B-5.1 Research on the Development and Improvement of a Climate Model (Final Report)

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Abstract An atmospheric general circulation model and a ocean general circulation model have been developed and improved to reproduce the climatology of the real atmosphere.The accuracy of reproduction of the atmospheric general circulation model was increased by improving parameterizations of physical processes, such as radiative transfer, clouds, and land surface, based on physical considerations. Long-term integration of the model indicated that it has sufficient ability to reproduce climatology. Moreover, the model showed good reproducibility even for the stratosphere when the calculated upper boundary was extended to the lower mesosphere. The ocean general circulation model was made efficient by improving the program code. Various kinds of numerical experiments were carried out with the model. These showed that the model reproduces the climate of the ocean well. The inclusion of some parameterizations of physical processes with a sub-grid scale is neccesary to get quantitatively better reproducibility. The atmospheric general circulation model and the ocean general circulation model were coupled by sophisticated means: Long-term integration with a coupled model has become available. A study on global material transport in the atmospheric circulation, which is obtained by integration of the atmospheric general circulation model, was also started. Results of the study showed that there are latitudinal bands in both of the mid-latitudes, where the meridional material transport is less active than that in other latitudes.

Key Words climate model, general circulation, ocean general circulation, hydrological cycle, land-surface process, parameterization, couple of atmosphere and ocean, material transport

1 Introduction

Highly sophisticated numerical models of the physics of the climatic system and material transport in the atmosphere are necessary for us to quantitatively evaluate a climate change such as future global warming. One purpose of this study was to develop such a highly precise and highly efficient atmospheric general circulation model (referred to as "atmospheric GCM" hereafter) and an ocean general circulation model (referred to as "ocean GCM") and a model that couples both of these.

We succeeded in developing these models, and good reproduction was shown by both the atmospheric GCM and the ocean GCM. These two models were also coupled together through the use of a sophisticated technique.

The results of our study are listed here:

1. The development of the atmospheric GCM
    - Improvement on parameterizations of physical processes
    - Numerical experiments for reproduction of the atmospheric climate
    - The extension of the vertical range to include the entire stratosphere
2. The development and improvement of the ocean GCM

3. The development and improvement of the coupling of the atmospheric GCM with the ocean GCM

4. A study of global material transport in the atmosphere

2 Results

2.1 Development and Improvement of the Atmospheric GCM

(1) Optimization of Code in the Radiative Transfer Parameterization

A precise evaluation of a atmospheric radiation process is important to estimate a climate change quantitatively, though precise evaluation of the process takes much CPU time. A new algorithm for optimization of the radiative transfer calculation was developed to improve accuracy and to accelerate calculation speed. We became able to include band absorption by CH4, N2O, CFCs, and so on, with a calculation time that was similar to that required before the improvement.

(2) Improvement of the Treatment of the Interactions of Clouds and Turbulence

An equation for estimating vertical diffusion is improved by incorporating the effect of condensation on the turbulent flux to the Richardson number. This new scheme evaluates an interaction between cloud and turbulence more precisely. Accuracy of reproduction for the climatological horizontal distribution of clouds was improved.

(3) Improvement of Land Surface Parameterization

The surface roughness length for heat and moisture transfer is recognized to be one-order smaller than that for momentum transfer. To represent that effect, the estimation of bulk surface transfer coefficient is modified, allowing for the difference of roughness length. Moreover, to incorporate the effect of stomatal resistance of plants in a simple manner, an upper limit of evaporation efficiency due to stomatal resistance is applied. The value of stomatal resistance is determined for each type of land use. Because of these modifications, overestimation of summertime evaporation over continents is suppressed and a general drying bias over the land surface is improved.

