I-3. Global Warming Research Program

Program Director: Syukuro Manabe (Till Nov. 2001) Taroh Matsuno (Acting from Dec. 2001)

The main goal of the global warming research program is the projection and predictive understanding of global warming. The program consists of three research projects, which conduct research on global warming, carbon cycle and paleoclimate. Here selected research accomplishments during the last year are briefly described.

In the later half of FY 2000 a new group for numerical experimentation of global warming was formed by cross-cutting several research programs. During FY 2001 some of the staff of the Global Warming Research Program are participating in this new activity.

a. Global Warming Research Group

(Group Leader: M.Sugi, Group Members: J. Yoshimura, Z. Geng, Y. Tsushima, Y. Iwasa)

Following the research in FY2000, the mechanism of the decrease of tropical cyclone frequency under global warming conditions was investigated by Yoshimura and Sugi. In order to understand what mechanism is operating to cause the decrease, impacts of the two factors, i.e. increase of the opacity of atmosphere due to CO_2 increase and increase of the sea surface temperatures were separately investigated by conducting numerical experiments under various conditions as listed in Table 1. A summary of results of the experiments is shown as Fig.1 which indicates annual mean numbers of tropical cyclones

	SST	CO_2
COOL1	2°C cooling	normal
CLIM1	Climatology	normal
WARM1	2°C warming	normal
WARM2	2°C warming	2 × CO_2
WARM4	2°C warming	4 × CO_2

Table1. Specification of experimental conditions for the study of impacts of SST rise and CO2 increase.

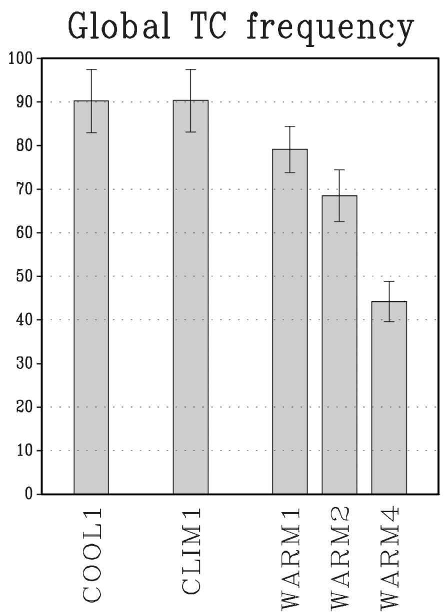

Fig.1: Globally averaged tropical cyclone frequencies (numbers per year) obtained by numerical experiments

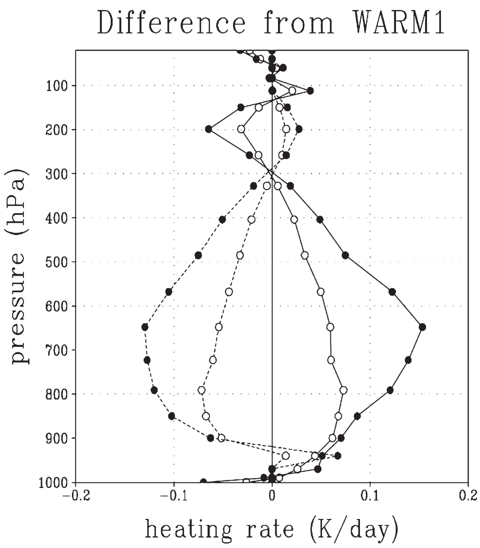

Fig.2: The vertical distributions of the differences of radiative and convective heating rates between increased CO_2 experiments and the control case (averaged in the tropical belt 30S–30N).

generated over the globe under specified conditions. As understood from Fig.1 both factors are important but the increased opacity effect contributes more than the increased SST effect. Simply by raising SST keeping the CO_2 concentration unchanged (WARM 1) more heat is transported from the sea surface to the upper troposphere mainly by the moist convection. The enhanced "back ground convection" so to say causes a larger temperature rise in the upper troposphere resulting in an increase of static stability at least in the present model (Kuo parameterization). The increased static stability reduces the intensity of tropical cyclones leading to a decrease of TC numbers as the same threshold is applied. When the CO_2 concentration is increased by keeping the SST at the same level (WARM 2, WARM 4), the radiative cooling in the lower troposphere decreases (as a due result of increased greenhouse effect) so that the convective heating to balance with it should also decrease. These changes are confirmed in the Fig.2 showing the difference of long-wave heating rates and convective heating rates in the cases of increased CO_2 from the control case. Noted that these experiments were conducted by specifying the same SST regardless of increase of CO_2 concentration so that we must be cautious about the interpretation of experimental results.

