Development of an Atmospheric General Circulation Model for Climate Research

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1 Background

Future climate change due to the anthropogenic release of the carbon dioxide is one of the most important issues of the global environment problem. In order to estimate the possible future climate change, a comprehensive numerical model of climate, which can realistically represent the dynamics of climate system and the circulation of energy and material, is an indispensable tool. However, the performance of currently available climate models is not sufficient for the quantitative estimation of the future climatic change. Under these circumstances, this project of the development of a climate model and improvement of the representation of physical processes is started toward the quantitative estimation of the climate change.

2 Objective

The goal of our research is the quantitative estimation of the climatic change using a comprehensive climate model of atmosphere-ocean-land climate system. Currently, as the first step, we are developing a atmospheric part of the model, *i.e.*, an atmospheric general circulation model (AGCM).

The model is based on a simple AGCM developed at University of Tokyo [1]. This original model is a three-dimensional global primitive equation model using spectral transformation method. It contains rather simple parameterization of physical processes, such as radiation, vertical diffusion, and convection. It was designed for the basic research on the atmospheric dynamics. In order to make the model suitable for climate research, developments on the following three points are required. The first is the improvement of the parameterization of physical processes. Particularly, the parameterizations of radiative transfer, cloud precess, and land-surface processes are very important. The second is the preparation of dataset for use of the model as boundary condition. The third is the testing on the model ability for reproducing the current climate and the tuning of the model parameters, the parameterization schemes, and the boundary conditions.

3 Model Description

The outline of the current model is summarized as the followings.

Basic Equations: 3-dimensional hydrostatic primitive equations on sphere.

Coordinate: longitude, latitude, and normalized pressure (σ).

Prognostic Variables: horizontal velocity, temperature, surface pressure, total water content, soil temperature, soil moisture, snow depth.

Horizontal Discretezation: spectral transformation method with Gaussian grid.

Vertical Discretezation: grid differentiation [2].

Time Integration: leap-frog scheme with time filter. Euler scheme for diffusive terms.

Resolution: vatiable, currentry tested with T42 (2.8° grid) 20 levels.

Diagnostic Variables: vertical velocity, precipitation, evaporation, cloud water, radiative flux *etc.*.

Physical Processes: k-distribution model for radiative transfer [3].
Arakawa-Schubert [4] type cumulus parameterization with prognostic closure.
estimation of cloud liquid water by prognostics of the total water content.
Mellor-Yamada [5] level 2 closure for turbulent diffusion.
bulk scheme for surface fluxes [6].
multi-layer treatment of land-surface energy budget and hydrology [7].
gravity-wave drag scheme included [8].

The radiation code treats absorption, emission and scattering of the solar and terrestrial radiation in one consistent way using correlated k-distribution method and adding theory, with reasonable accuracy up to 70km height. This scheme is still under development. Therefore, another scheme developed by M.D. Chou is used in the experiments that described in the next section. As for the cumulus parameterization, codes of three schemes (Arakawa-Schubert type, Kuo type, moist convective adjustment type) are prepared as plug-in modules. Some comparison tests of the schemes are performed. A estimation scheme for cloud liquid water content is incorporated to realistic representation of cloud-radiation interaction, which is the critical feedback process in the global warming problem. A land surface model incorporating the effect of cryosphere and biosphere is also under development.

4 Preliminary Results

4.1 Perpetual July experiment

A 200 day integration is performed with fixed boundary condition of July using a isothermal initial condition. The time averaged values for the last 100 days period are shown in the figures.

The distribution of zonally averaged temperature is shown in Fig.1. The model result reproduces observed climate rather well, except for the large cool bias at the polar tropopause, which is a well-known common bias of the current agcms. a warm bias at the tropical tropopause is also evident.

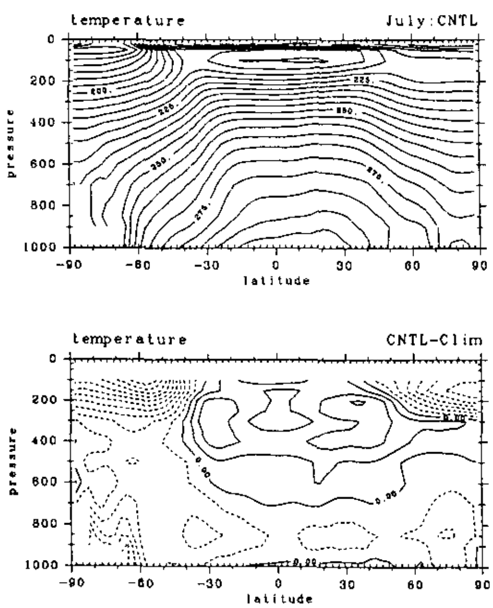

Fig.1 Zonally averaged distribution of zonal wind for perpetual july case. Upper: Model result. Contour interval is 5k. Lower: Model-observation. Contour interval is 2k.

The distribution of precipitation (fig.2) also reproduces observed climate well. However, there are several discrepancies, for example, the ITCZ (inter tropical convergence zone) of tropical eastern Pacific is too weak and the precipitation at the equatorial western Pacific is too small.

