B-1 Study on climate model improvement for projection of future changes in atmospheric water and energy circulation (Abstract of the Final Report)

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1. Introduction

It is required to reduce uncertainties in the future projection (or prediction) of the global scale climate change associated with global warming for contributing to evaluation of the impact of the global warming on society and human beings. It is also required to develop climate models incorporating material circulation. These subjects remain as issues to be overcome, and classified as important issues by IPCC (Intergovernmental Panel on Climate Change).

2. Research Objective

The main objectives of the project are to clarify the effect of tropospheric aerosols and ozone on climate, to clarify the effect of water cycle on climate change and climate variability, and to establish the basis of climate models incorporating interaction of material circulation with climate. Moreover, the project aims at developing numerical, global three-dimensional climate models on the basis of the above results of process studies, and to apply the models to global warming issues.

3. Methods and Results

This research project carries out modeling of processes affecting the evaluation of the impact of climate change, such as aerosols, ozone, and water cycle, as an attempt to contribute to development of a climate model of the CCSR/NIES/FRCGC coupled atmosphere-ocean general circulation model (AOGCM) named MIROC, which is developed through joint research of CCSR (Center for Climate System Research, University of Tokyo), NIES (National Institute for Environmental Studies), and FRCGC (Frontier Research Center for Global Change). The aerosol modeling group of MRI (Meteorological Research Institute), working for MRI AOGCM, also joins the research project. Some analyses of observational data from satellite observation, etc., are done as validation of the modeling. Developing appropriate models of the processes naturally leads to understanding of the processes. We keep in mind applying the climate model to future projection of climate change associated with emission scenarios of greenhouse gases and aerosols. The project consisted of the following two sub-themes.

1) Study on improvement of tropospheric aerosol and ozone process model

The ultimate aim of this study is to gain the knowledge on uncertainties in the projection of climate change that are attributed to the insufficient modeling of tropospheric aerosols and ozone. The concrete purpose is to obtain spatial and temporal distributions of aerosols and ozone *in response to* emissions of sulfur dioxide, carbon, ozone precursor gases, etc. at the stage of increased greenhouse gases with use of global climate models incorporating transport and chemical reaction processes, and to evaluate climate change and variability considering uncertainties in the effects of aerosols and ozone with use of a global climate model.

Primary achievements in the research project period are as follows, some of which are detailed in the papers[1-13]: (A) A global three-dimensional chemistry-climate model was developed to describe the interaction between tropospheric ozone and sulfate aerosols, and to incorporate the interaction processes into the atmospheric general circulation model in an on-line manner. Future prediction (projection) numerical experiments by the year 2100 with use of the global chemistry-climate model were carried out under three future emission scenarios of anthropogenic materials from IPCC SRES. The result suggested that the interaction of tropospheric ozone with climate change due to global warming should be taken into account if future prediction of ozone and its effects on climate are concerned, and that sulfate aerosols change with links not only to emissions of sulfur dioxide but also to torpospheric ozone chemistry and the climate change. (B) With use of the chemistry-climate model, we carried out the reproduction experiment of the past variability (increase) of troposheric ozone and evaluation of radiative forcing due to tropospheric ozone. The model well reproduce the observed ozone variability for the period from 1970's to the present while the model gave about 1.5-2 times of the observed ozone for the period before 1900, suggesting the uncertainty of the estimate of radiative forcing due to tropospheric ozone. The observed variability of the tropospheric ozone for the period from 1970's to the present may be partly due to stratospheric ozone destruction and climate change. (C) The Madden-Julian Oscillation (MJO) of equatorial tropospheric ozone in satellite observation is well reproduced by the chemistry-climate model. The depictions of water vapor and cumulus convection that are related to MJO are also evaluated. (D) A simplified scheme of global aerosol modeling incorporated into AOGCM made it possible to integrate the AOGCM model with the aerosol module in time for several decades to several hundred years using available super computer resources. (E) A realistic simulation of indirect effects of aerosols became possible because a parameterization based on cloud physics processes was introduced into an aerosol-climate model. The result of the simulation shows that in most areas the aerosol indirect effect of the second kind cannot explain the long term change of cloud and precipitation because it is masked by feedback mechanisms while in East Asia of large amount of anthropogenic aerosols it can explain main features of the change. (F) A long term (44 years) simulation with a global mineral dust aerosol model experiment shows that the long term decrease trend of annual dust emission of the South Arab region occupies about a half of the trend of the whole earth, and is larger than the trend of the Sahara the annual dust emission itself of which is about a half of that of the whole earth. (G) The effect of vertical resolution of chemical transport model on vertical transport, especially Stratosphere-Troposphere Exchange (STE), of ozone and aerosols are investigated. (H) To investigate long-term variation in optical properties, optical depth and Angstrom index, of tropospheric aerosols during the past 20 years with use of satellite data, we determined sensor calibration coefficients of two visible channels of AVHRR sensors on board NOAA satellite series which accumulate the data since 1981 using effectively surface observations and other data. As a result, considerable overestimation that had been seen in optical depth and Angstrom index of aerosol was improved to be reduced. With use of the calibration coefficients, global distributions of the optical properties of tropospheric aerosols were derived for about 20 years, and they were used to investigate long-term variation in the optical properties. (I) The optical properties derived from satellite observations are compared to those calculated from two global tropospheric aerosol models to evaluate the data quality.