Tsushima and Manabe continued the analysis of change of global mean cloud radiative forcing corresponding to global mean temperature change of one-year cycle. The global mean temperature is higher in the northern summer (JJA) than in the southern summer (DJF) by about 3K as shown in Fig.3. The origin of the difference may be attributed to the asymmetry of continental land masses between the two

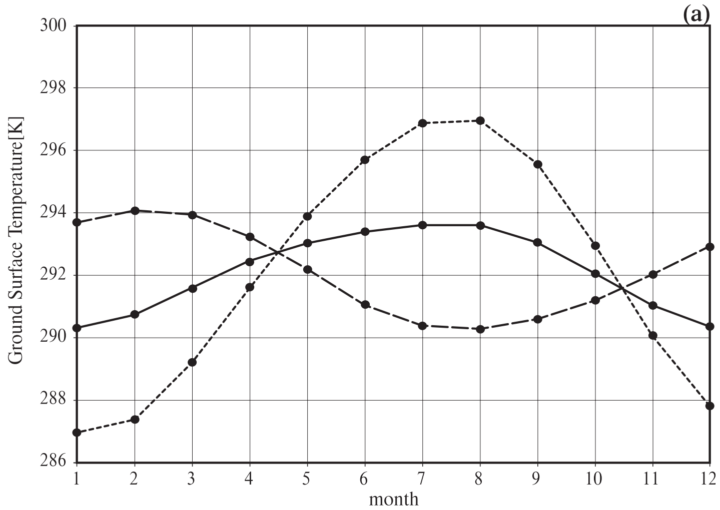

Fig.3: Annual variation of surface temperature (K). Solid, dashed and dotted lines stand for the temperature of global mean, southern-hemisphere mean and northern-hemisphere mean respectively.

hemispheres. The authors took advantage of this fairly large difference of global mean temperature so as to regard this global-scale temperature change as a substitute of global warming and also to regard that change of cloud's properties, if any, represent the change which might occur associated with the global warming. The short wave component of cloud radiative forcing normalized to unit cloud cover is calculated for each month of year using the observed data by ERBE and also using data from 3 model simulations. The results are shown in Fig.4. As seen from the figure all models are distinctly more sensitive than the real state to give larger trends of increase of cooling rate per unit cloud area (increase of reflectivity) with increase of global mean temperature, whereas the observed ERBE data show very little dependence though the tendency is the same. The origin of the dependency common to model results can be attributed to the increase of cloud water thickness with increasing global mean temperature as shown in Fig.5.