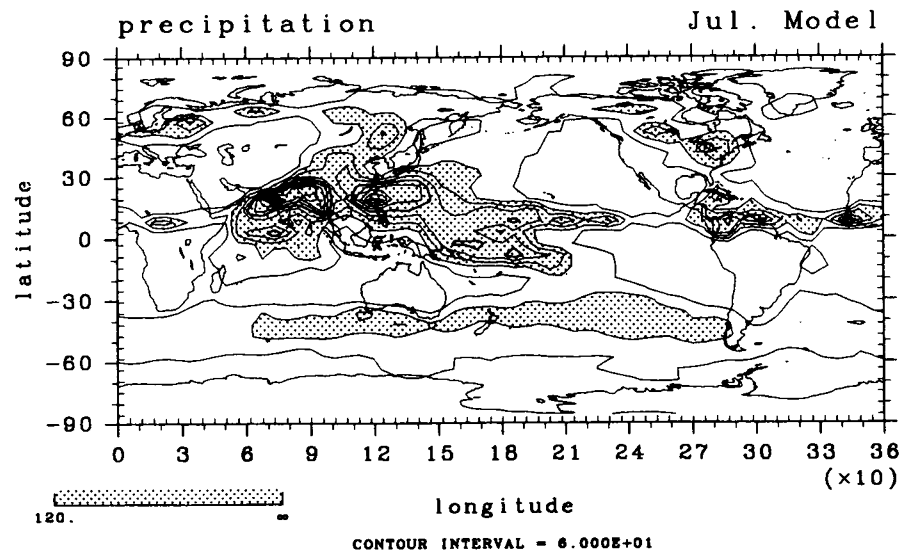

Fig.1: Precipitation distribution in July; the contour interval is 60mm/month; values greater than 120mm/month are stippled.

2.2 Reproduction of Climate by the Atmospheric GCM

After the improvements of the atmospheric GCM described above, a long-term integration of the model with a climatological distribution of sea surface temperature is conducted to evaluate the performance of the model. Generally, the model reproduces the present climate fairly well (Fig.1), though the following problems still remain:

1. A drying bias of lower troposphere and land surface in subtropics.
2. An overestimation of high cloud amount over subtropics in the west Pacific in the summer.
3. A cold bias of the stratosphere.

2.3 Coupling of the Atmospheric GCM and Ocean GCM Models

Coupling of the atmospheric GCM and the ocean GCM models has been started. We have developed a driver that integrates and controls both models, and an interface that controls fluxes of energy and materials transferred between these two models. We will be able to adopt developments of each general circulation model into the coupled model by means of this sophisticated treatment, which involves using the driver and the interface.

The obtained coupled model reproduced climatological sea surface temperature and so on well, though the results depend much on how the sea ice process and other processes are treated in the model. Further development is necessary to get a better result.

2.4 Extension of the Vertical Range of the Atmospheric GCM Including the Entire Stratosphere

The stratospheric climatology of the atmospheric GCM was investigated. The GCM reproduced the stratospheric climatology well. The performance of the model was comparable with those of other advanced GCMs currently available in the world. However, two significant problems remain in the GCM; namely, a poleward shift of the stratospheric westerly jet and a cooling bias in the polar stratosphere. These problems, which many of the other GCMs in the world also confront, are related through the thermal wind balance. Some additional parameter studies suggest that gravity-wave drag has a large influence on the stratospheric climatology. Moreover, these studies also suggest that the introduction of another physical process into our model might improve the result qualitatively.

