Multi-century global warming projections under CO_2 stabilization and overshoot scenarios
― Estimation of stabilization effects of greenhouse gases ―

Background

The Kyoto Protocol's entry into force in February 2005 will trigger further discussion and negotiation on the reduction of green house gases (GHGs) putting, for example, participation of developing countries in perspective. However, the effects of GHGs stabilization in atmosphere have almost never been estimated on the scientific basis.

Objectives

The ultimate goal of the United Nations Framework Convention of Climate Change (UNFCCC) is to stabilize atmospheric concentration of GHGs to prevent dangerous anthropogenic interference with climate system. To find a pathway to this goal, future climate changes are projected using a coupled climate system model based on several kinds of GHGs stabilization scenarios, thereby, the effects of GHGs stabilization are investigated.

Principal Results

1. Model and GHGs concentration scenarios

The National Center for Atmospheric Research Community Climate System Model (CCSM3) was used for the global warming projection experiments. The CCSM3 is the state-of-the-art coupled climate model consisting of atmosphere, land, sea ice and ocean components. Its spatial resolution is about 150 km in the atmosphere and 100 km in the ocean. The GHGs stabilization experiments were conducted using two stabilization scenarios based on IPCC SRES (Special Report on Emission Scenarios) A1B and B1 scenarios. In both cases, GHGs concentrations beyond year 2100 were held fixed to the level of year 2100. Hereafter, the stabilization scenarios based on SRES A1B and B1 scenarios are respectively called "A1B+750 ppm" and "B1+550 ppm" scenarios. In addition to these stabilization scenarios, an overshoot scenario is proposed, where the GHGs concentration once overshoots to higher SRES A1B level, then, decreases to lower B1 level. The dependency of climate system on GHG concentration pathways can be investigated through this overshoot experiment. As described in the IPCC synthesis report in 2001, it takes at least several hundreds years for the climate system to be stabilized. Therefore, we have conducted very long term experiments up till year 2450. All the numerical experiments were carried out using the Earth Simulator, one of the fastest supercomputers in the world.

2. Results and implications to world energy policy

(1) A three-member ensemble experiment was conducted on each GHGs concentration scenario. Thus, the representation of present climate was much improved (see Fig. 1).

(2) The future climate changes due to global warming beyond 21st century were predicted using the state-of-the-art climate system model (for example, see Figs. 2 and 3). The stabilization of GHGs concentration works as a brake to weakening of meridional overturning circulation, thus, catastrophes such as a severe cooling event due to the shutdown of deep ocean circulation are likely avoidable. However, the sea level keeps increasing due to thermal expansion for very long time throughout the projection experiments up till year 2450.

(3) GHGs stabilization level under the "A1B+750 ppm" stabilization scenario should not meet the goal of UNFCCC. This is because it may result in dangerous anthropogenic interference such as disappearance of sea ice (see Fig. 3). However, an overshoot pathway is expected to be useful for risk management to cope with delay in the emission reduction of carbon dioxide.

(4) The GHGs stabilization level under the "B1+550 ppm" scenario is one of the candidate target levels. However, the response of ecosystem to climate changes has not been scientifically clarified yet. Therefore, it is necessary to further study such uncertainties to establish scientific criteria for appropriate stabilization levels.

Future Developments

To develop higher resolution atmosphere-ocean coupled climate model to improve reliability of climate change projections on regional scale.

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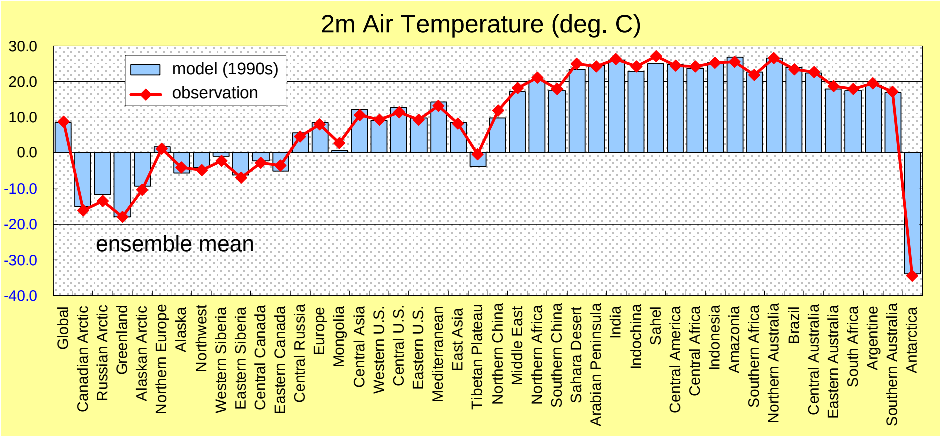

