Simulation of Interaction between External Energy and Clouds

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The effect of the energy injection from Space Solar Power Systems (SSPS) to atmosphere is numerically investigated using the Multi-Scale Simulator for Geoenviroment (MSSG) developed by The Earth Simulator Center (ESC). A finite amount of energy is numerically added as a heat source to the calculated energy of the typhoon in which the calculation is started from an initial condition obtained from the existing observed data. The effect of the heat source is parametrically predicted and the calculated results are compared with each other. In the current status, a huge amount of the energy may be effective to the deformation of the typhoon. This suggests that the actual energy injected from SSPS is too trivial to deform the typhoon. However, we also found that the initial value obtained from the typhoon data had a self-organized structure with a huge amount of energy even though it is an early condition for the typhoon. This suggests that we should select more early data from the observed typhoon data to predict the effect of a lower heat source to the typhoon.

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

1. Introduction

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 with the microwave or the laser beam. JAXA is proposing the roadmap that consists of stepwise approach to utilize commercial 1GW class microwave SSPS (M-SSPS) and laser 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 Geoenviroment (MSSG) developed by The Earth Simulator Center (ESC).

In last year, the effect of the energy injection from SSPS to atmosphere involving cloud and rainfall was numerically investigated using MSSG coupled with the mathematical model for the energy induced by the laser (EI model). In this algorithm, the laser or the microwave from SSPS injected to atmosphere is taken as a heat source. Typhoon No.23 in 2004 was reproduced by the present code in 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. Also the energy injection to the typhoon was numerically conducted. In those results, however, the effect of the energy injection was not clarified enough and a typical condition which is effective to typhoons has not been found yet.

In this half year, additional computations were conducted to find a condition where the heat source is effective to the typhoon.

2. Numerical Method

The effect of laser on 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. In last year, the Energy Injection (EI) model for the heat induced by the laser was added to MSSG. The earlier EI model employs a very simple algorithm based on the heat addition to the local energy directly and a homogeneous absorption in atmosphere is assumed. In this year, the EI model is modified to that considering the distributions of water liquid and vertical velocity in local region.

3. Numerical Results

Typhoon No.23 in 2004 is calculated with the energy injection. As the initial condtion, 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 3600km wide in longitude and 2400km wide in latitude. The computational grid has $1440 \times 960 \times 32$ 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 12 hours after the initial time.

Figures 1(a)-(e) show the visualized values of sea level pressure and horizontal velocity, vertical velocity, density of water vapor, density of water liquid and the cross sectional density of water liquid in vertical direction, respectively, in the case with no energy injection. The positive value of vertical velocity in Fig. 1(b) is mainly located in the region where the higher density of water liquid is observed in Fig. 1(d). This result indicates that the vertical velocity induces condensation of water vapor. The condensation starts at a low altitude and the droplets move toward upper space in vertical direction as shown in Fig. 1(e).

The actual laser beam produced in L-SSPS works at a low energy 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. It is also known that laser lights are attenuated strongly by water drops in the atmosphere such as cumulonimbus, fog, and rain.

But, the actual expected energy level and the receiving area are not considered in this study. We focus on how EI model works in MSSG at first. Then, a huge energy injection is assumed to clarify the effect of the injection to the typhoon.

The following shows the typical calculated results in which the typhoon is obviously deformed.

Figure 2 shows the schematic of the region where the energy is injected. The 100km × 300km is located at 250 km south from the center of typhoon and the energy is received according to the distribution of water liquid or vertical velocity. The energy-injected region moves according to the center location of the typhoon. The heat source is added at

