

Global Warming Simulation due to the High Resolution Climate Model by Using the Earth Simulator

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Global warming simulation for IPCC AR4 has been conducted by using the high-resolution climate model, which was developed last year (Sumi, 2003). Various simulations are conducted following IPCC guidance and these results are submitted to IPCC Data Center. Warming of the global averaged surface temperature is consistent to the previous estimate. However, regional climate change in the East Asia is obtained. That is, the subtropical High south of Japan and the Ohotuku High is intensified and precipitation associated with the Baiu-front is increased. Hot summer day is 3 times increased. Snow accumulation in winter along the Japan Sea is decreased. New information about the Kuroshio is firstly obtained, that is, the location of the Kuroshio separation from Japan is unchanged but the intensity of current is increased. This is due to the intensification of the Aleutian Low. Compared with the medium resolution model results, a large difference in SST is noted.

Keywords: climate model, global warming, regional climate change, high-resolution model, Kuroshio extension

1. Summary of the 2004 fiscal year

The main objective of our research effort of this fiscal year was to finish the model integration for IPCC AR4 and provide the data to PCMDI. Requested runs are (1) a control run, (2) 1% increase run, (3) 20 century climate change run, and (4) mixed layer run to evaluate climate sensitivity.

These runs are computed by using the high-resolution and the medium-resolution climate models. These runs are shown in Fig. 1. Due to the resource allocation of the Earth Simulator, we have succeeded in finishing all of the computation. After the finish of the computation, we have dedicated to analyze results.

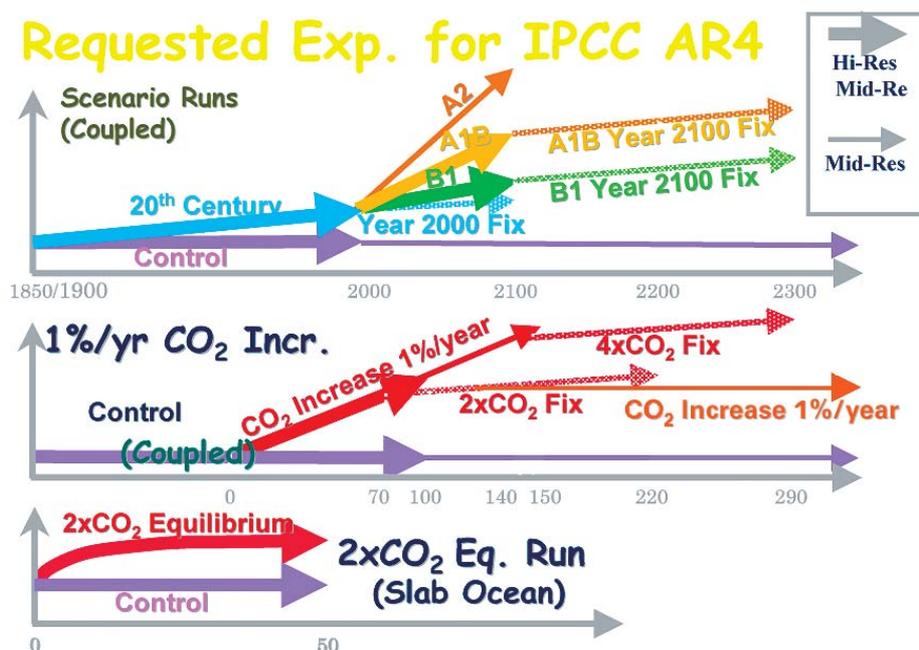


Fig. 1 A summary of simulation runs for IPCC AR4. Thick lines mean the runs by the high-resolution model and thin lines mean the runs by the medium resolution model. (Top) represents IPCC Scenario runs, (middle) represents 1% increase run and (bottom) is a mix-layer run to evaluate the climate sensitivity. Figure.1 Summary of runs for IPCC AR4.

2. Global Aspects

First, the global features are analyzed. In Fig. 2, the change of the globally averaged surface temperature of the various runs is presented. In the control run, there remains no climate drift. It should be noted that a flux adjustment is not used in our model. It is one of the successes that we have developed a climate model without a flux adjustment. In the 1% run, globally averaged surface temperature increase corresponding to doubling CO₂ is approximately 2.8 degree, which is consistent to the previous estimates. The same computation was done by using the medium resolution climate model (thin line). By comparing results of the high resolution with the medium resolution, there is little difference between these two model results. This is because the same physical processes are plugged in the models, although its performance is sensitive to the model resolution.