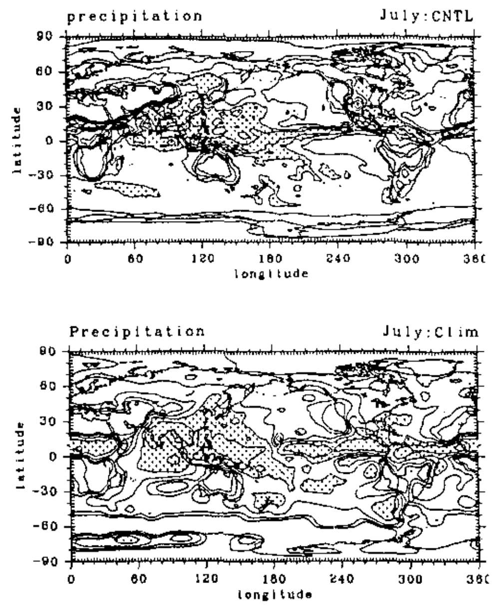

Fig.2 Horizontal distribution of precipitation for perpetual july case. Upper: Model result. Lower: Observation compiled by Legates. Contour levels are, 16, 32, 64, 128, 256, 512mm/month. Areas over 128mm/month are shaded.

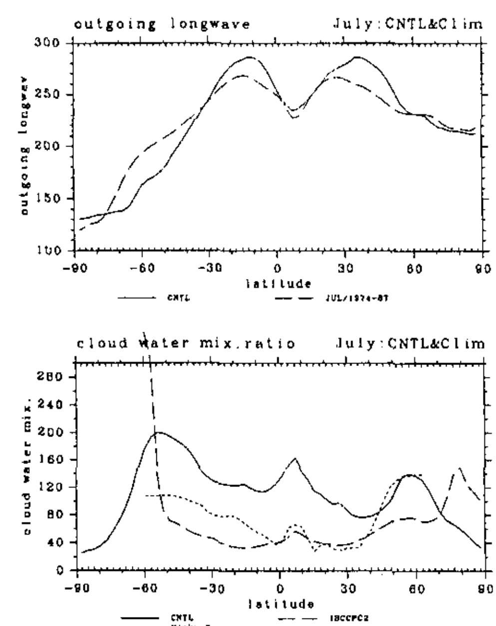

Fig.3 Zonally averaged distribution of outgoing longwave radiation (upper) and integrated cloud liquid water (lower). Solid lines are model results and the dashed and dotted lines are observation.

The model result of outgoing longwave radiation from the top of the atmosphere (Fig.3) is rather poor compared from other agcms. The difference between model result and observed value is large also in the cloud liquid water content. It is apparent that the parameterization of the cloud-radiation interaction must be further improved.

4.2 Seasonal march experiment

A two year integration with seasonal change of boundary conditions is performed. The result shown in Fig.4 reproduces the seasonal migration of the monsoon wind system fairy good except that the wintertime easterly in the northern hemisphere subtropics is too strong.

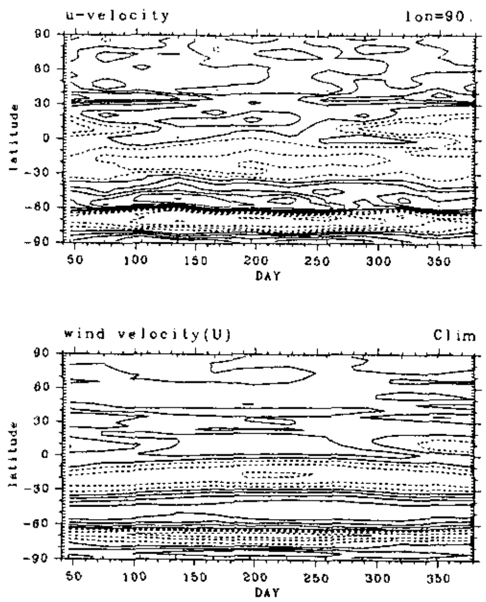

Fig.4 Latitude-time distribution of zonal wind at 90e longitude. Upper: Model. Lower: Observed. Contour interval is 3m/s.

For the current version of the model, there are some problems in the result for the seasonal experiment. One is the too large snow amount in summertime high-latitude. the other is too dry condition of the continental surface. Improvement of the parameterization schemes of the land surface processes is needed.

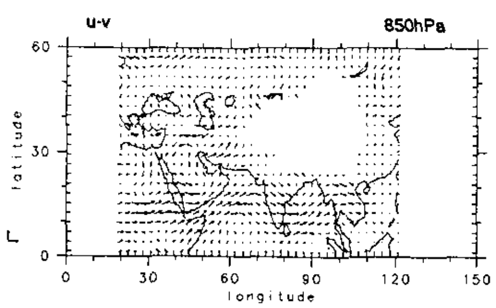

Fig.5 Snapshot of horizontal wind field of 850hpa in july. Unit vector at lower left represents 20m/s.

A snapshot in asian monsoon region in July is shown in Fig.5. We can see a disturbance well resembles the monsoon depression over the Indian subcontinent.

5 Summary

An atmospheric general circulation model for use of the climate study is developed and tested in the ability reproducing the present climate. The result is generally fair, except for some problems probably due to inadequateness of physical parameterization. The improvement of the parameterization schemes, particularly for the cloud-radiation interaction and land surface processes is required. Also, more comprehensive test of the model performance not only for the averaged climate but also for the variability is needed for the validation and further improvement of the model.

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