(a) Sea level pressure and
horizontal velocity vectors

(b) Vertical velocity distributions

(c) Density distributions of water vapor

(d) Density distributions of water liquid

(e) Density distributions of water liquid
(vertical direction)
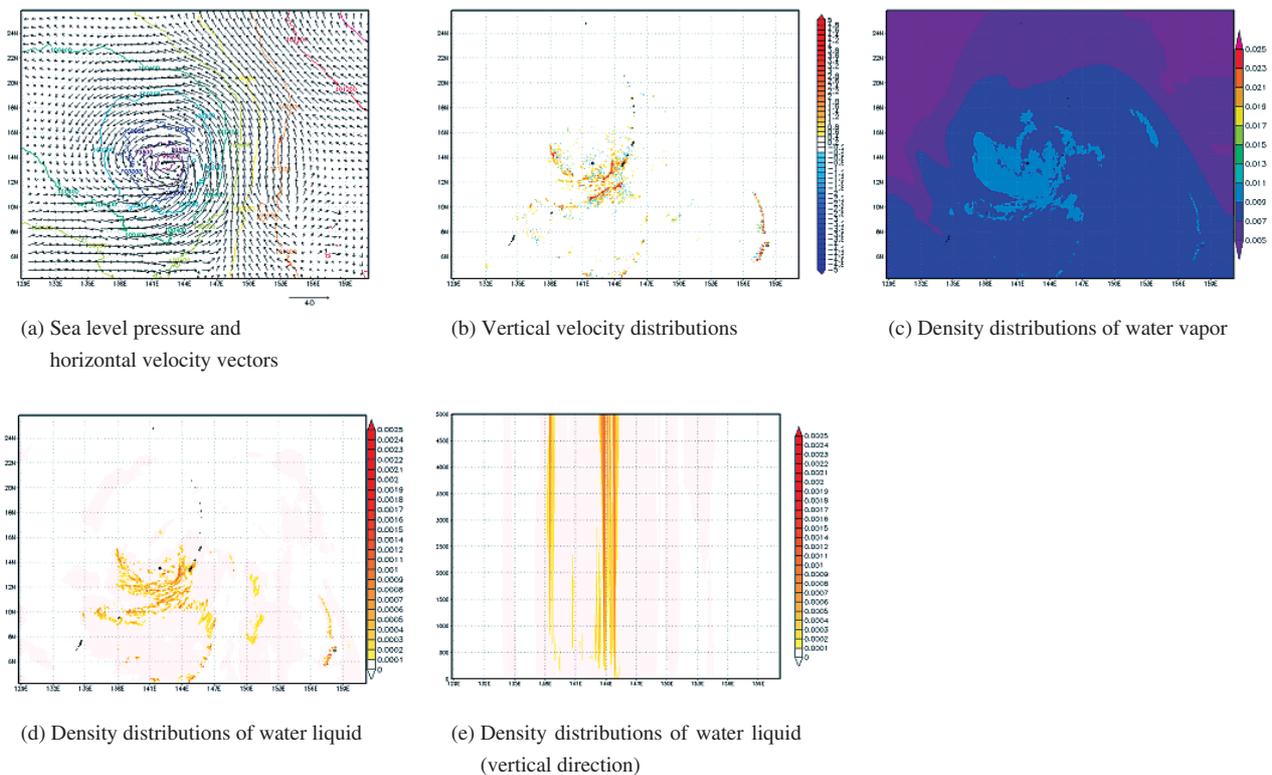
Fig. 1 Visualized physical values at 12 hours after the initial time.
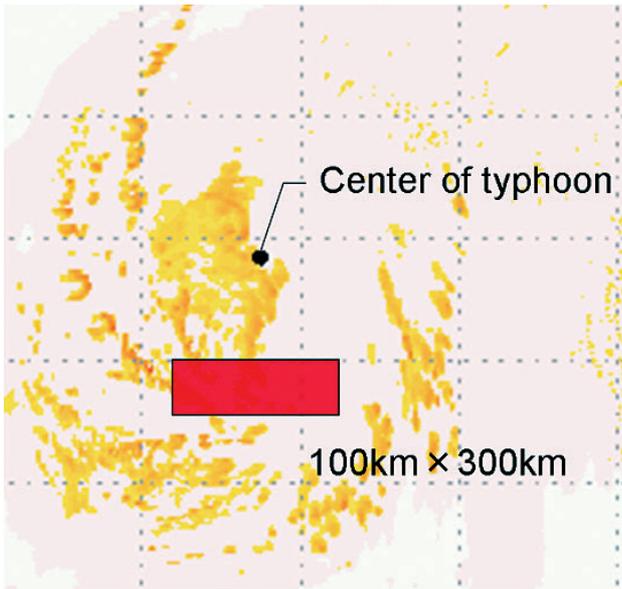
Fig. 2 Location of energy injection.

the region. 0.01K in temperature is forced to increase at the region in each time step. The heat addition is started from the same initial condition and is continuously added for 12 hours. Typical two cases obtained are reported here. In CASE 1, local discontinuous regions where the density of water liquid is more than 0.0005 kg/m^3 are heated. In CASE 2, local discontinuous regions where the vertical velocity is below 0.0 m/s are heated.