Fig. 1 Comparison of surface air temperature simulated by CCSM3 model with observations. The model results employ ensemble means for 1990-1999 period.

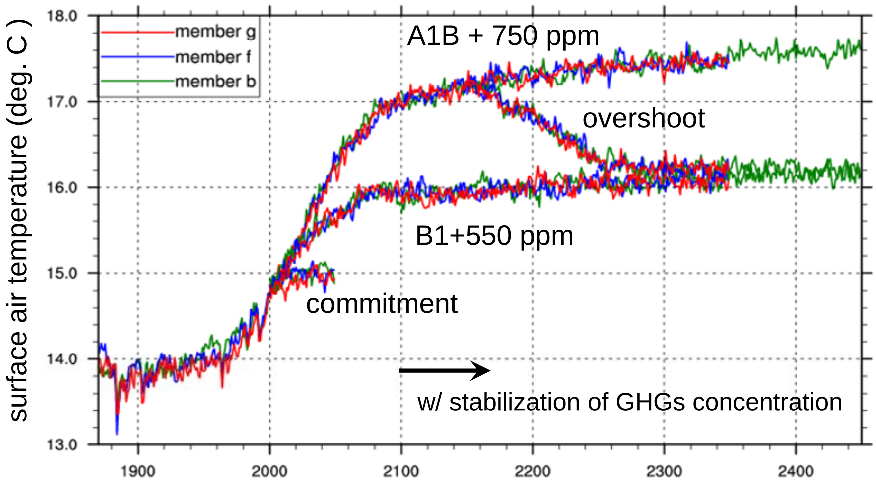

Fig. 2 Projected results of global mean annual surface temperature for all the scenarios. Temperature and precipitation increases during 21st century are respectively about 2.5 degree C and 6% under the A1B scenario: about 1.5 degree C and 3.9% under the B1 scenario. Under the "A1B+750 ppm" scenario, the surface air temperature keeps increasing even after the stabilization of GHG concentration.

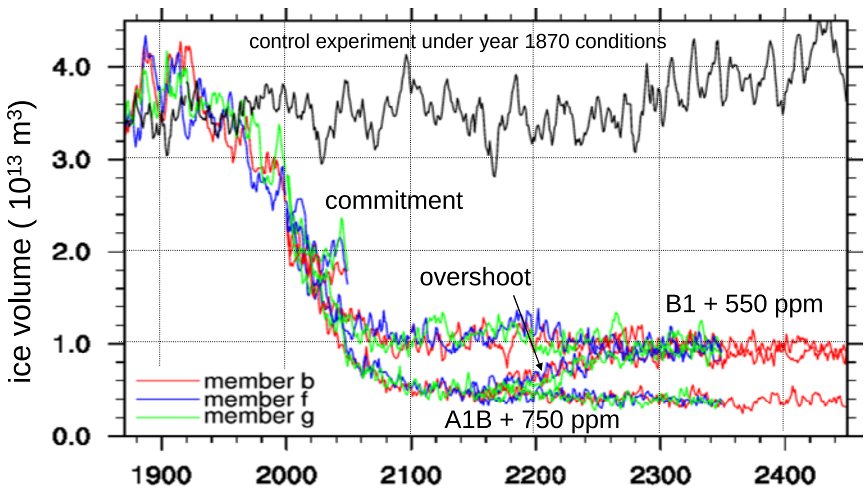

Fig. 3 Decrease in sea ice volume in Northern hemisphere. Throughout 21st century, the sea ice volume decreases by about 80% and 65% under A1B and B1 scenarios, respectively. Under the "A1B+750 ppm" scenario, the ice volume keeps decreasing and it may disappear at all.

