Development of a Simple Procedure for Climate Change Projection Based on an Impulse Response Model

Background

Projection of global warming is conducted using a complex numerical model termed an atmosphere-ocean general circulation model (AOGCM). Despite the complexity of AOGCMs, their basic behavior can be represented by a simplified computation procedure, and therefore, simple climate models can be used alternatively for understanding basic properties of the climate system and quantification of uncertainties. In particular, simple models are used exclusively to investigate the mitigation of global warming for a variety of CO_2 emission scenarios. As global warming issues move into the mainstream, decision making based on the latest information of global warming projections has become a requisite for planning in many sectors. It is hoped that simple climate models are further developed, leading to a useful tool as liaison between the science of global warming projection and the society coping with global warming issues.

Objectives

As an effective tool to derive basic information regarding measures dealing with global warming, this study aims to develop a simple procedure for climate change projection based on an impulse response model of global carbon cycle and climate change including additional functions.

Principal Results

1. Development of a simple procedure for climate change projection

This procedure calculates atmospheric CO_2 concentrations from CO_2 emissions considering the carbon cycle associated with oceanic and terrestrial CO_2 uptake (Fig. 1), and globally-averaged values of climate variables corresponding to the CO_2 concentrations. Although the calculation method is based on an existing impulse response model, this study incorporates the following functions for improved usability.

(1) To easily compose a test scenario from reference data of past observations and standard future scenarios in combination with theoretical curves for time series.
(2) To generate an emission scenario corresponding to a concentration scenario by an inverse calculation of the carbon cycle.
(3) To illustrate the magnitude of climate change with variability ranges depending on the uncertainty of climate sensitivity.
(4) To derive spatial distributions from global averages using the latest AOGCM experiments (Fig. 2).

2. Practical examination of climate change scenarios

This study validates basic properties of the carbon cycle and demonstrates experimental calculations to examine pathways reaching stabilized CO_2 concentrations. The experiments are completed within a few seconds on a normal PC. The results are summarized as follows.

(1) The model calculates atmospheric CO_2 concentrations under representative emission scenarios so that their changes during the 21st century are almost equivalent to reference values shown in the IPCC assessment reports.
(2) The model produces climate change projections reflecting scientific information concerning delayed climate responses and the uncertainties of climate sensitivity, leading to adequate understanding of a key characteristic of climate change that is often overlooked in emission-reduction arguments.
(3) The experiments demonstrate that the model is suitable for investigating various pathways toward a target concentration level, which are indicative of emission-reduction plans and energy technology development (Fig. 3).

Future Developments

A future study is planned on incorporating the latest knowledge about the carbon cycle and additional functions, such as the calculation of climate forcing by other greenhouse gases, and improving usability as an application software.

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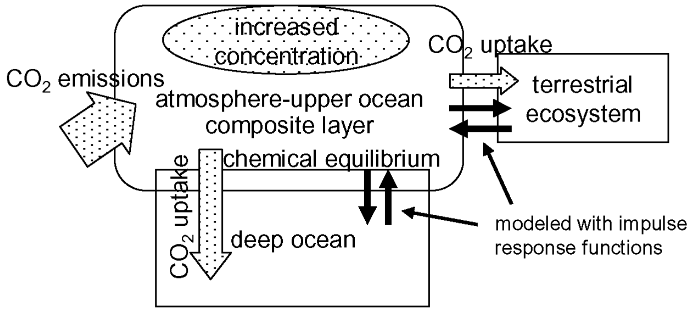
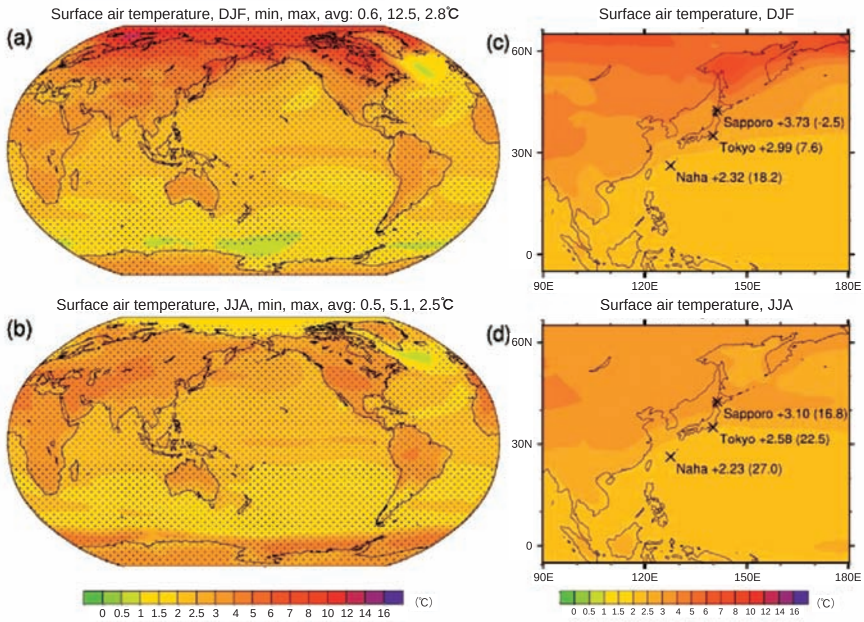
Reference

