

Numerical Investigation of Effect of Energy Injection to Cloud and Rainfall

Project Representative

Masahiro Mori Japan Aerospace Exploration Agency

Authors

Takashi Furusawa Dept of Computer and Mathematical Sciences, Tohoku University

Yuka Saito CSP Japan

Masahiro Mori Japan Aerospace Exploration Agency

Masayuki Niino Foundation for Promotion of Japanese Aerospace Technology

Yoshio Hatsuda Foundation for Promotion of Japanese Aerospace Technology

Kunihiko Watanabe The Earth Simulator Center, Japan Agency for Marine-Earth Science and Technology

Satoru Yamamoto Dept of Computer and Mathematical Sciences, Tohoku University

Hiroyuki Nagayama Mitsubishi Research Institute

The effect of the energy injection from Space Solar Power Systems (SSPS) to atmosphere is numerically investigated using the Multi-Scale Simulator for Geoenvironment (MSSG) developed by The Earth Simulator Center (ESC). The energy injected from SSPS is taken as a heat source adding to the atmosphere. The computational algorithm of the heat addition is developed and added to MSSG code. A typhoon generated in 2004 is reproduced by MSSG in ES as the test case for evaluating the effect of the heat addition. In this report, first, the feature of the typhoon is numerically demonstrated by showing time-dependent physical values organizing the typhoon such as pressure, velocities, vapor density and water density. Next, the simulations with the heat addition are conducted and the simulation results are compared with no heat addition case. Finally the current status of the present work is remarked and the next works we plan are also noticed.

Keywords: Space Solar Power Systems (SSPS), laser, energy injection, cloud, rainfall, typhoon

1. Introduction

Energy resources such as oil and natural gas may not always be sustained within 21st century, because the current consumption of them is extraordinarily being increased and causing emission of carbon dioxide (CO₂). One of sustainable method to keep the energy supply and solve the environmental problems is the use of the solar power.

Japan Aerospace Exploration Agency (JAXA) has been conducting studies on Space Solar Power Systems (SSPS) in which the solar energy obtained in space is transmitted to the ground via microwave or laser beam. The transmitted energy is converted to clean fuels such as electricity or hydrogen in ground facilities. The exhaust of CO₂ in this system is much less than that of other systems. Also a stable supply of energy may be accomplished.

JAXA is proposing the roadmap that consists of stepwise approach to utilize commercial IGW class microwave based SSPS (M-SSPS) and laser based SSPS (L-SSPS) around 2030^{[1][2]}.

In L-SSPS, 1.06 μm wavelength Neodymium-doped

Yttrium Aluminum Garnet (Nd:YAG) laser is employed, and this laser has a good transmitting efficiency through atmosphere. The efficiency through a clear sky is expected as up to 98%^[3]. However, the efficiency has not been evaluated for actual weather.

The purpose of this study is to evaluate the effect of energy injection to the cloud and rainfall using the Multi-Scale Simulator for Geoenvironment (MSSG) developed by The Earth Simulator Center (ESC). The basic concept of this study is that the laser or the microwave from SSPS injected to atmosphere is taken as a heat source. The computational algorithm of the heat source is added to MSSG code.

As numerical examples, a typhoon generated in 2004 is reproduced by MSSG in ES. First, the calculated results are shown in detail. The time-dependent physical values organizing the typhoon such as pressure, velocities, vapor density and water density are visualized. From these values, the mechanism of the typhoon is investigated especially from the viewpoint of the onset of condensation (cloud) and the growth to water liquid.

Next, the computations with the heat addition are conducted and the calculated results with and without the heat addition are compared with each other.

Finally the current status of the present work is remarked and the next works we plan are also noticed.

2. Numerical Method

The effect of laser on the cloud should be locally evaluated from the point of the energy absorption. Also the effect of the heat release to the cloud and rain should be evaluated in the wider region surrounding them. Therefore, high resolutions of the computational grid and the numerical method are required. Recently, ESC developed a computational code for global atmosphere and ocean physics named MSSG[4]. MSSG may resolve our issue how the energy injection influences the atmosphere. MSSG is based on a coupled non-hydrostatic atmosphere-ocean-land global circulation model. This simulation code is optimized on ES for the high performance by the parallel computation. In this study, a mathematical model for the heat induced by the laser that we call the Energy Injection (EI) model, is newly developed and EI model is added to MSSG. The current EI model employs a very simple algorithm based on the forced change of temperature locally and a homogeneous absorption in atmosphere.