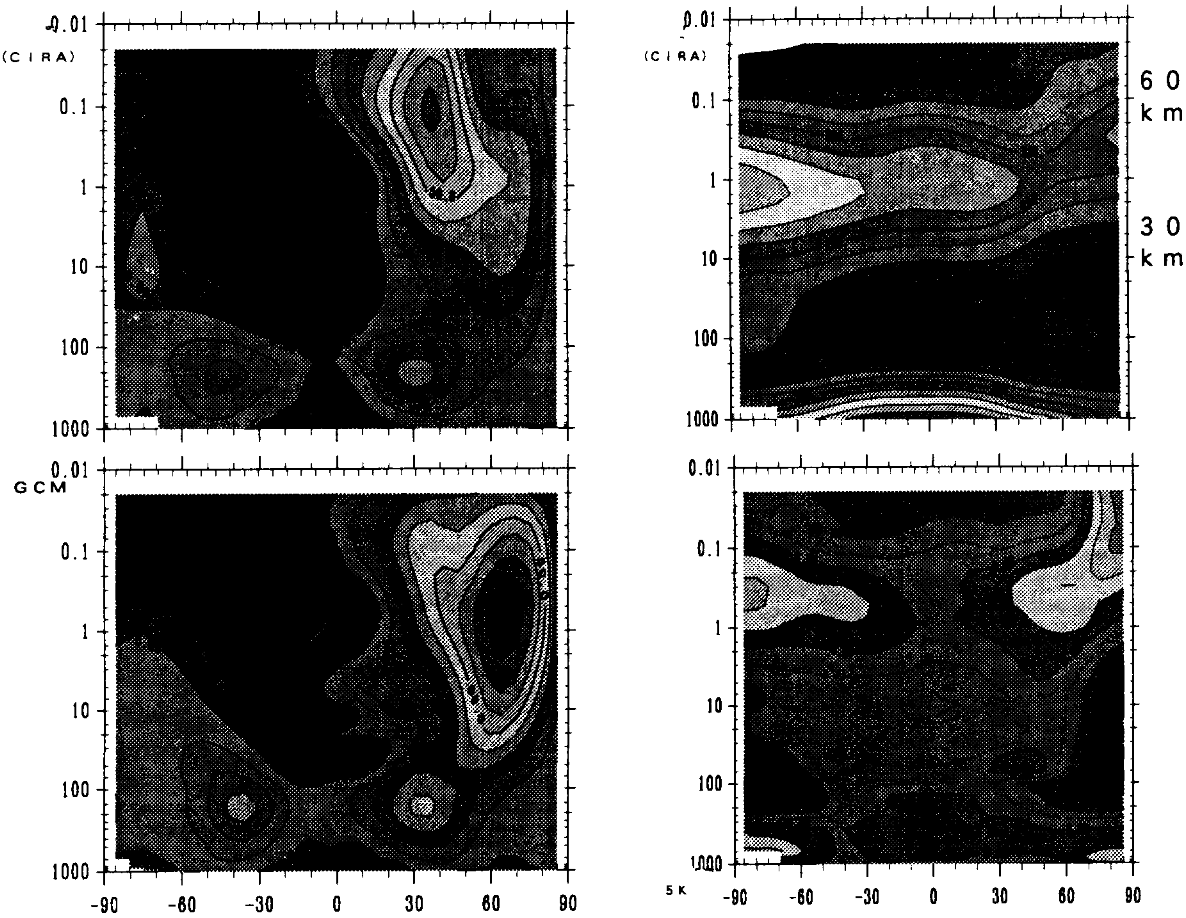

Fig. 2: Meridional Sections of Zonal Mean Zonal Wind and Temperature. Both are averaged from December through February. Observation and the model of zonal wind (upper left and lower left), observation of temperature (upper right), and difference of temperature between the model and observation(lower right). Contour intervals are 10m/s(left),10K(upper right), and 5K(lower right).

2.5 Research on Global Material Transport in the Atmosphere

A new scheme is proposed for analyzing the flux of a particle whose trajectory is given through a surface. The scheme uses Lagrangian trajectory information. A time-scale T of the motion we want to describe is assumed and a successive time T location is defined as an effective location used as a standard for the selection of an effective transit. A transit through a surface is selected as the effective transit contributing to global transport when it is the most recent transit sandwiched temporally between 2 "effective locations" existing on opposite sides of the surface. The scheme acts as a kind of low-pass filter to the trajectory and discriminates between transits that are effective for global material transport and those that are not.

The scheme is applied to motions of a large number of particles in a general circulation obtained from the CCSR/NIES atmospheric GCM. Four-hour averaged interval data of velocities, surface pressure, temperature, and upward mass flux of cumulus convection were stored by integration of the GCM for 1 year. The trajectories of a large number of particles were calculated by a tracer model developed for this study. This tracer model considers advection and convection of the particles. The upward convection due to cumulus convection is suitably handled by using the stored data of cumulus mass flux data from the GCM. Trajectories of nearly four hundred-thousands particles were calculated for 3 months, from January through March. The scheme of flux described above is applied for trajectories of the particles for one month, February, for surfaces of equal latitude. The flux obtained by the scheme shows the existence of potential barriers to global material meridional transport in the mid-latitudes in addition to that near the ITCZ.

