Global Warming Projections Using the Community Climate System Model, CCSM3

YOSHIDA Yoshikatsu, MARUYAMA Koki, TAKAHARA Hiroshi

Abstract

This paper provides an outline of the global warming projections made using the atmosphere-ocean coupled model CCSM3. Results show that even if the concentration of greenhouse gasses in the atmosphere is stabilized, the temperature and sea level will continue to rise over the next few hundred years, and that hysteresis effects appear in sea level changes depending on the pathway of the concentration in future. It will become increasingly important that, in our future activities, we fully consider adaptations to climate change in addition to attempting to mitigate the global warming (through emissions reduction).

Keywords

global warming, atmosphere-ocean coupled model, emission scenario
concentration stabilization, rise in sea level, Greenland ice sheet

1. Introduction

The Central Research Institute of Electric Power Industry (CRIEPI) participated in the "Research Revolution 2002: Research Project for Sustainable Coexistence of Human, Nature, and the Earth" (also known as the Kyosei Project) of the Ministry of Education, Culture, Sports, Science and Technology of Japan. This project ran for 5 years beginning in 2002 and its goal is to scientifically contribute to the IPCC (Intergovernmental Panel on Climate Change). CRIEPI conducted global warming projections based on various types of future scenarios in conjunction with NCAR (National Center for Atmospheric Research) of the United States, and the results were reflected in the IPCC Fourth Assessment Report released in 2007. The Earth Simulator and SX-8 were used for these projection experiments. The following will offer an overview of the global warming projections as well as how the matter of global warming should be considered.

2. CCSM3 Model

For this research we used NCAR's third-generation atmosphere-ocean coupled model CCSM3 [1)] for our global warming projections. This particular Community Climate System Model is comprised of 4 components - atmosphere, land, sea ice, and ocean - and attempts to calculate various factors within each component, such as for instance changes in air and water temperature, water vapor, wind, oceanic current, and salinity, as well as the flux exchange between these components. In CCSM3, the flux exchange between the component models is handled by an independent program called coupler. The overall system thus comprises an MPMD type parallel program made up of the coupler plus the four component programs (each individual component or coupler is an SPMD type parallel program).

The atmosphere component of CCSM3 is CAM3, an atmosphere general circulation model based on Eulerian spectral dynamics, with a horizontal resolution of approximately 150km, composed of 26 vertical layers. The ocean component is POP, an ocean general circulation model developed by the Los Alamos National Laboratory, formulated using the orthogonal curvilinear coordinate system. Grid spacing is approximately 1 degree, with 40 vertical layers, and to avoid the singularities associated with the physical North Pole, the pole on the computational grid was shifted to a point on Greenland. Horizontal resolution for land and sea ice components is respectively same as atmosphere and ocean components.

The optimized processor allocation for this resolution of CCSM3 on the Earth Simulator is as follows: 128 for atmosphere, 20 for land, 4 for sea ice, 12 for ocean and 4 for coupler. With this processor allocation, throughput on the Earth Simulator is 16 simulated years per wallclock day, so 100 simulated years can be integrated in about one week.

3. Experimental Setup

The starting point for global warming projections is the emission scenario. This predicts future energy demands and greenhouse gas emission levels based on suppositions of future figures of population, economic growth and so on. In the IPCC Fourth Assessment Report, global warming projections were undertaken based on three scenarios representing low, medium, and high emission, through the SRES scenarios as defined in the Special Report on Emissions Scenarios [2] released by the IPCC in 2000.

Fig. 1 shows the greenhouse gas concentration scenarios used in our projections. In regards to the 21st century, we applied three types of SRES scenarios (high emission A2, medium emission A1B, low emission B1) as mentioned earlier. The atmospheric concentration was derived using a simplified carbon cycle model from the emission specified by the SRES scenarios. The longitudinal axis is a CO_2-equivalent concentration of greenhouse gasses which factors in the warming effects of greenhouse gasses other than CO_2. Subsequent to 2100, the concentration of greenhouse gasses is assumed to be held fixed at 2100 levels for each scenario, as per a request from the IPCC Working Group I. This experiment was set up for the purpose of studying climate change after concentration levels have been stabilized.

