Research on Global Warming Prediction by using the High-Resolution Atmosphere-Ocean Coupled Model

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As analyses for IPCC AR4 was completed in the previous year, various research projects relating to the future development of the coupled atmosphere-ocean coupled model have been conducted in this year. Several results are presented.

First, detection of extreme events in a near-term climate prediction has been investigated, because we think that the near-term prediction on the global warming becomes more and more important. It is demonstrated that a number of a hot summer day will increase. Secondly, a hindcast experiment by using a high-resolution OGCM has been conducted. This is done for confirming a performance of the ocean component model in the atmosphere-ocean coupled mode. It is shown that variability in the northern Pacific Basin is well simulated not only at sea surface temperature but also in the mid-ocean. This means that the ocean component model captures well the ocean dynamics itself. Thirdly, difference of transient responses for the global warming due to horizontal resolution is investigated. It is shown that there are little differences in a equilibrium response but there exist differences in a transient response. This is due to the difference of ice-albedo feedback and ocean heat-uptake.

Keywords: atmosphere-ocean coupled model, global warming, and 30year climate prediction

1. Introduction

A high resolution atmosphere-ocean coupled model has been developed in this project and global warming simulation results obtained by this model are presented in IPCC AR4 (the 4-th Assessment Report). Our model has the highest horizontal and vertical resolution in atmosphere-ocean coupled models, which participate in the IPCC AR4. However, there remain a lot of problems and continuous effort should be conducted to improve the model. In order to contribute the model improvement, various research activities have been conducted in this fiscal year.

2. Detection of extreme events in a near-term climate prediction

One of the critical issues about the global warming is reliability of the simulation. Although our knowledge about the climate system is recently increased very much, there are many unknown processes and parameters, which cause uncertainty in the global warming simulation. When we consider the reliability, we should pay attention to the time-scale, because physics responsible for uncertainty is different due to the time-scale. Sumi (2006) proposed to introduce two time-scales, that is, 30 year prediction and 300 year simulation. In 30 year prediction, we may investigate the global warming phenomena through a framework of an initial-value problem.

Of course there is no guarantee that we can treat it as the initial-value problem. For example, Stott and Kettleborough (2002) reported that the results are relatively independent on emission scenarios in 30 year time-scale, which is positive aspect. However, amplitude of natural variability is large and signal due to the global warming is small. In other words, signal-to-noise ratio is small in the 30-year simulation. Then, the possibility of detection of climate change should be investigated.

In this study, the signal-to-noise ratio is examined by using extreme events of the temperature. By using MIROC-medium (T42L20 AGCM), 30 year simulation from 2001 to 2030 was conducted. 10 ensemble members were computed from different initial conditions. An ensemble averaged temperature increase is 0.97K, which is in the middle of temperature increase given by IPCC models. Daily minimum temperature in the summer time (TN) is investigated. When TN is higher of 95% percentile of climate value (1951–1970), it is defined as a hot summer night. Then, frequency of hot summer night is compared with the climate value (1951–1970). Then, a ratio between these two climates (RF95) is defined in the following way;

RF95 = averaged TN days (2011–2030)/averaged TN days (1951–1970).

IF RH95 > 1, a hot summer night will be increased. Similarly, RF95 for 1981–2000 is computed. Results are shown in Fig. 1. First, effectiveness is checked. RF95 in

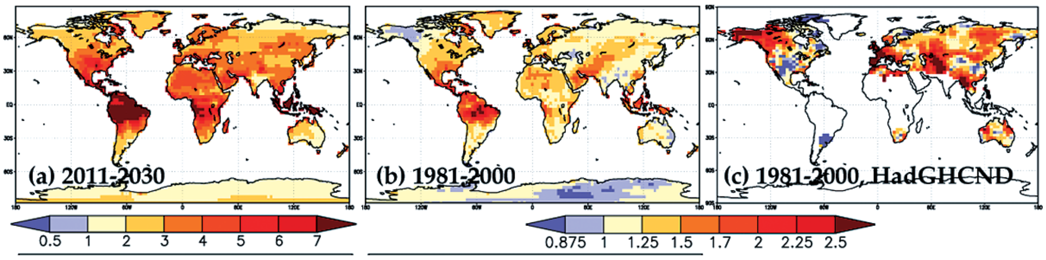

Fig. 1 (a) RF95 in 2011–2030 averaged by 10 members. (b) RF95 in 1980–2000 averaged by 10 members. (c) RF95 computed by observation.