Principal Research Results in 2006

Long-term Global Warming Projections of GHG Stabilization Scenarios —What is the Dangerous Anthropogenic Interference with Climate System? —

Background

The ultimate goal of UNFCCC Article 2 is to achieve stabilization of greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent "Dangerous Anthropogenic Interference" (DAI) with climate system. Such a level should be achieved to allow ecosystem to adapt naturally to climate change and to satisfy another conditions. Recently, EU countries have proposed to stabilize global temperature increase within 2℃ for the Post Kyoto Protocol. However, there is not sufficient information of feasible stabilization levels of GHG concentrations in the atmosphere described in .the Article 2.

Objectives

To have good scientific information regarding the ultimate goal of UNFCCC, we conduct long-term global warming projections of GHG stabilization scenarios. We analyze the large amount of output data and have information about climate changes and environmental impacts under the stabilization scenarios to make clear the question; "What is DAI?"

Principal Results

1. GHG stabilization scenarios and climate model

We applied two stabilization scenarios based on IPCC A1B and B1 scenarios for projections from year 1870 to 2450. In both scenarios, the concentrations of GHGs, such as CO_2, CH_4, N_2O etc., beyond year 2100 were held fixed to the level of year 2100 (Fig.1). In addition, CRIEPI proposed an idealized overshoot scenario where the concentrations of GHGs reduced from the A1B stabilized level to B1 stabilized level between 2150 and 2250 followed by 200 years integration with that constant B1 level of concentrations to investigate how the climate system would respond to such a large change in the concentrations If all the countries in the world could achieve zero emission world beyond 2150, the concentrations of GHGs would decrease due to absorption of CO_2. by the terrestrial ecosystem and the ocean. Through the international research consortium with the National Center for Atmospheric Research (NCAR) and others, we conducted long-term global warming projection for the scenarios using the world fastest class supercomputer; the Earth Simulator with the atmosphere ocean coupled model (CCSM3) with the resolutions of about 150 km in the atmosphere and 100 km in the ocean.

2. Climate changes and impacts

(1) In A1B scenario, the permafrost deceases rapidly in the regions with high latitudes (Fig.2). Projected thawing of the permafrost both in Eastern Siberia and Alaska compares well with observation in the 20th century.

(2) In general, "Thermohaline Circulation" (THC) in the oceans transports the solar energy from the tropical regions to the regions with high latitudes (Fig.3). A part of .THC near the Greenland is called the Atlantic "Meridional Overturning Circulation" (MOC). Although the MOC decreases both in A1B and B1 scenarios, the MOC keeps almost constant after stabilization of GHGs and recovers under the overshoot scenario (Fig.4). Temperatures over the North Atlantic Ocean and Europe are projected to warm despite such decrease of the MOC. It is likely that DAI such as occurrence of the ice age will not happen.

(3) The sea ice in the Arctic shrinks rapidly under two scenarios. In the latter part of 21st century for A1B scenario, the sea ice is projected to disappear in September (Fig.5).and it suggests the serious impact to the arctic ecosystem. Sea level rise due to thermal expansion of seawater continues for almost millennium even after stabilization of GHGs. Under the overshoot scenario, climate changes almost recover to B1 level except for a significant hysteresis effect shown in the sea level change (Fig.6).

3. Implication for the ultimate goal of UNFCCC

The projected climate changes suggest that GHGs stabilization level at 2100 under A1B scenario will not meet the goal of UNFCCC due to the possibility of DAI such as disappearance of the sea ice in the Arctic and stabilization level under the B1 is one of the candidate target levels. However, the response of ecosystem to climate changes has not been scientifically clarified yet.

Future Developments

We will conduct projections to make clear the feedback between ecosystem and climate changes using a new Earth System Model including carbon cycle model component through the international collaboration with NCAR in USA.

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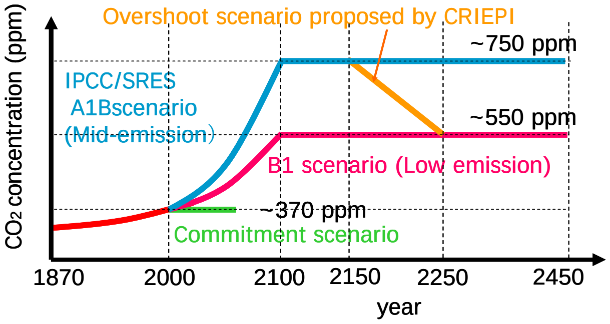

Fig. 1 Emission scenarios. We conducted three member-ensemble projections with different initial conditions at year 1870 for each scenario.