Although oscillating meridional movements with short time-scales are dominant in the mid-latitudes because of active baroclinic waves, longer time-scale movements are suppressed in these regions. Clearly, the longitudinal positions where meridional transport is suppressed are localized in the longitudinal direction.

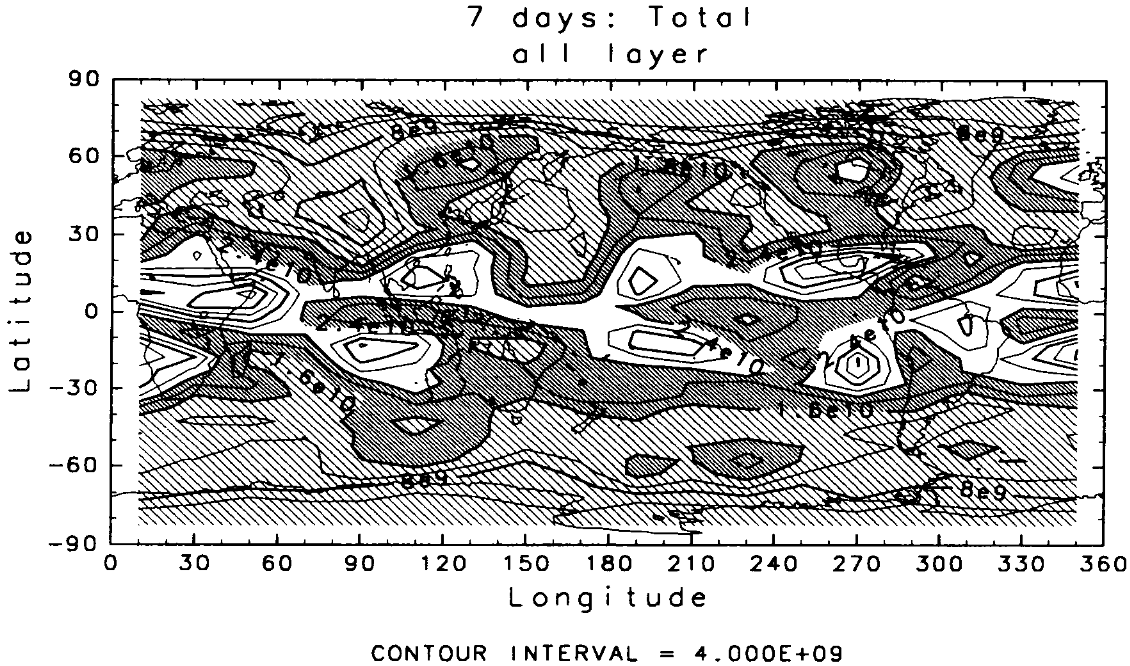

Fig. 3: Longitude-latitude distribution of meridional flux of the atmospheric parcels during February. The flux is integrated through height and selected with T = 7 days condition. The coarser diagonal hatching indicates less flux, the finer hatching indicates medium flux, and no-hatching indicates more flux.

3 Summary

The atmospheric general circulation model and the ocean general circulation model have been developed and improved to be used also to investigate climatic change. Reproduction of the climatological atmosphere was improved in the atmospheric general circulation model by improving parameterizations of physical processes. Integration of the model for a long time indicated that the model has sufficient ability to reproduce climatology. Moreover, the model showed good results even when its vertical range was expanded to a range between the surface and the lower mesosphere. The ocean general circulation model was made more efficient by improving program coding. Various kinds of numerical experiments were carried out with the model. It was shown that the model reproduces climate well. The atmospheric general circulation model and the ocean general circulation model were coupled through the use of a sophisticated method. A long-term run with this coupled model became available. A study on global material transport in the atmospheric circulation that is obtained by integration was also started. Results of the study showed that there are latitudinal bands in both mid latitudes, where the meridional material transport is less active than that in other latitudes.

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