3. Numerical results

3-1 Visualization of Typhoon

It is known that laser lights are attenuated strongly by water drops in the atmosphere such as cumulonimbus, fog, and rain. The understanding of the mechanism how water drops are generated in atmosphere is quite valuable to conduct the present study.

As the first step of the present work, a typical typhoon actually generated in 2004, that is Typhoon No.23 named TOKAGE, is reproduced by MSSG in ES. As the initial values of the computation, the actual data observed at 0:00 on Oct.13, 2004 by the meteorological satellite is employed. The center of computational domain is fixed at 140 degree of east longitude and 15 degree of north latitude and 3600 km wide in longitude and 2400km wide in latitude. The computational grid has 1440 × 960 × 32 grid points. The grid size is corresponding to 2.5 km in actual length. 10 nodes of ES (80CPU) are used for the present computation. The calculated physical values which may dominate the typhoon physics are visualized at three different physical times.

Figures 1, 2 and 3 show the values of the sea level pressure and horizontal velocity in Fig. (a), the vertical velocity distributions in Fig. (b), the density of water vapor in

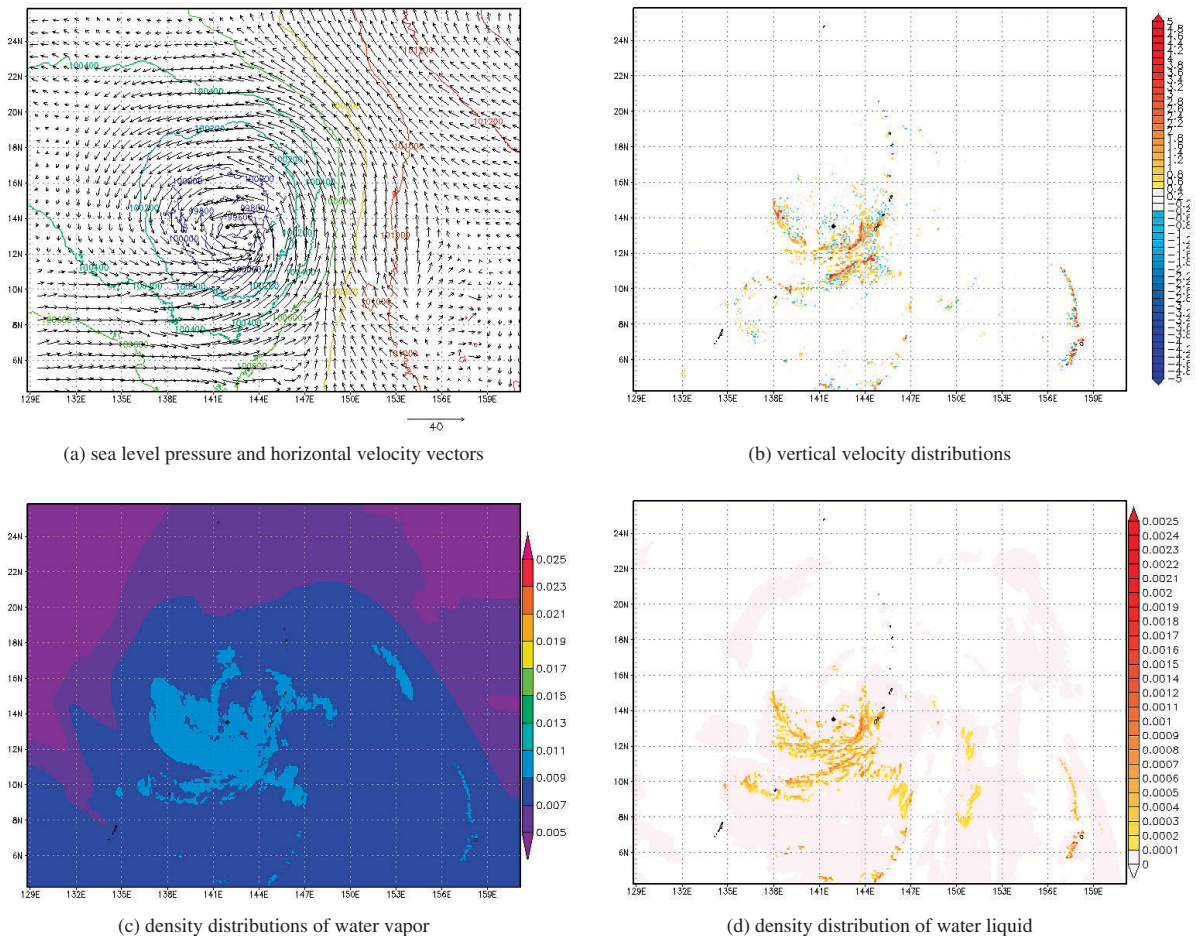


Fig. 1 Visualized physical values at 12 hours.