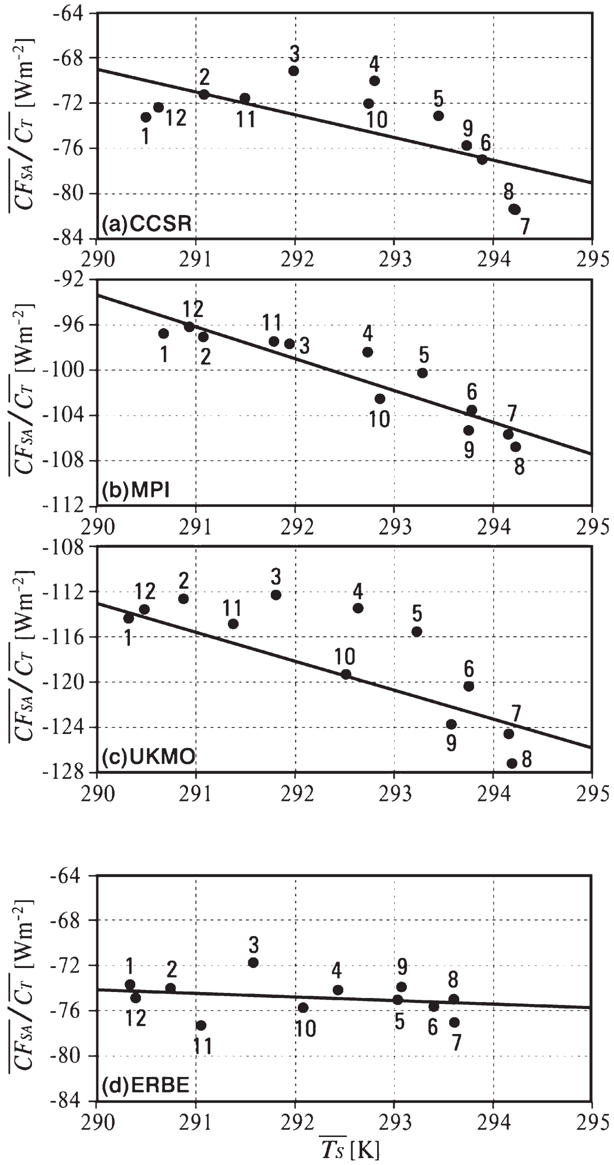

Fig.4: Monthly mean values of short wave component of cloud radiative forcing per unit cloud area plotted against corresponding monthly mean value of the globally averaged surface temperature obtained from climatology simulation by 3 models and the observed data of ERBE.

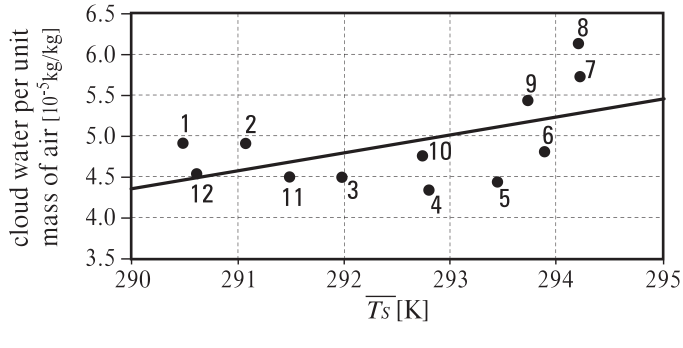

Fig.5: Globally averaged monthly mean cloud water content per unit cloud-containing air mass plotted against the global mean temperature calculated from climatology simulation by CCSR/NIES AGCM.

As continuation of the work in FY2000 Iwasa investigated radiative-convective equilibrium of a gray atmosphere by use of both dynamical convection and kinematical circulation models (DCM and KCM). Global warming experiments were made by increasing the concentration of non-condensating greenhouse gas. In equilibrated states both DCM and KCM gave significant increases of temperature and water vapor mixing ratio for increases of the greenhouse gas concentration but the corresponding changes (decrease) of relative humidity were rather small (Fig.6). As the result it was confirmed that water vapor change has a significant positive feedback unlike Lindzen's arguments.