1980–2000(Fig. 1 (b)) is compared with RF95 due to observation (Fig. 1 (c)). Difference over the Alaska and the northern Siberia is noted and the model results are relatively small compared with observations. In general, increases over the continents are well simulated, and it is clearly shown that RF95 in 2011–2030 is greater than 1 all over continents in Fig. 1 (a). Due to these results, it is concluded that a number of hot summer night will increase in 2011–2030. Robustness of this result is investigated by comparing differences between members. It is concluded that the extreme event of temperature may be robust in the 30-year simulation. However, further research is necessary for precipitation.

3. Hindcast experiment by using a high-resolution OGCM

In order to evaluate a performance of the ocean component model in the atmosphere-ocean coupled model, a hindcast experiment from 1950 to 2000 is conducted by using the ocean component model. Boundary condition at the ocean surface is based on CORE (Coordinated Ocean Reference Experiment). For details, see Large and Yeager (2004).

In the northern Pacific Ocean, the climate regime shift in 1976/77 winter is well known. In Fig. 2, the first EOF component of annual mean temperature at 50m depth and 400m depth over the region (150E–120W, 24N–56N) based on observation (left) and model results (right). 50m temperature reflects the sea surface temperature in the winter, because ocean is well mixed in winter. Drop at 1969–70 and rise in 1989 is well represented in the model results. In Fig. 3, difference of time averaged sea temperature between two periods from 1968 to 1976 and from1977 to 1988 are displayed. Observational results are in the left and model results are in the right. In the observation, cooling over the central part of the Pacific basin and warming along the American continent is well noted, which is well represented in the model results. Besides the basin-scale regime shift, cooling and warming around the Kuroshio extension is shown in the model results. This corresponds to the southward shift of the Kuroshio extension, which is not represented in the observation.

Similarly, sea temperature at 400 m depth is compared (see Fig. 1), which is not influenced by fluxes at the sea surface, but determined by the upper ocean dynamics. The variation of the sea temperature at 400 m depth is also well represented in the model simulation. Horizontal pattern of the

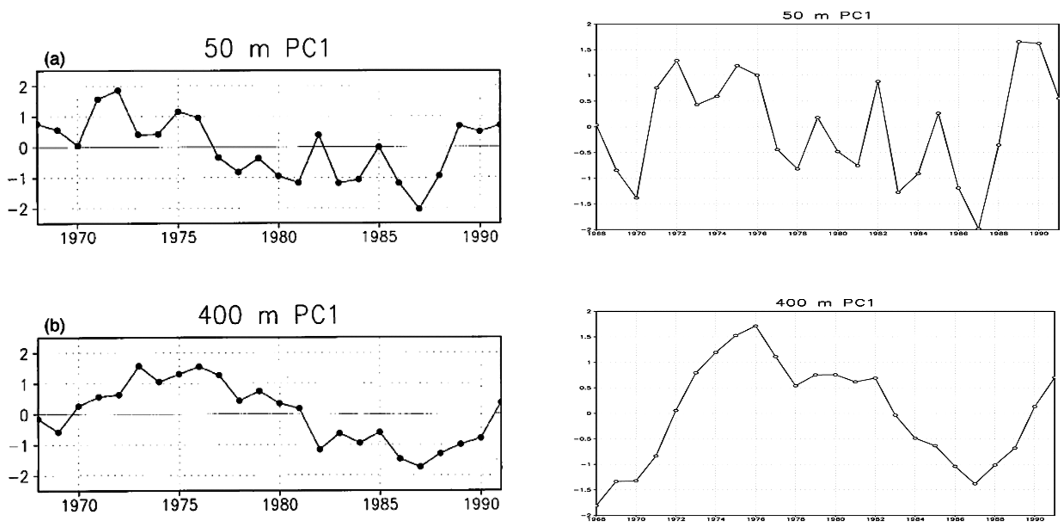

Fig. 2 (Left top) the first EOF component of annual mean sea temperature at 50 m over the region (150E–120W, 24N–56N) due to observation (Deser et al., 1999) and (right top) model results. (Left bottom) The first EOF component of the annual mean sea temperature at 400 m depth due to observation and (right bottom) model results. Amplitudes are normalized due to standard deviations.