Fig. (c), and the density of water liquid in Fig. (d), at 12, 24, and 36 hours after the initial time, respectively. The altitude is at 3000 m.

In both Figs. 1(a) and 2(a), a lower pressure region and an anti-clockwise vortex is organized. The lowest pressure point, the so called typhoon's eye, moves to the west. In Figs. 1(c) and 2(c), the concentration of the water vapor increases gradually as decreasing the pressure. In Figs. 1(b) and 2(b), the region with positive values and that with negative values of vertical velocity are self-organized. The positive region is mainly located in the region with the higher density of water vapor. Especially as shown in Figs. 1(d) and 2(d), the points with water liquid are coincide with the points where a higher positive value of vertical velocity is observed. Since the upward wind brings water vapor to the higher altitude with lower temperature, the water vapor is saturated and condensed to water liquid.

Compared with Figs. 1 and 2, the distributions of physical values in Fig. 3 may be distinguished from those in Figs. 1 and 2. The typhoon is obviously self-organized at 36 hours after the initial time. The center of the typhoon is clearly observed and streak-shaped regions where water liquid is observed are organized toward the outer direction from the center of the typhoon.

3-2 Simulation of energy injection

The laser beam produced in L-SSPS works at a low ener-

gy level which is evaluated from the environmental and safety aspect. Also the area of the energy receiving at the ground is limited within several hundreds meter square. But in this preliminary simulation, the actual expected energy level and the receiving area are not considered. We only focus on how EI model works in MSSG. A higher energy injection is assumed to clarify the effect of the energy injection to the typhoon. In this report, typical two cases of the energy injection are explained. Typhoon No.23 is computed again with the energy injection.

Figure 4 shows the schematics of the region where the energy is injected. In CASE 1, a 5 km × 5 km region for the energy receiving is located at 25 km south from the center of typhoon. This region moves according to the movement of the center. In CASE 2, the region is three times spread to the south. The heat addition at the regions is approximated as the forced temperature increase in the computation, where 1K in temperature is forced to increase at the region in each one hour. The heat addition is started from the same initial time and is continuously added for 24 hours.

Figures 5(a), (b) and (c) show the calculated pressure contours focused on the close region to the center of typhoon in the no energy injection case, CASE 1, and CASE 2. In this period from the initial time to 24 hours, the center of typhoon is not always self-organized sufficiently as shown in Figs. 1 and 2. A couple of lower pressure points are found at the center of typhoon in all three cases. The pressure dis-

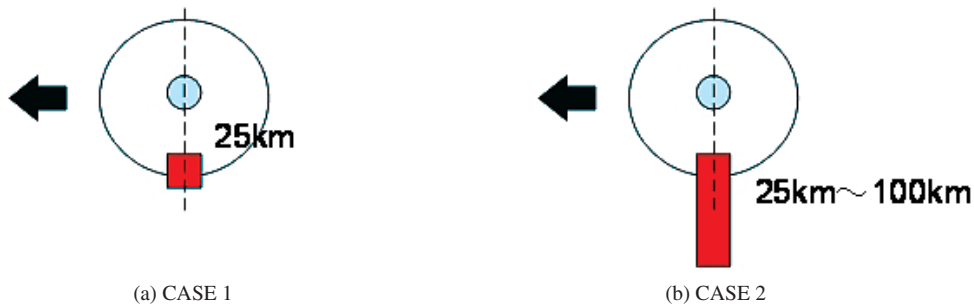


Fig. 4 location of energy injection.