Global distributions of surface temperature increase (top) and precipitation change (bottom) due to CO₂ doubling are shown in Fig. 3. General features that temperature increase is larger especially over the continents in the high latitude is consistent to the previous results (IPCC, 2001). Precipitation increase over the Asia Monsoon region is noted, which is also consistent to the previous results.

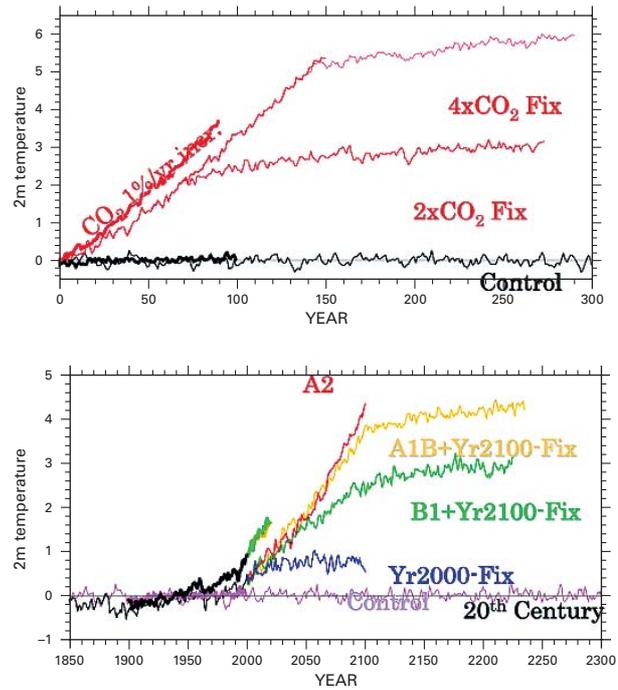


Fig. 2 Increase of global averaged surface temperature due to different scenarios. Stability runs are also presented. 2 × CO₂ Fix means that after CO₂ is doubled, CO₂ concentration remain to be fixed. A1B (B1) + Yr2100 Fix means that CO₂ is increased following A1B (B1) scenario until 2100 and is fixed after 2100.