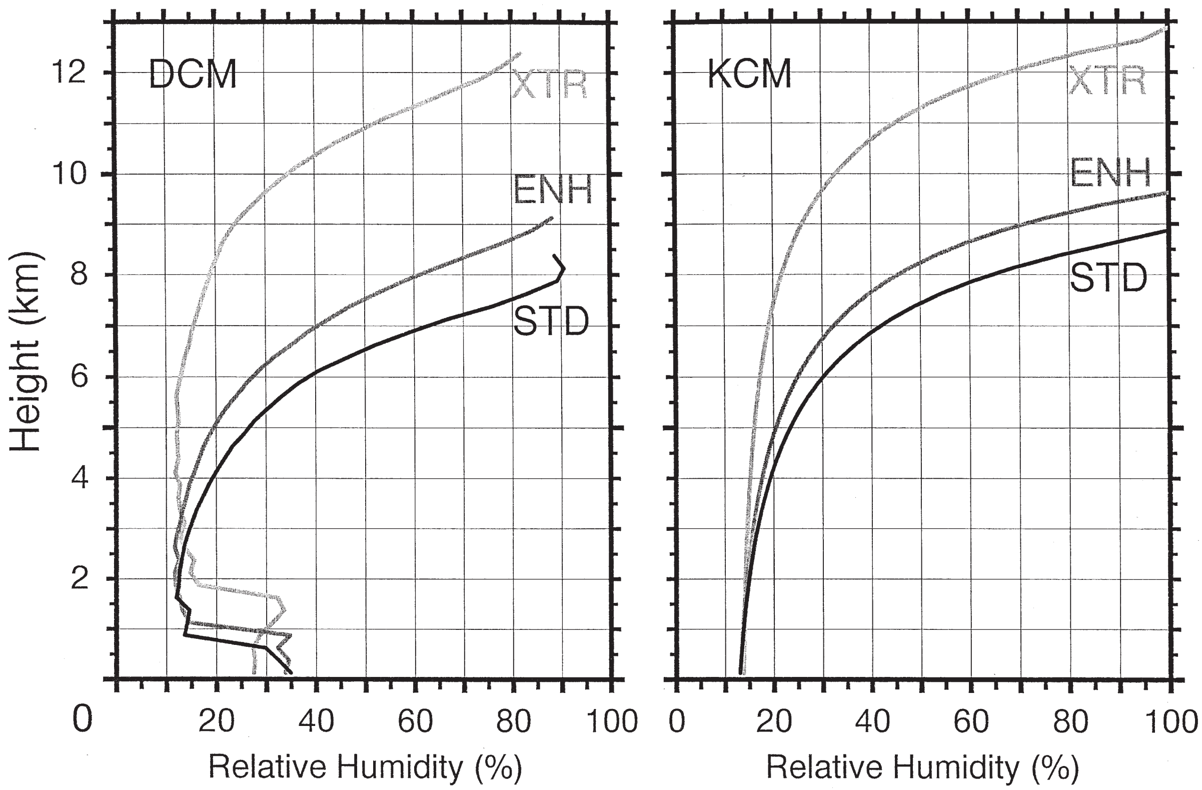

Fig.6: Vertical profile of relative humidity in the subsidence center averaged over 10 days in equilibrated states under different warming scenarios (ENH, XTR) and the control case (STD) obtained by the dynamical convection model (DCM, left) and the kinematical circulation model (KCM, right).

Carbon Cycle Research Group

(Group Leader: Y. Yamanaka, Sub Leader: A. Ishida, Group Members: M.J. Kishi, S.L. Smith, Y. Sasai, M. Aita-Noguchi, M.Ohata)

During the last few years, the carbon cycle research group has participated in the International Ocean Carbon Cycle Intercomparison Project (OCMIP), comparing its model to other models. As a part of OCMIP, the group conducted a biotic experiment and estimated oceanic uptake of CO_2 during 1980s to be 2.1 GtC/year, which is the same value as an abiotic experiment conducted in the previous year. These results are preparing to publish as a special issue of Global Biogeochemical Cycles, a journal of American Geophysical Union (AGU), and contributed to chapter 3 of the 2001 report of Intergovernmental Panel on Climate Change (IPCC).

The carbon cycle research group has developed an ecosystem model (Fig.7) coupled with Biogeochemical General Circulation Models (BGCMs), which represents explicitly the dynamics of oceanic ecosystems and settling particles, to predict the effects of global warming on ecosystem dynamics and the effects of those changes in ecosystem dynamics on biogeochemical cycles and oceanic CO_2 uptake. The development of the ecosystem model has been contributed as a part of the North Pacific Task Team (NPTT) the Joint Global Ocean Flux Study (JGOFS) and to the Lower Trophic Level Modeling Workshop in the North Pacific Marine Science Organization (PICES). This model is applied to several time-series observation stations: Hawaii Ocean Time-series Program (HOT), Kyodo North Pacific Time-series (KNOT), and A-line in the Northwestern Pacific. The model results successfully simulate the observed seasonal variations and interannual variability of chlorophyll-a and primary productions (Fig.8). Simulated primary production by diatoms (green line) has its highest peak in spring, the spring bloom, which compares well with observations. The spring bloom of diatoms has large interannual variations. After the diatom bloom, primary productions by PS increases (red line), in the often-observed transition