Figures 3 (a), (b) and (c) show the calculated distributions of water liquid in the case without energy injection, CASE1, and CASE 2. Figures 4 (a), (b) and (c) show the distributions of water vapor in the same cases with Fig. 3. In this time at 12 hours, the typhoon is partially but not sufficiently organized as shown in Fig. 1. We can find the different distributions of water liquid in Figs. 3 (b) and 3 (c) as compared with that in Fig. 3 (a). The typhoon is obviously deformed by the heat addition in CASE 1 and CASE 2. Especially, the deformed region is more widely spread in CASE 2. This suggests that the searching the region where the vertical velocity is negative may be meaningful for the present study. The similar trend is also found in Fig. 4.

Here, we should note that the amount of heat source added in the present calculation is not a realistic quantity. The actual energy injection from SSPS must be relatively quite smaller than that in the present calculation. It means that the actual amount of heat source assuming the energy injection from SSPS is too small to deform the typhoon in the calculation.

Today, however, one issue to be resolved for this study is additionally found. Figure 5 shows the horizontal velocity vectors in the initial condition used for the present calculation. The typhoon has been already self-organized even though it is quite at an early data provided from the observed

(a) Without energy injection   (b) CASE 1   (c) CASE 2
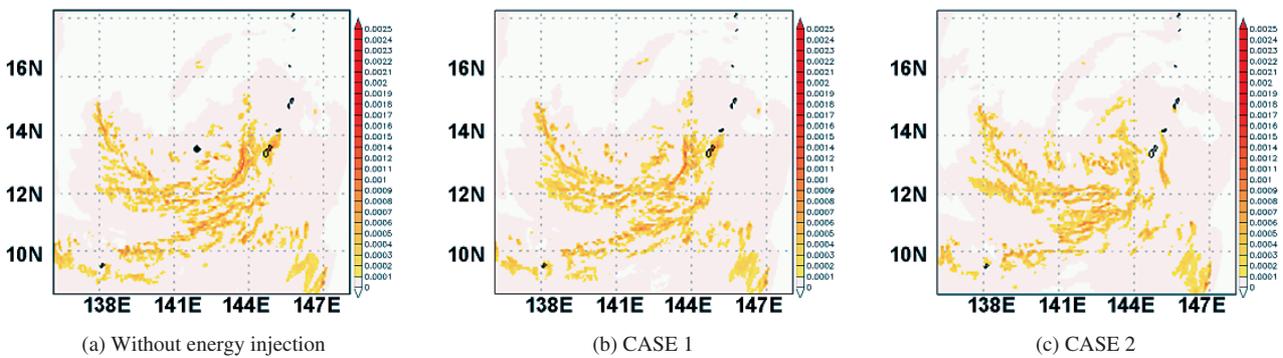
Fig. 3 Densities of water liquid at 12 hours after the initial time.

(a) Without energy injection   (b) CASE 1   (c) CASE 2
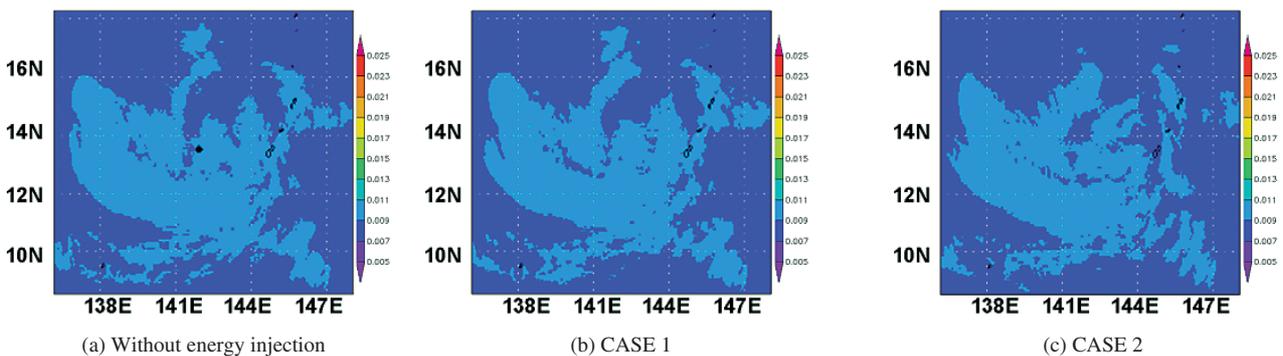
Fig. 4 Densities of water vapor at 12 hours after the initial time.
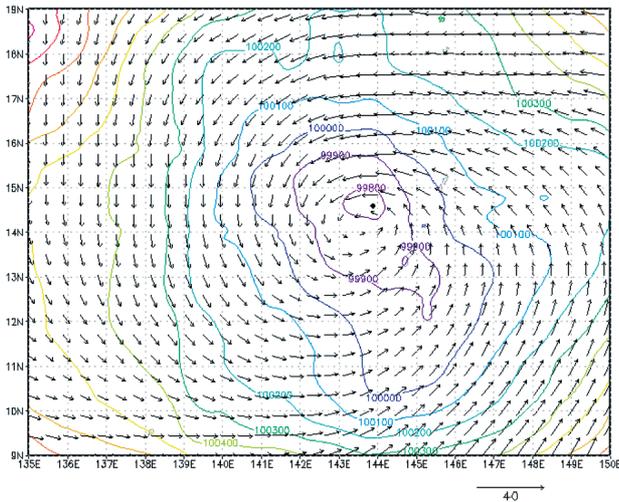
Fig. 5 Horizontal velocity at the initial time.