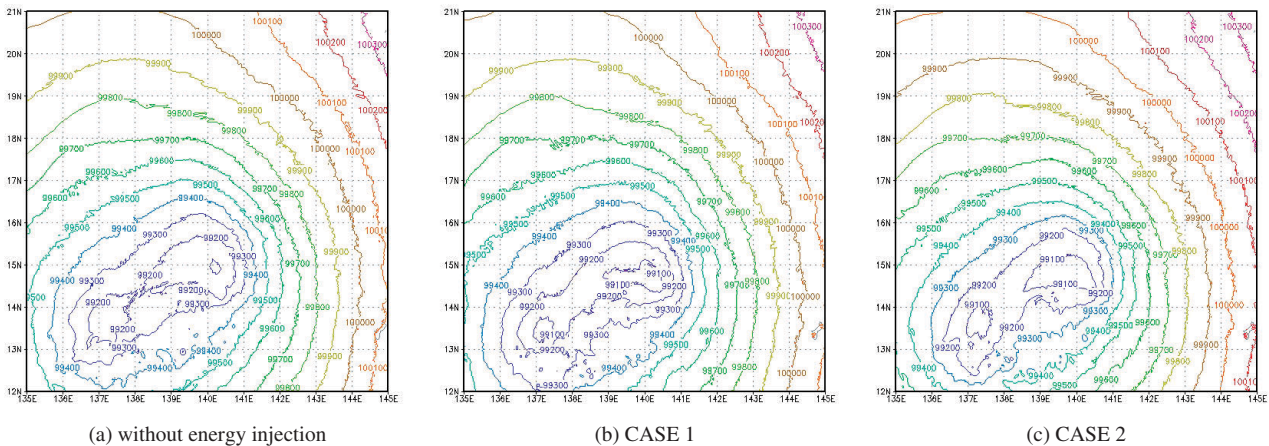


Fig. 5 Sea level pressure at 24 hours after the initial time.

tributions in CASE 1 and CASE 2 are not always distinguished from those in the case without the energy injection. However, the location at the lowest pressure point and the value are slightly changed due to the energy injection, even though the effect may be sufficiently trivial.

4. Conclusions and comments

The effect of the energy injection from Space Solar Power Systems(SSPS) to atmosphere involving cloud and rainfall was numerically investigated using MSSG coupled with EI model. Typhoon No.23 in 2004 was reproduced by the present code by ES. The calculated physical values such as the sea level pressure and horizontal velocity vectors, the vertical velocity distributions, the density of water vapor, and the density of water liquid were visualized. The obtained values indicate that the self-organization of the typhoon is successfully demonstrated by MSSG. The organization may depend strongly on the condensate process of water vapor in the atmosphere. The region with water liquid coincided with the region where an upward wind is observed.

Next, the computations with the energy injection were conducted. In those results, however, the effect of the energy injection is not clarified enough. A number of other cases except for the present results have been also investigated. But, a typical condition which is effective to typhoons has not been found yet. One of the reasons must be still a lack of parametric computations. Also the grid resolution of the present computation may be not sufficient to get the local physical process such as condensation accurately. Therefore, we should continue this study to seek a proper condition which can indicate the effect clearly. The understanding the mechanism how laser and cloud are interacted with each other is also important. The scattering and absorption of laser energy should be more accurately evaluated and considered in EI model.

Due to the green house gases, the global warming on the

earth is being accelerated and people encounter extraordinary weather such as strong typhoons, local rainstorms, and hot days which have never been experienced. Another application of SSPS we expect is to a positive weather control for resolving the above certain problems in weather. We expect that the heat addition using SSPS into the condensation process of weather could control clouds and rainfalls to suppress or to generate them. This issue is a next work of the present study.

Acknowledgements

We are greatly thankful to Multiscale Simulation Research Group, Earth Simulator Center for allowing us to use MSSG code and support modifying the code.

References

- [1] M. Mori, T. Fujita, Y. Saito, "SUMMARY OF STUDIES ON SPACE SOLAR POWER SYSTEMS OF JAPAN AEROSPACE EXPLORATION AGENCY (JAXA)", 25th International Symposium on Space Technology and Science, 2006-r-1-03, 2006.
- [2] M. Niino, K. Kisara, M. Mori et.al., "Investigation and Research on the Applicability of FGM Technology for Advancement of Space Solar Power System (SSPS)", Proc. 9th Multiscale & Functionally Graded Materials, 2006.
- [3] V. Kmetec and M. Niino, "Influence of the Atmospheric Effects of the Lightwave Energy Transmission Link Performance", Proceedings of the 23rd ISTS, pp.1325–1332, 2002.
- [4] K. Takahashi, Xindong Peng, R. Ohnishi, M Ohdaira, K. Goto, H. Fuchigami and T. Sugimura, "Multi-Scale Weather/Climate Simulations with Multi-Scale Simulator for the Geoenvironment (MSSG)on the Earth Simulator", Annual Report of the Earth Simulator Center, April 2006 - March 2007, pp.31–39, 2007.