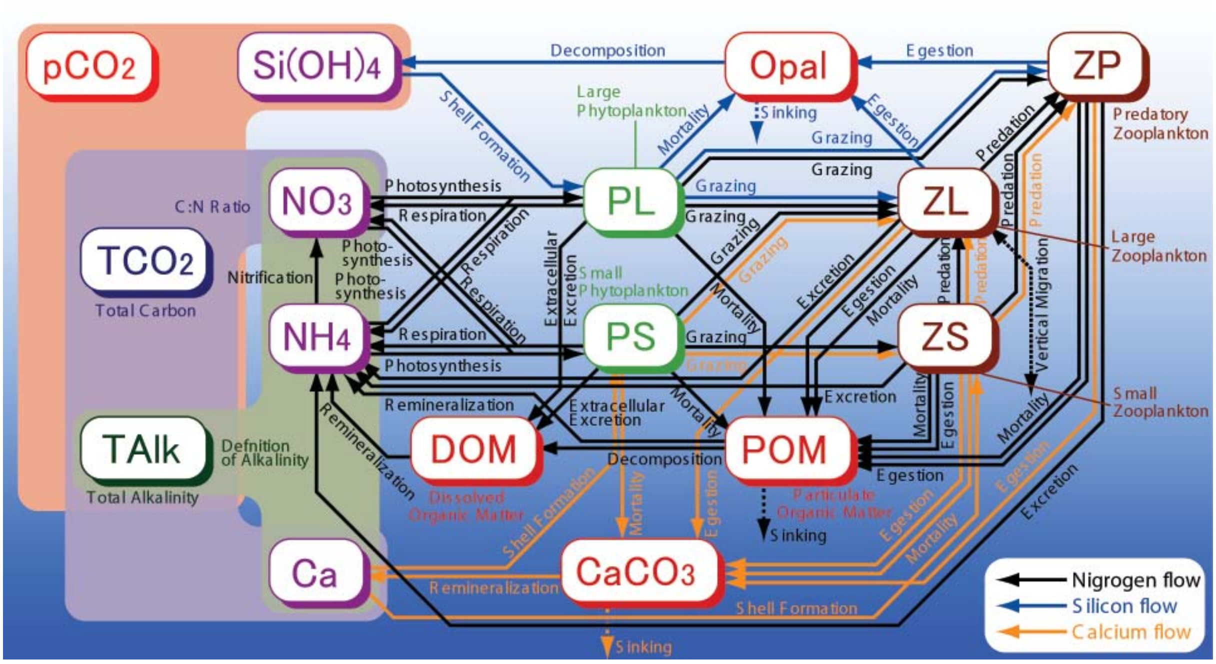

Fig.7: Schematic view of interactions among the fifteen model compartments

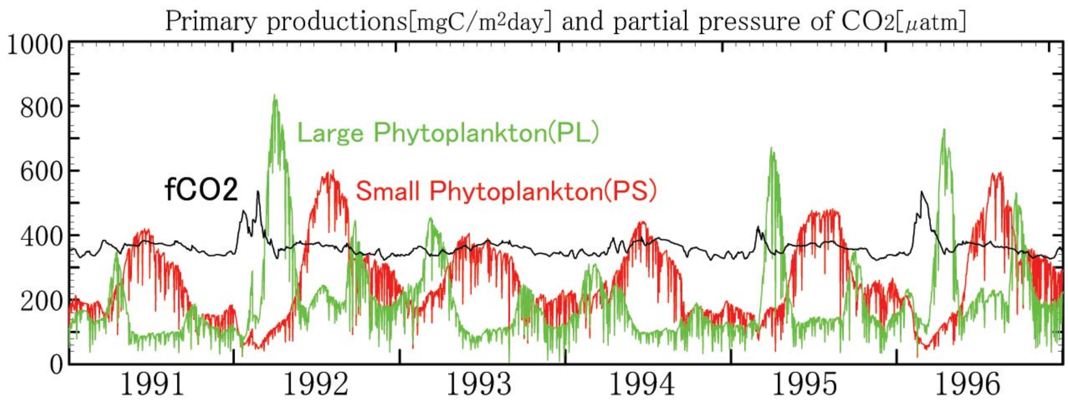

Fig.8: primary productions by diatoms (PL, green line) and other phytoplankton (PS, red line) and partial pressure of carbon dioxide (black line) from 1991 to 1996