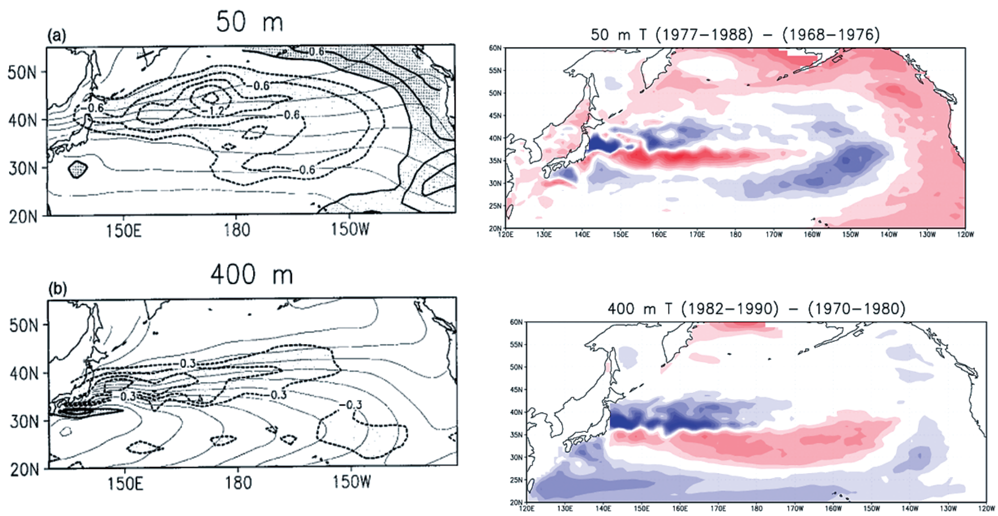

Fig. 3 Difference of time averaged sea temperature at 50 m(top) and 400 m(bottom) depth between (1968–1976) and (1977–1988). (Left) is observation (Deser, 1999) and (right) is model results.

sea temperature at 400 m depth is also shown in Fig. 3, and generally both patterns look similar. It is pointed out that effect due to the southward shift of the Kuroshio extension is noted at the 400 m depth.

4. Difference of transient responses for the global warming due to horizontal resolution

In our project, the atmosphere-ocean coupled model with different horizontal (MIROC-hi) and vertical resolution (MIROC-med) is developed. By using these two models, difference of transient response of a climate model for the global warming due to horizontal resolution is investigated. In Fig. 4, the time-sequence of the globally averaged surface temperature in 1% increase run is displayed. The response of the high resolution model (thick red) is larger than that of the medium resolution model (thick blue). Thin blue lines are corresponding to ensemble members. The reason why this happened is investigated by using a feedback analysis developed by Yokohata (2005a, b). The results are shown in Fig. 5.

Compared between both figures, meaningful differences are noted in the ice-albedo feedback and the ocean heat uptake. Difference is noted in CLR-LW, which is considered to be due to the insufficient separation of feedback processes. The ice-albedo feedback is due to the difference of the sea-ice distribution, which is dependent on the horizontal resolution of the ocean model component. The ocean heat uptake is also considered to be dependent on the horizontal resolution. It should be noted that transient response is dependent on the horizontal and vertical resolution.

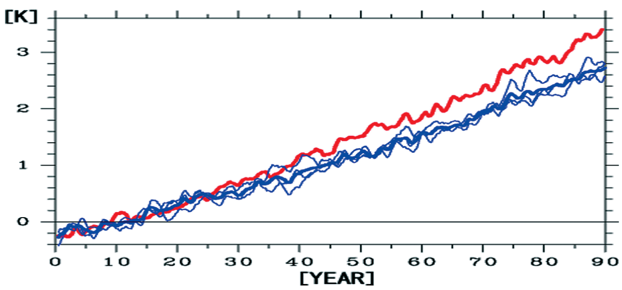

Fig. 4 Results of 1% increase run. (Red) is the high resolution model and (blue) is the medium resolution run.