In addition to the above, this research also includes projections based on overshoot scenarios. With the overshoot scenario, the concentration of greenhouse gasses will once surpass the stabilization target level, after which emissions will be substantially reduced, or the effects of emissions reduction appear slightly delayed, thereby enabling the stabilization target to be achieved. To be specific, as shown in Fig. 1, after rising to medium or high emission levels, concentration comes down to low emission levels in about a century or two. Projections were made based on a total of three types of scenarios. As stated earlier, these are meant to shed light on the hysteresis properties of climate system and the possibility of climate recovery that may occur when greenhouse gas concentration is reduced.

4. Results

Fig. 2 shows the change in globally averaged annual mean surface air temperature over time. First, during the 21st century, the continued rise in the concentration of greenhouse gases will be accompanied by a rapid rise in the earth's surface temperature. Next, after concentration levels stabilize in 2100, the rate of rising temperature will decrease, but temperatures will continue to climb steadily nevertheless into 2450 and beyond. So in other words, even if the concentration of greenhouse gasses stabilizes, temperatures will continue to rise for hundreds of years. This is an important piece of scientific knowledge among the IPCC Fourth Assessment Report from the viewpoint of mitigation of greenhouse gas emission. On the

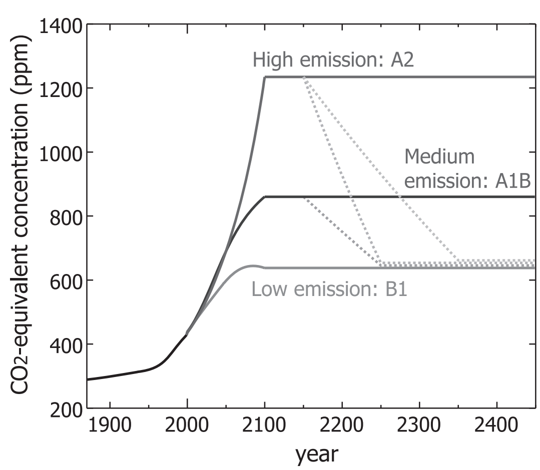

Fig. 1 Greenhouse gas concentration scenarios used in global warming projection experiments (dotted line is for overshoot scenario).

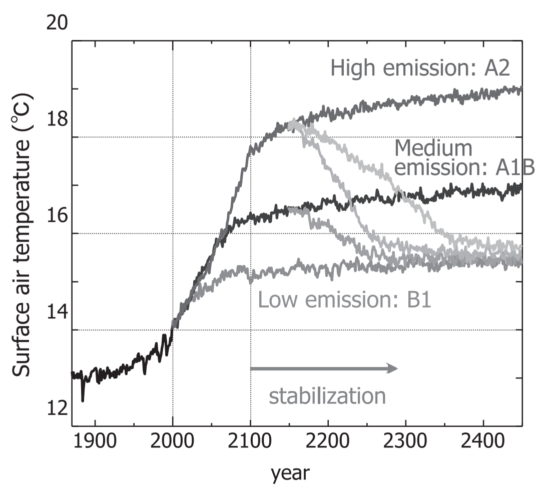

Fig. 2 Changes in globally averaged annual mean surface air temperature over time.

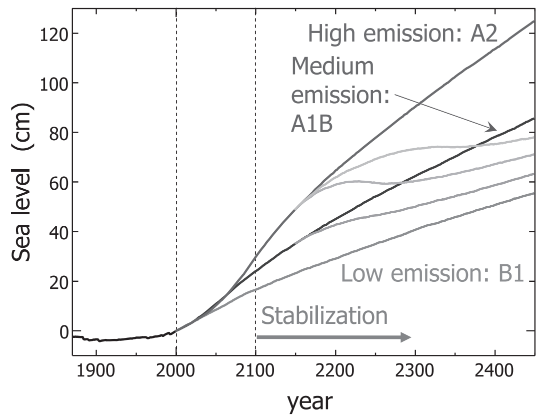

Fig. 3 Changes in global mean sea level over time.