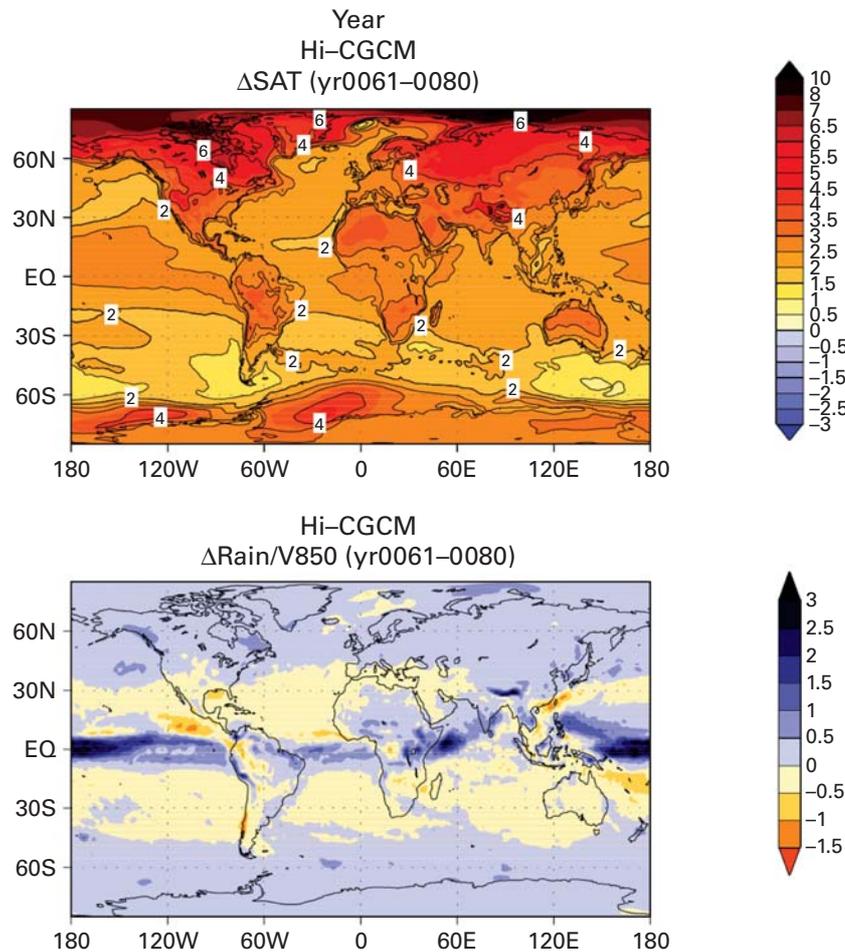


Fig. 3 (Top) the increase of the surface temperature due to 1% CO₂ increase run. It is a twenty-year average value (61-80). (Bottom) Precipitation change due to doubling CO₂.

As our model has the high-resolution, the smaller scale feature is well represented, for example the far-reaching effect of the Hawaiian Islands are well represented in the high-resolution climate model (Sakamoto et. Al, 2003). Similarly, the regional aspects of climate change can be expected to be demonstrated. One example is the regional climate change over the East Asia. For countries in the East Asia, behavior of the Baiu-Meiuyu front is very important and one of the objective for development of the high resolution climate model is to represent the Baiu front well (Sumi, 2003). Figure 4 represents the regional climate change over the East Asia due to the CO₂ doubling. It is noted that there remains the Baiu front in the early summer and the precipitation is increased. The subtropical anti-cyclone south of the Japan is intensified. This is considered to be due to the enhancement of the convective activity in the tropical region. This result is confirmed by using the time-slice method where various SST anomalies given in IPCC-TAR are used. It should be pointed out that these features are consistent to the impact of ENSO in the present climate.

Another interesting feature is the existence of the Ohotuku High. In the global warming run, surface temperature in the northern part of the Eurasian continent is

increased, which may be considered to be one of the reason for the enhancement of the Ohotusku High.

3. Regional aspects

Local climate features are well represented by using high-resolution models. For example, an influence of the Hawaiian Islands in the present climate can be well simulated by the high-resolution model (Sakamoto et al., 2004). Therefore, it is expected that a regional climate change associated with the global warming simulation is better represented. As one example, we will discuss the behavior of the Kuroshio to the north of Japan, because its behavior is very important for the Japanese society. Here, we should recall that the sensitivity of resolution to the Kuroshio is demonstrated in the stand alone OGCM experiments with given wind stress. In Fig. 5, the climate change of SST off the Japan Island in the high resolution and the medium resolution models are presented. It is the differences between 60-80 year averages in the 1% CO₂ increase run. It is well noted that there exists a large difference between two fields. Especially, large differences are noted in the northern Pacific Ocean east to the Japan (Honsyu) Island. The difference in the Arctic region is due to the difference in the sea-ice dis-

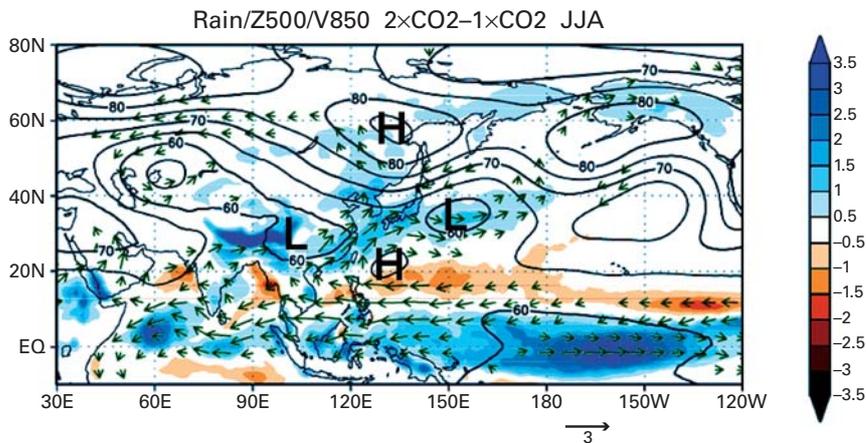


Fig. 4 Regional climate change based on the CO₂ 1% increase run using the high-resolution climate model.