エネルギー注入による雲・降雨の数値シミュレーション

プロジェクト責任者

森 雅裕 宇宙航空研究開発機構 総合技術研究本部

著者

古澤 卓 東北大学大学院 情報科学研究科

斉藤 由佳 シー・エス・ピー・ジャパン株式会社

森 雅裕 宇宙航空研究開発機構 総合技術研究本部

新野 正之 航空宇宙技術振興財団

初田洋司雄 航空宇宙技術振興財団

渡邊 國彦 海洋研究開発機構 地球シミュレータセンター

山本 悟 東北大学大学院 情報科学研究科

長山 博幸 三菱総合研究所

今日、エネルギー問題は人々の暮らしを支える上で非常に重要であり、特に資源の少ない日本ではエネルギーの多様化が望まれている。このような問題の解決の手段として宇宙太陽光利用システム(SSPS: Space Solar Power Systems)が注目されている。SSPSは、宇宙空間で得られる太陽光エネルギーをマイクロ波やレーザーにより地上に伝送し、地上でそのエネルギーを電気や水素等の無公害燃料に変換し利用するシステムであり、二酸化炭素を最小限に抑えたクリーンで安定したエネルギーを得ることができる。宇宙航空研究開発機構(JAXA)では、2030年頃の商用システム運用開始を目標に1GW級マイクロ波方式SSPS(M-SSPS)及びレーザー方式SSPS(L-SSPS)の研究開発を実施している。この中で、レーザー方式SSPSではレーザー媒質として、大気伝送効率のよい $1.06\mu\text{m}$ の波長のレーザーを発振するNd:YAGレーザーの使用を想定し、晴天時には98%以上の伝送効率を得られると試算されているものの、実際の気象条件の考慮、さらに気象へ及ぼす影響については未だに評価されていない。そこで、本研究ではL-SSPSを想定した雲・レーザー相互作用モデルを開発し、地球シミュレータセンターによって開発されたMSSG(Multi-Scale Simulator for Geoenvironment)コードに導入し、レーザーが雲・降雨にどのような影響を与えるかを検証する。

レーザー光は大気中のエアロゾルなどによって減衰されることが知られている。特に、雲や霧などの水滴によって強く減衰されるため、これらの分布を考慮することが重要となる。まず、エネルギー注入がない場合の水蒸気量、雲水量の評価を行った。Fig. 1、Fig. 2、Fig. 3に2004年の台風23号(TOKAGE)の10月13日0:00の計算開始から12時間後、24時間後、36時間後の(a)気圧と水平方向流速ベクトル、(b)垂直方向流速、(c)水蒸気量、(d)雲水量の分布を示す。どの結果でも上昇流が水蒸気からの凝縮を促進するため、上昇流の位置と雲水量の位置がほぼ一致している。また、時間が進むにつれて台風の構造が明確となり、組織化が進んでいることが示唆される。

次に、MSSGにエネルギー注入による影響を考慮するためのエネルギー注入がある場合について検証した。ただし、レーザー光によるエネルギーは大気に均一に吸収されると仮定し、エネルギー注入の影響を明らかにするために、十分広い領域が加熱される場合の計算を行った。計算対象は同じく2004年の台風23号とした。Fig. 5に24時間後の気圧分布を示す。それぞれには明確な違いはなく、エネルギー注入による影響は確認されなかったが、最低気圧の位置については多少の違いが生じた。

本研究ではエネルギー注入による明確な影響は確認できなかったものの、明らかに計算結果に何らかの影響を与えていることを確認することができた。今後の様々な条件での計算やより詳細なモデルを導入した研究が望まれる。

さらに、得られたエネルギー注入の影響を精査することにより、最近異常気象として社会問題化している巨大な台風や集中豪雨の軽減への応用なども期待される。

キーワード:SSPS, レーザー, エネルギー注入, 雲, 降雨, 台風