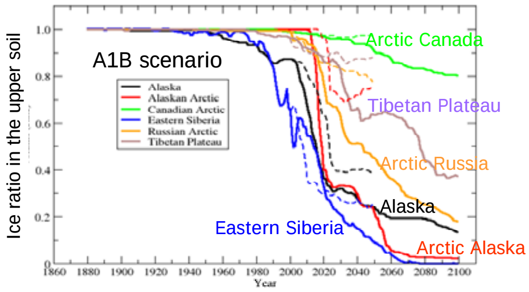

Fig.2 Thawing of permafrost in regions with high latitudes in A1B scenario. The ice in the upper soil both in Eastern Siberia and Alaska is projected to start to thaw before year 2000.

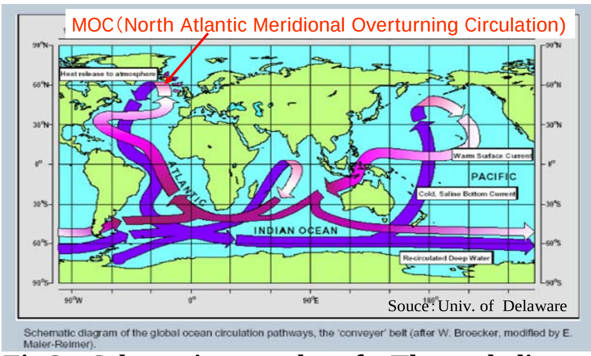

Fig.3 Schematic graph of Thermohaline Circulation (THC) and MOC.

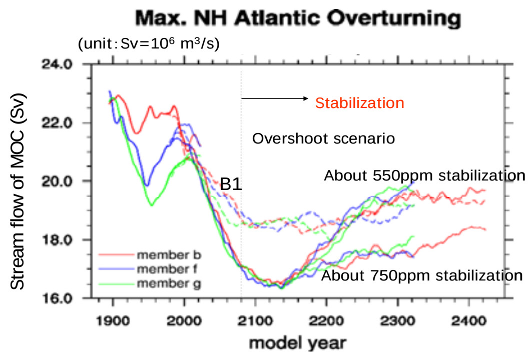

Fig.4 Changes of the MOC. After stabilization of GHGs, the MOC keeps almost constant and recovers under the overshoot scenario.

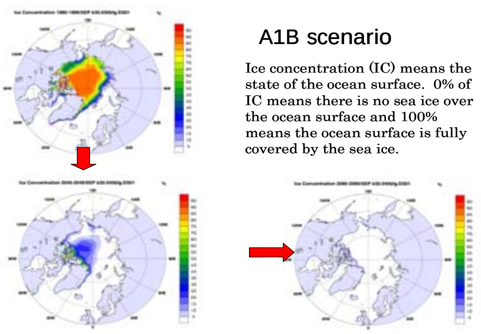

Fig.5 Decrease of the sea ice in the Arctic. In the latter part of 21st century, the sea ice disappears in September.

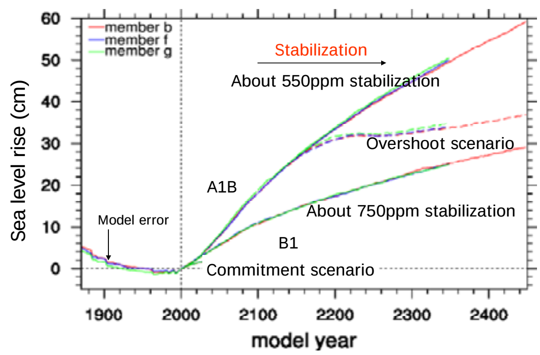

Fig.6 Sea level rise due to thermal expansion of seawater. Sea level rise continues for almost millennium even after stabilization of GHGs.