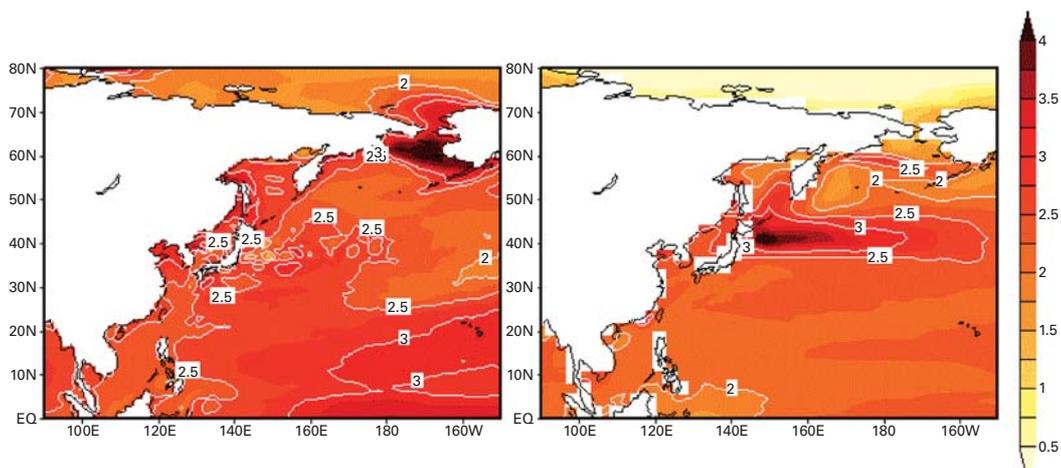


Fig. 5 SST increases due to the doubling CO₂ in the high resolution model (left) and in the medium resolution model (right).

tribution, which is due to the difference of the performance between two ocean components in the Arctic Sea. This aspect will be discussed in the separate paper. Here, we will concentrate in the difference of the northern Pacific Ocean east to Japan (Honsyu) Island.

These differences are considered to be due to the behavior of the Kuroshio currents off the Japan in both models. In the medium resolution model, the Kuroshio tends to flow northward; however, the Kuroshio is separated from the Japan Island around 35N in the high resolution model. When the global warming occurs, the Kuroshio tends to move further northward in the medium resolution model, although the location of the Kuroshio extension remains at the same latitude in the high resolution runs. On the other hand, the speed of the Kuroshio Current is intensified in the high resolution climate model. These differences are corresponding to the change of the representation of the Japan Island and surface wind stress between two models.

The mechanism of the Kuroshio separation has been discussed (Dengg, 1993; Marscal and Tansley, 2001; Tansley and Marshal, 2004) and the shape of the coast line of the Japan Island is critical (Mitsudera et al., 2005). As the coast line of the Japan Island is well represented in the high resolution model, the Kuroshio separation is considered to be well represented in the high resolution model. This result is

also suggested by the OGCM experiments. In order to confirm this conclusion, the high resolution atmosphere model coupled with the medium resolution ocean model is run and the results are compared with the results of the high resolution and the medium resolution climate models (see, Fig. 6). The Kuroshio current is separated from the Japan(Honsyu) Island at 35 N and flow eastward with meandering in the high resolution climate model (Top right in Fig. 6). On the contrary, the Kuroshio current tends to flow northward along the Japan Island and tends to eastward along 40 N in the climate model with the medium resolution ocean component (bottom right and left in Fig. 6). No meandering is found in the medium resolution model. This feature is mainly determined by the resolution of the ocean component model. The high resolution atmosphere contributes to the SST distribution through the air-sea interaction. It is noted that SST is lower in the coupled model of the high resolution atmosphere (bottom right in Fig. 6) and the medium resolution ocean model than the medium resolution climate model (bottom left in Fig. 6). It is concluded that the resolution of the ocean component in the climate model is critical for the behavior of the Kuroshio (see, Fig. 6).