J. Tsutsui, 2009, "Development of a simple procedure for climate change projection based on an impulse response model", CRIEPI Report V08022 (in Japanese)



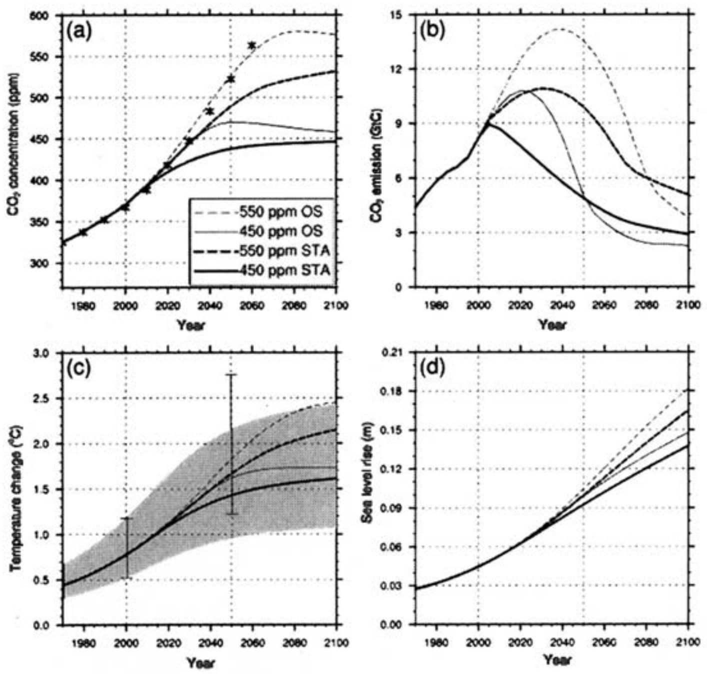
The carbon cycle in this study is based on an existing model termed NICCS (Hooss et al., 2001, Climate Dyn). Carbon loads from anthropogenic CO_2 emissions are allocated into the atmosphere and the upper ocean considering the chemistry governing oceanic CO_2 uptake. Increased atmospheric CO_2 leads to additional CO_2 uptake by the terrestrial ecosystem. Processes of further uptake into the deep ocean and a return of the terrestrial carbon to the atmosphere due to respiration are modeled with impulse response functions.

Fig.1 Concept of the simple carbon cycle model



Changes in surface air temperatures (units: degC) from 1980-1999 to 2080-2099 from multi-model (more than 20 AOGCMs) climate experiments under a representative scenario for December-February (a) and June-August (b). Stippling indicates regions where inter-model differences are relatively small, implying higher confidence. The region near Japan is magnified in (c) and (d), where values at grid points corresponding to Sapporo, Tokyo, and Naha are written with base (1980-1999) values in parentheses.

Fig.2 Examples of reference data used for the derivation of spatial distributions from global averages



Comparison between a monotonous increase (label STA) and an overshooting change (label OS) for each of two different stabilized levels of 450 ppm and 550 ppm. Panels (a) to (d) show, respectively, input CO_2 concentration, CO_2 emissions calculated by the inversion, temperature change, and sea level rise due to the thermal expansion of sea water. Star markers in (a) indicate CO_2 concentrations of the IPCC SRES A1B, a future scenario assuming global and rapid economic growth. Lines of the temperature change show best estimates where the climate sensitivity is set at 3 degC. An uncertainty range corresponding to the climate sensitivity of 2.0-4.5 degC are also shown by shading and error bars, respectively, for 450 ppm STA and 550 ppm OS.

Fig.3 Examples of stabilized CO_2 concentration pathways