Scientific Assessments of the Impacts Due to Global Warming —Increase in Precipitation Amounts and Droughts —

Background

It is widely accepted that surface air temperature will increase due to global warming. However, concerning precipitation, which means rain and snow, it seems to be contradictory that the occurrences of both floods and droughts are projected to simultaneously increase in many research results.. At the stage of the IPCC Third Assessment Report (TAR, 2001), projected changes in precipitation were still uncertain, because the reliability of climate models and the performance of computers were not sufficient.

Objectives

In order to assess the changes in precipitation, we analyze in detail the large amount of output data from the climate model experiments using the world fastest class supercomputer, the Earth Simulator. For evaluating the performance of the climate model used in this study, we compare simulated regional precipitations with observations.

Principal Results

1. Outline of the datasets used for analyses

We analyzed the long-term projected data by the end of the 21st century (year 2100) based on A1B and B1 scenarios from the IPCC Special Report on Emissions Scenarios (SRES, 2001). In medium-emission A1B scenario, the storyline is described as the world of rapid economic growth with emphasized introduction of renewable energy in Asia. In the low-emission B1 scenario, the storyline is described as the world of rapid change in economic structures with emphasized introduction of nuclear energy in Asia. These long-term data were obtained through the international research consortium with the National Center for Atmospheric Research (NCAR) and others with the atmosphere ocean coupled model (CCSM3) with the resolutions of about 150 km in the atmosphere. For comparing simulated precipitations with observations, we used the past 25-year reanalysis dataset (JRA-25) from year 1979 to year 2004 with the resolution of about 120 km. We have completed the JRA-25 dataset (Japanese Reanalysis dataset with 25years) in the FY 2005 in collaboration with the Japan Meteorological Agency (JMA).

2. Features of precipitation changes

(1) For a short period (1991-1994) without an apparent trend of climate change, we analyzed the projected data about the number of days with precipitation and compared them with the JRA-25 data (Fig.1). The projected number of days with precipitation (P) larger than 50 mm/day was extremely underestimated in comparison with the JRA-25 data. However, the projected number of days with precipitation (P) larger than 10 mm/day was in good agreement with the JRA-25 data.

(2) In these projections, three-member ensemble projections (named **b**, **f**, and **g**, respectively) with slightly different initial conditions were carried out for each scenario. In some regions (e.g., central Australia), the projected precipitations showed different manner among the members (Fig.2). Therefore, by introducing the ensemble mean which indicates averaging of three members, statistical uncertainties of the projected precipitation changes are expected to decrease.

(3) Under both the A1B and B1 scenarios, annual precipitations are projected to increase in most regions over land (Fig.3). However, in the regions included in the so-called Mediterranean climate type, the annual total precipitations are projected to decrease and, at the same time, the index of the annual maximum of consecutive dry days (CDD), which indicates the index of drought, is projected to increase (Fig 4). In such regions included in the so-called Mediterranean climate type, it is suggested that the precipitations decrease and the droughts increase simultaneously in the future.

(4) In the regions where annual precipitations are projected to increase, annual evapotranspirations, which mean evaporation from the land surface and forests, are also projected to increase due to the high increases of surface temperatures (Fig.5). In such regions with increased evapotranspirations, the annual mean runoff-to-precipitation ratio is projected to decrease under both the A1B and B1 scenarios (Fig.6), which might cause the shortage of water resources in the future.

Future Developments

We will investigate the methods of adapting ourselves to the unavoidable future climate changes and reducing the possible damages caused by global warming..

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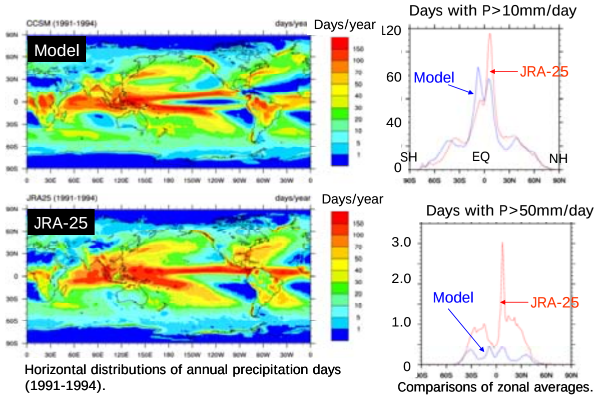

Fig. 1 Comparison of the annual number of days with precipitation (P) between the model and the reanalysis data(JRA-25).