The Oyashio current is also simulated around the Hokkaido in the high resolution climate model, although it tends to be weakened in the medium resolution model. This

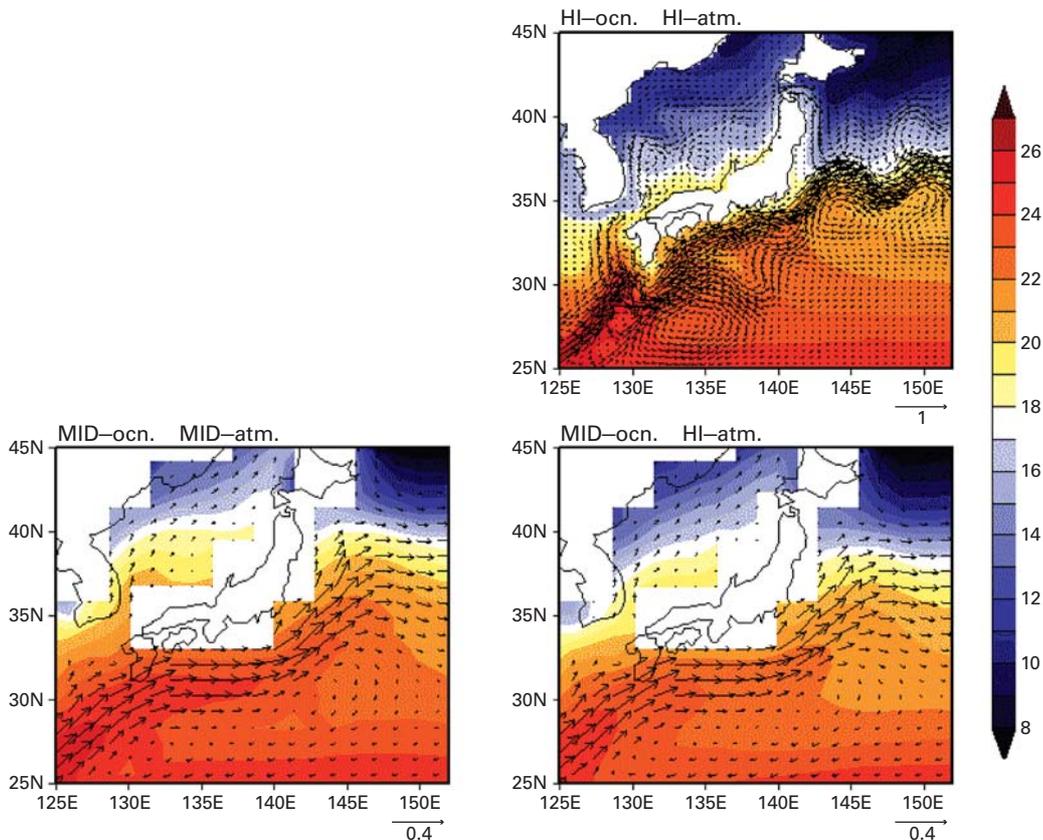


Fig. 6 SST and ocean currents around the Japan Island by different climate models. (Top right) the high-resolution atmosphere model coupled with the high-resolution ocean model, (bottom left) the medium resolution atmosphere model coupled to the medium resolution ocean model, and (bottom right) the high-resolution atmosphere model coupled to the medium ocean model.