data. The total energy making the typhoon may be sufficiently huge as compared with that by SSPS. It suggests that we should select another initial condition from the observed data where the typhoon has not been sufficiently self-organized yet, otherwise we would not be able to predict the effect of a lower heat addition such as the actual problem.

4. Conclusions

The effect of the energy injection to atmosphere involving cloud and rainfall was numerically investigated using MSSG coupled with EI model. Typhoon No.23 in 2004 was reproduced by MSSG and two cases with a huge heat addition were calculated and compared with that without the heat addition. The heat addition in both cases was quite effective to deform the typhoon structure. The region with water liquid was widely changed. But, the important point we should note is that the energy source was assumed to be a nonrealistic huge value. The actual heat addition by SSPS was not effective to the typhoon in the present calculation because of sufficiently a small heat source against the energy of the self-organized typhoon. We will find another initial condition for the Typhoon No.23 in which the data is just before the self-organized process and additional calculations assuming a lower heat addition will be conducted by using the additional initial condition in next year.

Acknowledgements

Reference

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外部エネルギーと雲の相互作用に関するシミュレーション

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　今日、エネルギーの確保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1.06μm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％以上の伝送効率が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や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て、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 Geoenviroment) コードに導入することで、レーザーが雲・降雨にどのような影響を与えるかを検証している。

　昨年度の研究では、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たエネルギー注入モデルを構築して、MSSGで再現された赤道付近の低気圧がエネルギー注入モデルにより加熱された計算をいくつかのケースで行ったが、エネルギー注入による大気への影響は明らかにならなかった。Fig. 1 (a)−(e) はエネルギー注入がない場合に計算により得られた物理量の分布である。この計算では、雲水量の分布と垂直方向の流速の分布がほぼ一致しており、上昇流と凝縮プロセスの関係が計算により示された。そこで、本年度はこれらの分布に着目して改良したエネルギー注入モデルによる計算を行った。ところで、実際の大気中でレーザー光は大気中のエアロゾルなどにより減衰されることが知られており、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。ただし、本年度は昨年度同様にエネルギー注入モデルの効果自体を検証するため、SSPSで実際に想定されているエネルギー量よりもかなり大きなエネルギーを注入する条件で計算を行った。Fig. 3、Fig. 4は、0.0005kg/m^{3}以上の雲水量がある領域、ならびに垂直方向の流速が負（下降流）の領域が加熱された場合の計算結果である。エネルギー注入がない場合とそれぞれ比較したところ、広範囲にわたり雲水量や蒸気量の分布が変化している結果が示された。なお、今回の計算に用いた初期条件では、すでにコリオリ力による大規模な渦構造を有していることがわかった。これは、実際のSSPSのエネルギー量がこの初期条件における低気圧のエネルギー量に比べて極めて小さいことを示唆する。しかし、赤道付近の積乱雲等の発生などにおいては、より少ないエネルギー注入でも雲や降雨等に影響を与える可能性があるため、今後はさらに初期段階における気象データに基づく初期条件を設定して、より現実的なエネルギー注入量による計算を再度実施する必要があると考えられる。

キーワード：SSPS, レーザー, エネルギー注入, 雲, 降雨