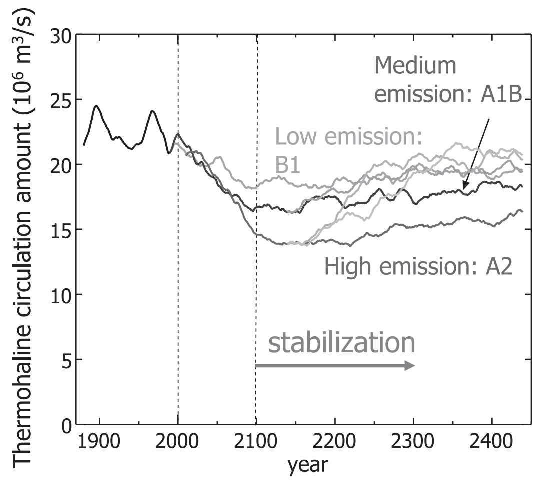

Fig. 4 Changes in thermohaline circulation over time.

other hand, based on the overshoot scenario, we see the decrease in concentration levels resulting in recovery of temperatures back to previous levels as depicted in the low emission B1 scenario.

Fig. 3 shows the projected rise in sea level. Although a rise in sea level can be brought about by factors such as melting of glaciers or ice sheets, this figure depicts only the rise that will result from thermal expansion of the seawater itself. The crucial point the result shows us is that the stabilization of greenhouse gas concentration levels will have little effect in stopping the rise in sea level, and that the rise will be prolonged over an extensive period, with repercussions that far outweigh that of surface temperature. Even based on the overshoot scenario, the effect on sea level is limited, with no return of sea level to low emission levels. The culprit here is the heat that was absorbed by the ocean during the phase of high temperatures before the decline of concentration levels, and due to the enormous scale of the thermal inertia of the ocean, recovery of sea level is expected to take an extremely long time.

Changes in the thermohaline circulation of the North Atlantic are considered one of the prime examples of the dangerous anthropogenic interference with climate system. If this oceanic circulation were to be disrupted due to continued warming, many fear that an abrupt, large scale cooling may be triggered as a result [3]. **Fig. 4** shows projected results for the amount of thermohaline circulation. During the 21st century, the amount of thermohaline circulation will gradually decrease as a result of continuous warming. However, as the atmospheric greenhouse gas levels stabilize, the decline in thermohaline circulation is also expected to end. The overshoot scenario is also effective in that it shows the reduction in greenhouse gas concentration will lead to a recovery in thermohaline circulation. However, it is important to keep in mind that these results do not take into account the effects of increased fresh water supply to the oceans due to the melting of Greenland ice sheet, which may weaken the thermohaline circulation.

Melting of sea ice in the Northern Hemisphere is also cause for great concern. Projections made by CCSM3 show that with the medium emission and high emission scenarios, most of the ice on the Arctic Ocean during late summer will have disappeared by the middle of the 21st century. If the high concentration levels of the high emission A2 scenario are maintained over an extended time period, CCSM3 projections show that Arctic sea ice will be greatly reduced even during the winter.

5. Scientific Perspective to Zero Emission

Even if the world succeeds in subduing the further increase of greenhouse gasses and is able to stabilize it, it is still not enough to prevent global warming. In addition to the prolonged increase in temperature and sea level that we have already described, there is also a risk of losing the Greenland ice sheet. If this were ever to completely disappear, it is estimated that the sea level would rise by 7m. For instance, observations of the Ilulissat glacier in Greenland have shown that in the past ten years, the dynamical ice flow rate has doubled. The contribution of this phenomenon to a rise in sea level remains largely unclear.

To prevent global warming, it is necessary to lower the con-

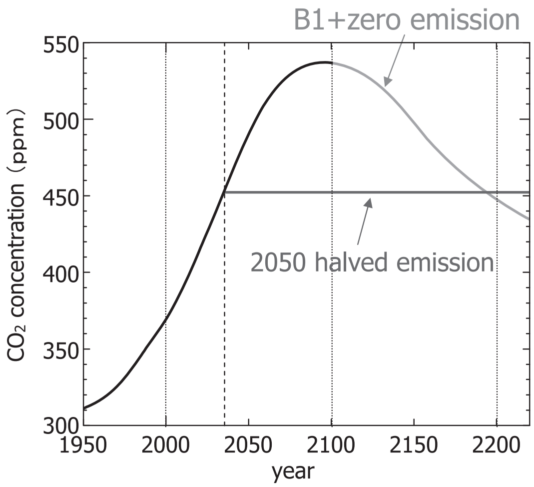

Fig. 5 2050 halved emission scenario and B1 + zero emission scenario.