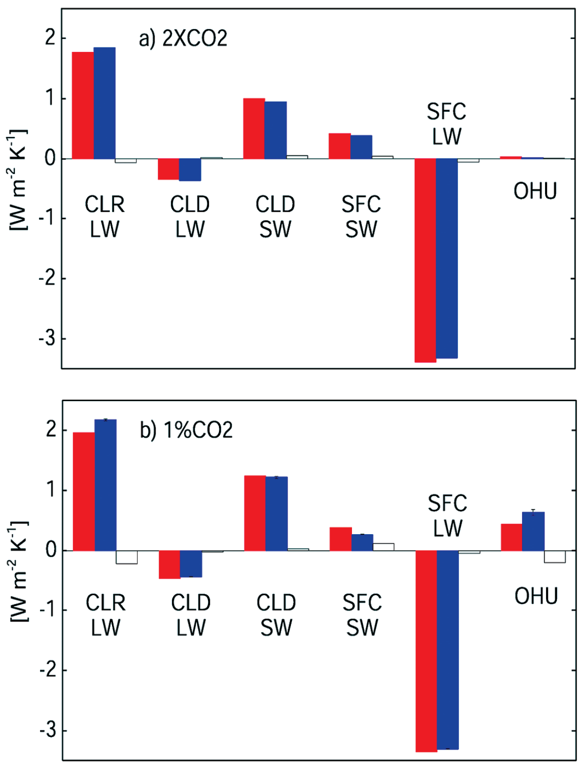

Fig. 5 Results of the feed-back analysis. CLR and CLD stands for Clear Sky and Cloudy Sky, repectively. SW and LW represent Short Wave and Long Wave radiation, respectively. SFC means Surface and OHU represents Ocean Heat Uptake. SFC-SW represents the ice-albedo feedback. CLR-LW represents the water vapor and lapse-rate feedback. CLD-SW and CLD-LW represents the cloud feedback. (Top) is the results of the equilibrium run and (bottom) is the transient run. (Red) means the high resolution and (blue) represents the medium resolution results.

5. Summary

This project was the first project for developing the high-resolution atmosphere-ocean coupled model funded by the government. Due to enthusiasm and efforts of participating members, our project has produced many successful results and model results are well appreciated in the world. Especially, I would like to emphasize that this success is not possible without students educated in CCSR from 1991 to the present. Through this project, huge experiences for developing models are accumulated in our team and it will contribute to the success of the follow-up project which started at April, 2007.

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高分解能大気海洋モデルを用いた地球温暖化予測

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2006年度は、最終年度でもあり、次につながる気候モデルの高度化に関する研究をおこなった。今後の地球温暖化予測研究は、30年スケールの、より詳細な、定量的な予測と300年スケールの炭素循環を組み込んだ地球システムモデルによる定性的な予測に分化してゆく。当研究プロジェクトの後継としては、30年スケールを目指しているので、その基礎となる研究をおこなった。

30年スケールの予測では、排出シナリオの影響が出ないなどの利点もあるが、一方、自然変動の振幅に対して温暖化シグナルの振幅が小さいという欠点もある。したがって、現在の気候モデルをもちいて30年後の気候に関する意味ある情報が得られるか？否かは今後の検討を要するテーマである。そこで、予備的に、MIROC中解像度版を用いて予備的調査を行った。2001年から2030年までの30年積分を10個行い、熱帯夜の出現頻度の差に関する研究をおこなった。熱帯夜は夏の最低気温の95％以上というのを定義としている。この結果によると、30年後の大陸上の熱帯夜の増加というような情報は確実にいえそうだが、降水量の極端現象は無理であることが示された。モデルのバイアスなどもあり、今後とも、モデルの改良と情報を獲得する手法の改良が望まれる。

30年後の気候に関する情報を求める際には、自然変動がノイズとなる。とりわけ、海洋には10年スケールの自然変動があり、それが正しく表現されるか、否かが大きな問題となる。それには、まず、海洋モデル単体での性能を調べる必要がある。そこで、高分解能気候モデルの中の海洋モデルを用いて、観測された風やフラックスを与えながら、20世紀後半の気候変動を再現できるか、どうかの調査をおこなった。その結果によると、表層のみならず、中層の気候変動もよく再現されており、30年予測に可能性のあることが示された。

また、30年ランを走らせるためには、大気や海洋の初期値が必要となる。大気に関しては、気象庁による客観解析があるが、海洋中に関しては、不十分である。そこで、海洋中の初期値を作成すべく、4次元データアシミュレーションが提案されている。そこで、簡単なスキームを用いてその可能性を調査した。このような簡単なスキームに基づく初期値からでも、1年程度の予測が可能であることが示されており、30年予測むけの4次元データアシミュレーションの可能性が示された。

そのほか、温暖化実験の解析も引き続き行われた。特に、我々のグループでは、高分解能と中分解能の2つの気候モデルを用いて温暖化予測実験をおこなったところ、同じシナリオに関して異なる応答が得られた。この理由に関して海外からの問いあわせがあり、その理由の解明をおこなった。

両者が異なるのは、transient experimentだけであり、平衡実験の方は、ほとんど同じであった。そこで、transient experimentの結果を、フィードバック解析の手法を用いて解析したところ、アイスアルベドーフィードバックと、海洋への熱の取り込みに差があることがわかった。アイスアルベドーフィードバックでは、コントロールとなる海氷分布に大きな差異があり、しかも、観測と比べると高分解能の海氷分布の方が正しそうで、高分解能モデルの応答の正しい可能性が示された。また、海洋への熱の取り込みは、より細かなスケールの現象で支配されており、水平分解能に影響されることは、納得される結論である。

キーワード：地球温暖化, 高分解能気候モデル, 大気・海洋結合モデル, 極端現象, 30年予測