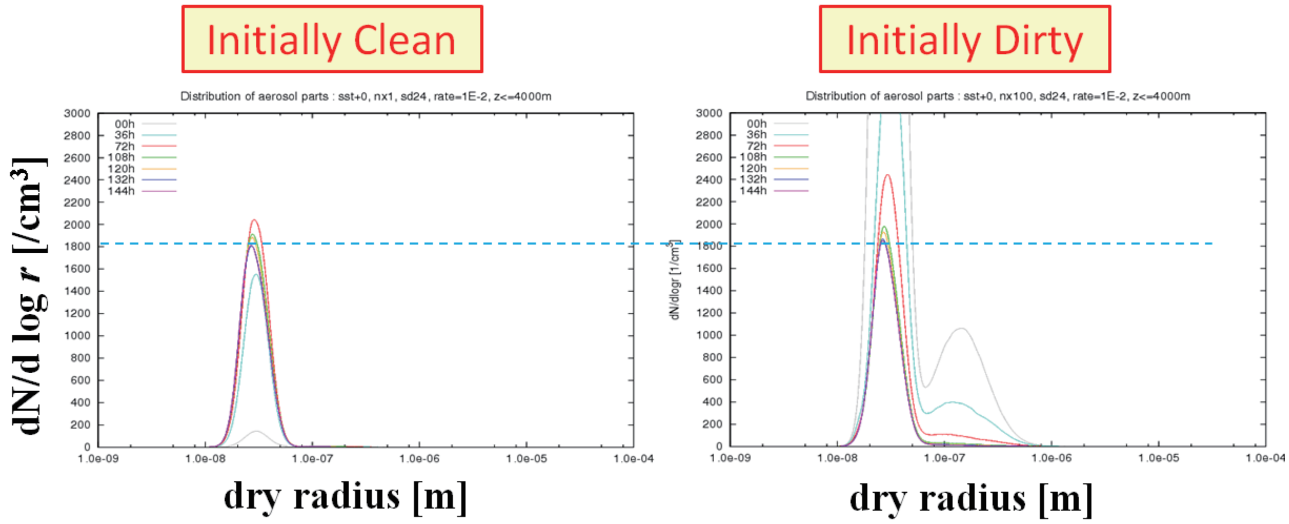

Fig. 1 The time evolution of the aerosol size distribution for initially clean air and dirty air. Convergence to the same size distribution is observed, but the Hoppel gap has disappeared.

3. Simulation study of solar eruptions

Solar flares and coronal mass ejections are the biggest eruptions in our solar system, and these solar eruptions sometimes impact the terrestrial environment and our infrastructure. Although the 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 magnetic field is capable to trigger the eruptions is unclear. This severely limits our capacity to predict the occurrence of solar eruptions and forecast space weather.

Recently, we proposed that there are two types of magnetic field structures which favor the triggering of solar eruptions [4]. The first type is called the opposite polarity field, in which the small magnetic bi-pole opposite to the major magnetic polarity in an active region drives the solar eruption. 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. We have compared the simulation results and the data of Hinode solar observation satellite, and revealed that the major flares observed by Hinode occurred in the region where these two types of small magnetic field indeed existed.

In FY 2014, we extended the simulation study to more realistic configuration of magnetic field. Magnetic field in solar active regions is complicated so that the magnetic disturbance which might cause the onset of eruptions is distributed. Although our previous study indicated that the two types of magnetic disturbance on the magnetic neutral line favor the triggering of eruption, the capability of magnetic disturbance off-neutral line is not yet investigated. Here, we analyzed the nonlinear magnetohydro-dynamics of force-free magnetic field, in which the small bipolar field displaced the distance d from the magnetic neutral line.

Through the survey of parameter d, we find that the capability of triggering solar eruptions is different between the opposite polarity and reversed shear fields. While the reversed shear field can trigger the solar eruptions even though it deviates from the magnetic neutral line, the opposite polarity field cannot cause the solar eruption if it gets off the magnetic neutral line (Fig. 2). It suggests that the reversed shear field may more efficiently trigger the solar eruption compared with the opposite polarity. The results are consistent with the recent analyses of observations [5], in which the number of solar flares triggered by the reversed shear field is more than that of flares triggered by the opposite polarity field.