from a diatom-dominated bloom to a flagellate-dominated bloom which exhausts the nitrate in the surface waters by late summer. Many frequent downward spikes appear in the line representing primary production in Figure 8. These represent decreases in primary productions resulting from decreases in solar radiation during the overcast conditions.
The carbon cycle research group has started a study of eddy-permitting high resolution model with 1/4x1/4 degrees, in order to understand effects of mesoscale eddies on the CFCs distribution.

Paleoclimate Research Group
(Group Leader: A. Abe, Sub Leader: T. Motoi, Group Members: K. Sakai, T. Nishimura, Y. Iwasa, Y. Tsushima, W.L. Chan, J. Hargreaves, H. Yih, T. Segawa, R. Ohgaito)

Paleo-climate group investigates the past, present and future climate through climate modelling and data analyisis.

1. Simulation of ice age climate using a GCM and paleo-data.

The paleoclimate research group has simulated past climates at various stages of the transition between the glacial and interglacial states, using a high resolution-atmospheric model (CCSR/NIES T106 GCM). Incorporating the results of the mass budget analysis into a dynamical model of continental ice-sheets developed at CCSR, the group has simulated the continental ice-sheets of the Last Glacial Maximum successfully. The role of ice sheet - atmosphere interaction was focused. The main conclusions are the ice sheet during the LGM is maintained mostly by albedo feedback and elevation-mass balance feedback, which means a careful treatment of albedo parameters are needed. Also stationary wave effect on temperature is extracted. Its effect is important for the advance in the east part of Laurentide ice sheet and prevents the migration in the Alaska region and also the Fennoscandinan ice sheet to the south in the western part. In order to clarify the relation amoung various paleo-data sources during the termination stages of ice age cycle, wavelet analysis was carried out. Future studies using both data and models are expected, as well as modelling studies linked to the carbon cycle group.

2. Development of a simple climate model

A coupled climate model which belongs to an intermediate level in the complex climate model hierarchy is at a final stage of development. It consists of a full-3D Ocean General Circulation Model (resolution: 2.8x2.8, 16 levels), a 2-layer statistical atmospheric model (2.8x2.8), and a surface model (2.8x2.8) including continental icesheet and bedrock models (1.4x0.7). It is designed for very long integrations on the timescales of the ice age cycles, namely 100,000 years, and the first target of the investigation is the so-called Dansgaard-Oeschger oscillation during the last glacial period. The model is also expected to provide useful ideas for those investigations using more complex but sophisticated coupled GCMs.

3. Role of thermohaline circulation in the past

To understand the role of the ocean in the Cretaceous warm climate of the Mesozoic era, GFDL R15 coupled ocean-atmosphere general circulation model was used. Research through a sensitivity experiment, whereby atmospheric CO_2 is quadrupled and both Greenland and Antarctic ice sheets are absent, was started. Results showed that the model ocean temperatures are much warmer in the sensitivity experiment and are similar to paleocean temperatures estimated from oxygen 18 analysis of planktonic and benthic foraminifera compiled by Savin (1977). A sensitivity experiment to study the effects of cutting off the Mediterranean outflow through the Strait of Gibraltar on the global climate and in particular on the North Atlantic THC has also been started. The blocking of the Mediterranean outflow results in weakening of the THC in the Atlantic Ocean, with largest changes in sea temperature and salinity at high latitudes. The ocean has variabilities in many spacial and temporal scales.

Data analyses of satellite observed sea surface temperatures were carried out to obtain fundamental features of interannual variations in the ocean, especially in the Southern Ocean which exhibits many variabilities in space and time. The methods used for these data analyses are applicable for both model-calculated and paleoclimate proxy datasets.