2) Study on changes in atmospheric water circulation processes associated with the climate change

For obtaining reliable information on future projections of the global water circulation changes accompanying the global climate change, this study aims to evaluate the accuracy and uncertainties of the water circulation processes simulated with climate models. This subproject basically consists of three researches: (i) Statistical analysis on the characteristics of multi-scale precipitating systems utilizing the state-of-the-art satellite observation data; (ii) Study on the cumulus convective parameterization based on the analysis of synoptic-scale precipitating systems simulated in the atmospheric version of CCSR/NIES/FRCGC climate model; (iii) Thorough examinations of dependences of tropical precipitation activities in an aqua planet model on the vertical structure of radiative cooling and on model resolution.

Primary achievements in the research project period are as follows, some of which are detailed in the papers[14-26]: (A) Utilizing the TRMM (Tropical Rainfall Measuring Mission) satellite precipitation radar data, we developed a method to determine the dominant factor phenomena for the rainfall from satellite data. We further applied this result to validate the simulated precipitation systems in the atmospheric version of CCSR/NIES/FRCGC climate model. (B) Utilizing the column water vapor data observed from space-borne microwave radiometer data together with the conventional data, we clarified the propagation properties of the Madden-Julian Oscillation (MJO) in the relatively dry western hemisphere and its connection to the initiation of convection of the next MJO event. (C) Utilizing the ECMWF 40-year reanalysis data (ERA-40), we extracted the equatorial westerly wind bursts (WWB) at all longitudes for 23 years. By a statistical analysis, an existence of a mutual interaction between the WWB and El Nino and Southern Oscillation (ENSO) was clarified. It is emphasized that not only WWB enhance the ENSO developments as previously suggested, but also certain ENSO phase provides a favorable environment for WWB to occur, WWB and ENSO thus interacting mutually. (D) Dependence on additional control of free-troposphere relative humidity on cumulus convection was studied comparing the atmospheric equatorial waves coupled with cumulus convective activity, simulated in the atmospheric version of the CCSR/NIES/FRCGC climate model. The mechanism of different behaviors of the equatorial Kelvin wave mode and the equatorial Rossby wave mode in the convective coupling was clarified by comparing results with and without implementations of the humidity control. It was also implied that although the free-tropospheric humidity control on the cumulus convection works to simulate more realistic synoptic systems, more physically based improvements on the parameterization should be pursued in future. (E) With aqua planet models in which the lower boundary of the atmosphere is covered by the ocean, we examined sensitivities of the equatorial precipitation characteristics against the vertical and horizontal resolutions of the numerical model experiments. With high-resolution experiments, a possible scale separation is suggested between the small-scale phenomena advected by the environmental flow and the wave-CISK type phenomena occurring as a result of coupling between the convection and circulation.

To make adequate future projections on changes of atmospheric water and energy circulation, it is significantly important to project changes of tropical and extratropical cyclone generation and development, monsoons, as well as long-term variations such as ENSOs. Results of our studies confirmed that in order to predict the long-term variations accurately, adequate representations of short-term variations associated with cumulus convection are indispensable, and adequate parameterizations of cloud and precipitating systems should be further pursued. It is also confirmed that such further pursuit of parameterization of physical processes should always be accompanied by validations based on newest knowledge utilizing the state-of-the-art satellite and in-situ observations. Accompanying the daily increasing ability of computing systems, resolution of climate models are increasing day by day, and adequate representation of physical processes for models with increased resolutions also should be changing. High nonlinearity of atmospheric phenomena always deserves persistent revalidations of physical parameterizations with new facts. Therefore, as a conclusion, we would like to emphasize that instead of simplistically fixing the selections of what should be included and what can be ignored in the future climate predictions, persistent pursuit of mechanisms of natural phenomena constructing our environment is extremely important.

4. Concluding Remarks

The sub-theme (1) develops a scheme to incorporate not only the direct effect of aerosols (whereby aerosols scatter and absorb mainly solar radiation, thereby perturbing the energy budget of the earth-atmosphere system) but also the indirect effects of aerosols (whereby aerosols serve as cloud condensation and ice nuclei, thereby modifying the radiative properties and microphysics of clouds) on radiative forcing into the CCSR/NIES climate model, and a scheme to incorporate the effect of the interaction of tropospheric ozone and aerosols into the climate model. The sub-theme (2) investigates how processes of the water circulation in the atmosphere, including cloud and precipitation processes, occur in the real atmosphere, and how they should be represented in climate models. The sub-themes (1) and (2) are related each other through the indirect effects of aerosols. The present research project requires computer resources, and utilized mainly the computer system of NIES including the supercomputer (NEC SX-6).

Part of the research project consequently aims at contributing to IPCC, especially IPCC AR4 (Fourth Assessment Report) scheduled in 2007, by applying the developed model to future projection of climate change. CHASER of the research project contributed to a chemistry-climate model intercomparison project and SPRINTARS of the research project contributed to AEROCOM (Aerosol Model Intercomparison Study), both of which are carried out for IPCC AR4. The project is related to the following international research projects of WCRP (World Climate Research Programme): GEWEX (Global Energy and Water Cycle Experiment) / GPCP (Global Precipitation Climatology Project) and WGNE (Working Group on Numerical Experimentation) / APE (Aqua Planet Experiment Project). The project is also related to the international satellite mission project of TRMM (Tropical Rainfall Measuring Mission).

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