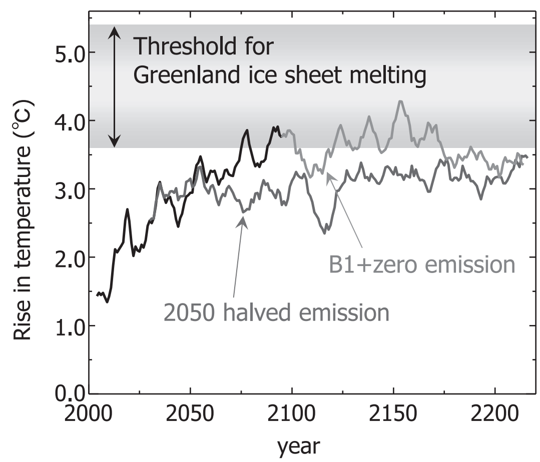

Fig. 6 Change in average temperature of Greenland over time.

centration levels of greenhouse gases in the atmosphere. On earth, terrestrial ecosystems such as forests, as well as the ocean, serve as a sink of CO_2. The concentration of CO_2 in the atmosphere is therefore dependent on the balance of emission and uptake by terrestrial ecosystem and oceans. So, if we are able to reduce the amount of emission to a level below the uptake, atmospheric concentration will likewise go down. In the following, we will show examples of our research in which we assume that the world is able to attain zero emission based on the low emission B1 scenario, and is thus able to lower the atmospheric concentration of CO_2.

First, let us consider a standard case in which emissions are halved by the year 2050. This is equivalent to being able to stabilize the CO_2 concentration at 450ppm at around the year 2035 (see **Fig. 5**, CO_2-equivalent concentration approx. 550ppm). Next, let us consider the case of zero emission, where we are able to further the emission reduction past the year 2100, based on the low emission B1 scenario. With the B1 scenario, emission levels will peak in the year 2040, and the trend will reverse itself during the latter half of the 21st century. If we extend the graph based on the angle of decline at 2100, we can see that at about 2150 we reach a zero emission situation. This path of zero emission is expressed as the line for "B1 + zero emission" in Fig. 5, which results from calculating the atmospheric concentration of CO_2 based on emission levels. This B1 + zero emission scenario shows that CO_2 concentration will rise to over 450ppm, but will gradually fall off after the year 2100 so that by 2200 concentration will have reached 450ppm.

Fig. 6 shows the results of projections based on the aforementioned concentration scenarios, using the CCSM3 model, also displaying the estimated average temperature for Greenland. Also shown is the threshold for melting of the Greenland ice sheet [4]. The melting threshold itself has a large degree of uncertainty, but as you can see in these results of the 2050 halved emission scenario, the temperature is maintained at a level lower than the melting threshold. On the other hand, the B1 + zero emission scenario shows the temperature for Greenland surpassing the low end of the melting threshold range, but subsequently returning to a level below the threshold by the year 2200. Since a few thousand years will be required for a complete meltdown of the Greenland ice sheet, it is expected that surpassing the threshold for something like 100 years will result only in partial melting of the ice sheet.

6. Conclusion

As stated previously, with the B1 + zero emission scenario, it may be possible to avoid the total meltdown of the Greenland ice sheet. However, since higher temperatures are maintained over a longer period of time with the B1 + zero emission scenario compared to the 2050 halved emission scenario, adaptations to climate change will be crucial. By investing heavily in the mitigation (i.e., emissions reduction), the cost we incur in the future will be lessened. By the same token, if we skimp on costs to mitigate the trend now, then the cost we will be faced with in the future will be much larger. The best balance of mitigation and adaptations will become an issue of growing importance in the future.

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Authors' Profiles

YOSHIDA Yoshikatsu
Senior Research Scientist,
Environmental Science Research Laboratory,
Central Research Institute of Electric Power Industry

MARUYAMA Koki
Executive Research Scientist,
Environmental Science Research Laboratory,
Central Research Institute of Electric Power Industry

TAKAHARA Hiroshi
Senior Director,
HPC Marketing Promotion Division,
1st Computers Operations Unit,
NEC Corporation