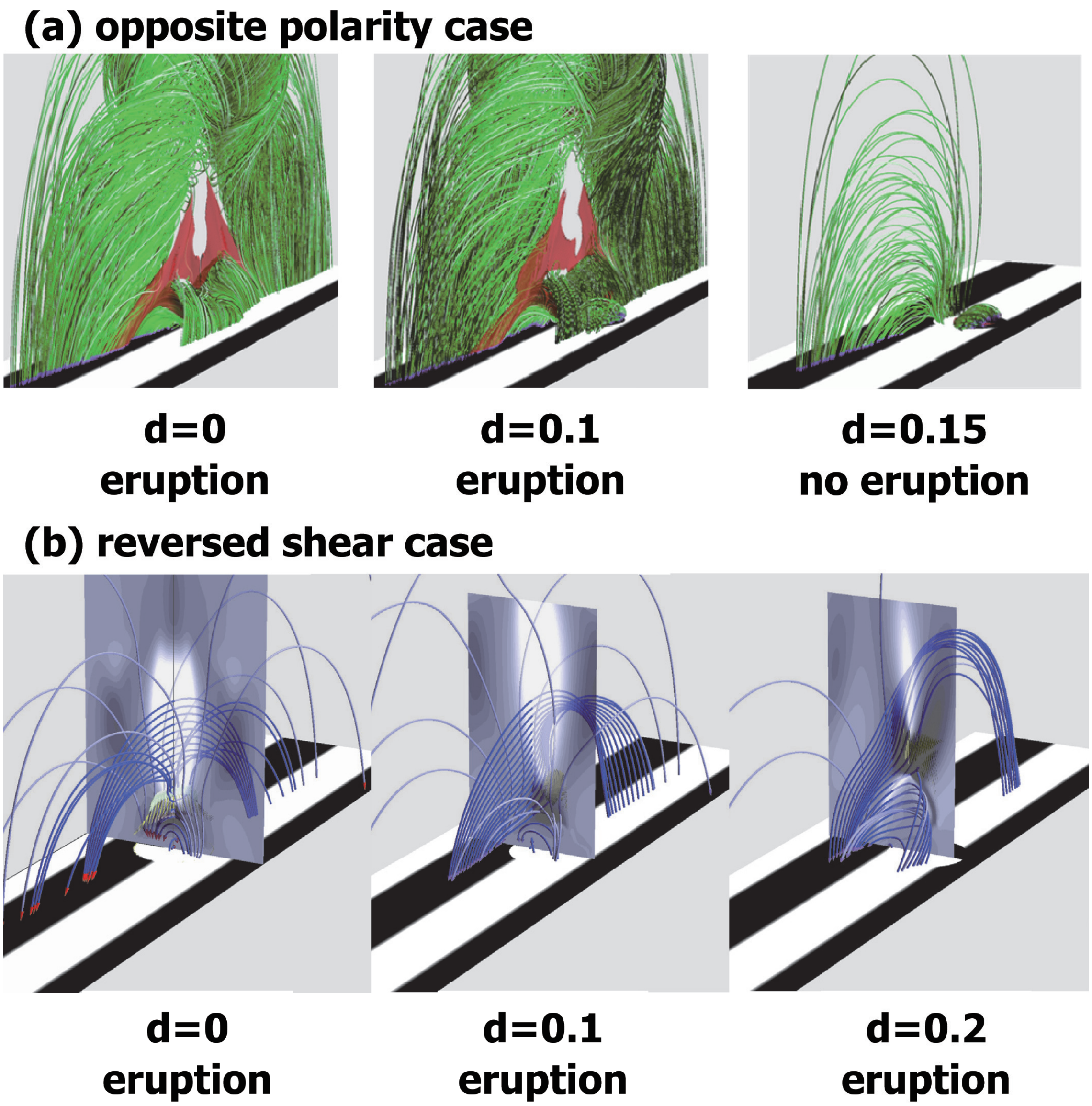

Fig. 2 The simulation results of solar eruption for the cases that (a) opposite polarity field and (b) reversed shear field are imposed on the location displaced d from the magnetic neutral line. Magnetic field lines and vertical velocity are plotted. The black and white patterns on the bottom surface indicate the distribution of vertical magnetic field on solar surface.

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宇宙・地球表層・地球内部の相関モデリング

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本プロジェクトでは、太陽活動と地球環境の関係に注目し、太陽面爆発と宇宙線変動の影響を中心にそのメカニズム解明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。2014 年度は主に２つの研究を進めた。第 1 に、超水滴法を利用した積雲層雲遷移の双安定性に関する研究においては、超水滴法を利用した雲分解モデル CReSS-SDM を用いて、RICO プロジェクトの設定に基づいて熱帯積雲の分岐構造に関するシミュレーション研究を進展させた。特に、雲核生成率に対する雲の長期安定性を解析した結果、積雲層雲遷移に関する双安定状態が存在することを示唆する結果を得た。第 2 に、地球環境と社会基盤に大きな影響を与える巨大な太陽面爆発のトリガ機構に関する 3 次元電磁流体シミュレーション研究を実施した。これまでの我々の研究ではフレア爆発が自由エネルギーの蓄積した磁場中に 2 種類の擾乱磁場が現れることで発生することを見出している。本研究ではこの擾乱磁場の位置と爆発発生の関係をシミュレーションによって調べることで、擾乱磁場が爆発の原因となれる磁気中性線からの臨界距離が磁場構造の違いによって大きく異なることを見出した。これは爆発の予知において磁場構造の分類が重要であることを意味するものであることから、宇宙天気予報にも貢献できる成果として注目されている。

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 ,
太陽面爆発 , 全球凍結 , 地球シミュレータ