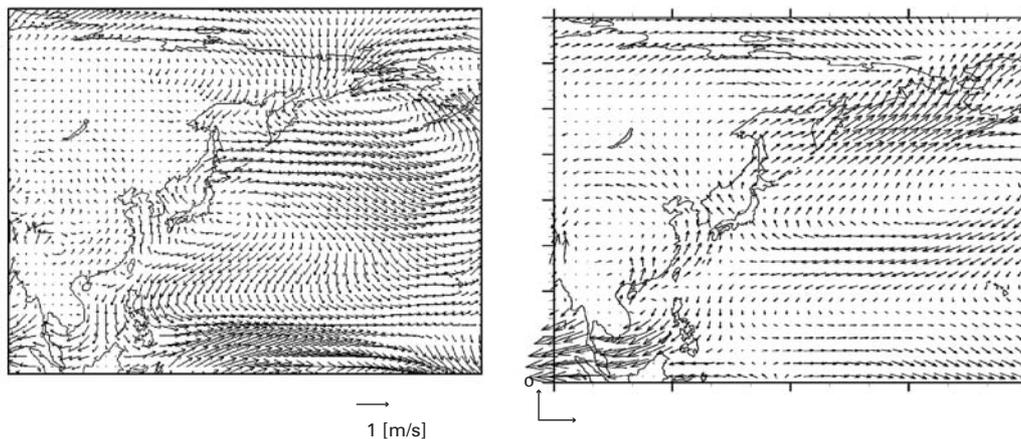


Fig. 7 Change of surface winds in the doubling CO₂. (Left) the high-resolution climate model and (right) the medium resolution climate model.

difference of ocean currents is considered to be forced by the difference of wind stress over the northern Pacific Ocean (see, Fig. 7). The difference of the current speed is due to the difference of the wind stress. The surface wind difference results from the difference of the cyclone intensity in the Aleutian area.

4. Process Studies

Many process studies are conducted to understand the reason why and how the global warming occurs. One of the important issues is the climate sensitivity. Main difficulty of the climate sensitivity is that we don't know what is the climate sensitivity in the real world. If we have the observational constraint about the climate sensitivity, we can tune the climate sensitivity of the model to the observed value. In our project, the possibility is proposed by using the cooling due to volcanic eruption. Fortunately, we have the high sensitivity model and the medium sensitivity model. First systematic survey was conducted by using these two versions and it is suggested that the medium sensitivity mode is more suitable (Yokohata et al., 2005).

Systematic experiments for the 20 century climate run was also conducted under the full range of climate forcing. It is noteworthy that besides the time sequence of the globally averaged surface temperature, the horizontal distribution is also well represented. By comparing the various runs chang-

ing the external forcing, it is concluded that the contribution of the CO₂ to the global warming cannot be neglected (Nozawa et. al, 2005)

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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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本年度の目標は、8月31日までに、IPCC AR4 (第4次報告書)に間に合うように、温暖化予測の計算を行うことであった。しかしながら、このためには、コントロールラン、2酸化炭素1%増加ラン、20世紀再現ラン、混合層を用いた気候感度測定ラン、SRESシナリオランなどの計算を行う必要があった(具体的な計算は図1に示してある)。この計算を、高分解能モデルと中分解能モデルの2つの分解能の異なるモデルを用いて行うことは、相当に大変な作業であった。しかしながら、地球シミュレーションセンター側の協力により予定通りに、8月31日までに計算を終了することが出来た。

これらの計算結果に基づいて得られた地球温暖化予測についての結果を簡単に報告する。我々のモデルの特徴は、まず、フラックス調節を用いないことであるが、フラックス調節がなくてもコントロールランで、気候ドリフトが無いことが確認された。グローバルな温度上昇について検討した結果、今までのIPCCの結果と比べ、大きな差異がないことが理解できる。全球平均に関しては、総じて、今までの結果を確認する結果になったと見てよい(そして、これは予想される結果であった)。

高分解能の特徴は、より、細かな現象を再現できるところにある。とりわけ、今回の高分解能モデルの開発では、東アジアの梅雨前線の表現などに焦点が置かれた。結果を見てみると、梅雨前線などがよく再現されており、温暖化したときの梅雨前線の変化や、冬の日本海側の降雪の変化など、日本付近の地域的な気候変化に関する結果が得られた。さらに、重要なことは、黒潮の離岸などの日本列島付近の海況の変化がよく再現されたことである。日本付近の海流を正しく表現することは、将来の温暖化の予測にも非常に重要である。実際、温暖化に伴う海面水温の変化を、高分解能モデルと中分解能モデルで比較してみると大きく異なることが示された。今後は、温暖化に伴う地域的な影響評価がますます重要になると考えられる。このような観点から、大陸棚や縁辺海での気候変化が非常に重要になる。このような問題に対応するには、高分解能の気候モデルを用いることが重要と考えている。少なくとも、現在開発した高分解能モデルが、今後の研究の基本になるように思われる。

キーワード：地球温暖化，高分解能気候モデル，黒潮，梅雨