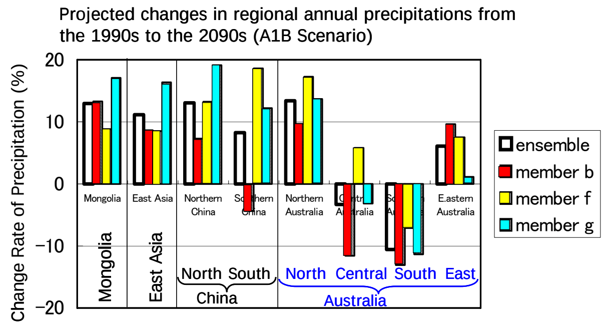

Fig.2. Changes in regional annual precipitations for each ensemble member (b, f, g)

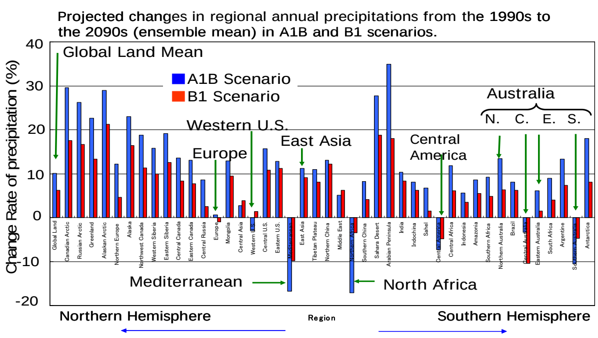

Fig. 3 Changes of annual precipitations

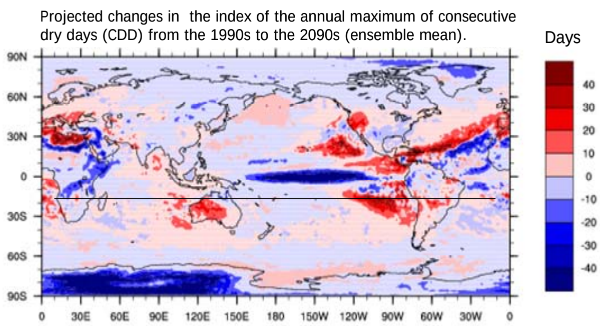

Fig. 4 Change of Consecutive Dry Days(CDD). In the regions with highlights of red, the index of CDD increases and it suggests that the drought increases in these regions..

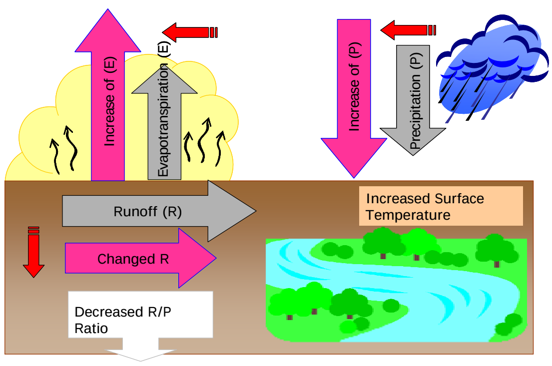

Fig.5. Schematic graph of runoff. The runoff (R) and precipitation (P) ratio decreases due to the high increase of lamd surface temperature.

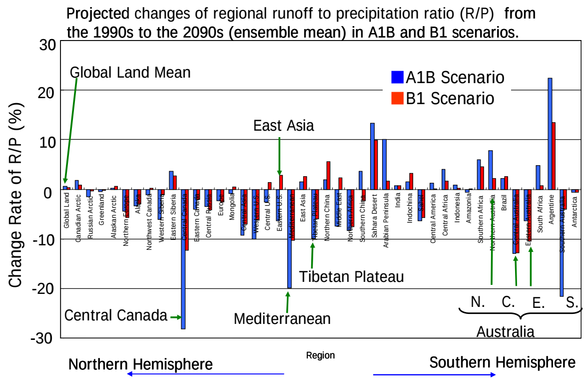

Fig.6 Decrease of the value of R/P in most regions. These results suggest shortage of water resources in the future.