B-11.1 Prediction of Hydrological Cycle Change in Japanese River Catchment scale using the Hydro-meteorological Model

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Abstract

Purpose of this study is to estimate the effect of global warming on the hydrological cycle over Japan. To predict the effects of greenhouse gas induced climatic change, we often use General Circulation Models (hereinafter called GCMs). However, the grid size of GCMs is too course to estimate the change of precipitation over Japanese river catchment scale, i. e. 10^2-10^3 km^2. So, we tried two kinds of approach to fulfill this gap. One approach is to analyze the historical relation between weather pattern and precipitation amount, which is then applied to the simulated weather pattern based on the output of GCM for generating the precipitation pattern under warming condition and for evaluating the change. The other approach is to use a hydrologic model coupled with a meso-scale atmospheric model, which utilizes the output of GCM as a boundary condition and can simulate the change of precipitation, temperature and soil moisture under the condition of doubled concentration of CO_2. Simulated results of both approaches using the output of MRI-GCM, developed by the Meteorological Research Institute, can be summarized that the annual precipitation amount in the warming world would decrease in the most part of Japan Island, though we have to keep in mind the limitation of the ability of the present GCM to simulate the growth of typhoon.

Key Words Global warming, Hydrological cycle, GCM, Hydro-meteorological model, Weather pattern

1. Research Objective

Global warming affects the patterns of the hydrological cycle, changing the amount of runoff into rivers and the amount of water resources. It is our concern that this would greatly influence the planning and management of rivers. In order to take the appropriate measures for coping with the possible change in the future, it is necessary to evaluate the extent of the change in advance. The purpose of this study is to develop a methodology for the quantitative assessment of the effect of global warming over Japan region and to predict the effects of green house gas induced climatic change on the water balance.

2. Research method

To predict the effects of greenhouse gas induced climatic change, we often use General Circulation Models (hereinafter called GCMs). However, the grid size of GCMs is too course to estimate the change of precipitation over Japanese river catchment scale, i. e. 10^2-10^3 km^2. So, we tried two kinds of approach to fulfill this gap. One approach is to analyze the historical relation between weather pattern and precipitation amount, which is then applied to the simulated weather pattern and precipitation amount, based on the output of GCM for generating the precipitation pattern under warming condition and for evaluating the change.

The other approach is to use a hydrologic model coupled with a meso-scale atmospheric model, which utilizes the output of GCM as a boundary condition and can simulate the change of precipitation, temperature and soil moisture under the condition of doubled concentration of CO_2.

The methods and the results of simulation are to be shown in the following section.

3. Weather pattern analysis method

In order to get the historical relation between weather pattern and precipitation amount, we began with analyzing the relationship between observed synoptic climatrogical phenomena and observed daily precipitation at several points in Japan, using Yoshino's weather pattern classification method[1)], in which daily climate was categorized into 15 types as in Table 1. Using this categorization, daily weather charts during 1961-1985 were classified into these patterns as shown in Table 2. We assumed each day's probability of precipitation occurrence obeys uniform distribution and each day's frequency of precipitation amount is expressed by exponential distribution and relate them with categorized weather patterns. Then we analyzed MRI-GCM output, which has been developed by the Meteorological Research Institute[2)], Japan, under the condition of doubled CO_2 concentration to generate weather pattern, which was used to calculate the transition probability matrix of weather pattern in the case of global warming. Fig. 1 shows the frequency of each weather pattern. These analysis were combined to make the Monte-Carlo simulation for generating quasi precipitation pattern over Japan Island in the warming condition, assuming that the probabilistic relation between the weather pattern and the rainfall event would be unchanged and also that the day to day transition of weather pattern can be expressed as Markov process in each month[3)]. The generated quasi precipitation series under different conditions were compared to evaluate the effect of global warming on the precipitation pattern over catchment scale in Japan.

In order to verify the quasi-precipitation model, 100 years daily precipitation were generated for Sofugamine observation station of Ura-Tsukuba basin using the past historical data of weather pattern and precipitation amount during 1969-1985. Annual average precipitation from the simulation was 1385mm, which showed a good agreement with the observed one (1381mm). Comparison of the simulated and observed daily precipitation for 6209 days ordered from the maximum to the minimum also backed up the validity of the model[4)].

The above mentioned quasi precipitation model was applied to 15 cities representing each local climatological characteristics.(see Fig. 2) The comparison of the daily precipitation series under the present and doubled CO_2 concentration showed a decrease of annual precipitation for Kanto, Chubu and Seinan outer belt, while in Hokkaido, Tohoku and Seinan outer belt, it almost did not change.(see Fig.3 and 4)

The difference of precipitation between each scenario is due to the change of frequency of some weather patterns. The distribution of the annual precipitation under each weather pattern at Morioka, Shizuoka and Kochi are in Fig. 5, which shows, in general, the precipitation under type Ⅴ (north Pacific anticyclone) and type Ⅳ (stationary front in a rainy season) increases and under type Ⅵ (typhoon) decreases according to the fluctuation of the weather pattern frequency. At Morioka, however, decrease of precipitation due to typhoon is less then those at Shizuoka and Kochi. This difference causes the change of annual precipitation. It can be said that where the precipitation due to typhoon in summer is large under the present concentration of CO_2, the annual precipitation decreases under doubled CO_2 condition, while it does not show decrease where precipitation due to typhoon is not large under the present CO_2 condition. Looking at the precipitation change under each weather

Table 1. Yoshino's pressure pattern classification

I		There are anti-cyclone at weat side of Japan and depressure at east side of Japan.
II	Depression	a. movig east around Hokkaido or Karafuto.
		b. moving from Japan sea to north-east.
		c. moving from East China sea to Pacific ocean at north-east side of Japan.
		d. existing at two places.
III	Migratory anticyclone	a. moving east over north-east area or north area in Japan
		b. moving over Honsyu Island.
		c. like Bands.
		d. moving east over East China Sea or Pacific ocean around Japan.
IV	Mainly stationaly front	a. locating over Japan Islands.
		b. locating over East China Sea or Pacific ocean around Japan.
V		North Pacific anticyclone as a rule.
VI	Typhoon	a. locating over sea at south side of Kyusyu Island.
		b. locating over Honsyu Island or along coast aroud Honsyu Island.
		c. locating over north area of Japan.

Table 2. Frequency distribution of weather pattern for 1964-1985

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
I	406	291	161	24	8	1			16	71	185	323	1486
IIa	75	61	105	121	127	58	43	54	101	129	118	77	1069
IIb	42	38	45	47	52	42	29	28	38	35	48	50	494
IIc	45	77	91	88	77	45	16	12	14	51	53	45	614
IId	63	53	58	58	55	37	19	7	17	39	40	54	500
IIIa	17	24	33	62	55	53	38	34	86	84	47	13	546
IIIb	76	91	164	202	171	83	26	22	113	167	152	115	1386
IIIc	14	9	23	25	85	41	10	10	37	101	64	39	459
IIId	27	34	57	45	28	10	1	5	8	10	21	42	288
IVa	3	12	7	24	21	104	183	112	98	19	3	2	588
IVb	7	16	30	30	61	229	117	62	109	51	13	10	735
V			1	23	33	38	260	308	63	1		1	728
VIa						4	21	68	16	5	5		119
VIb					1	5	11	52	28	11	1		110
VIc							1	1	6	1			9
Total	775	706	775	750	775	750	775	775	750	775	750	775	9131

Shaded columns shows relatively large number in each line.

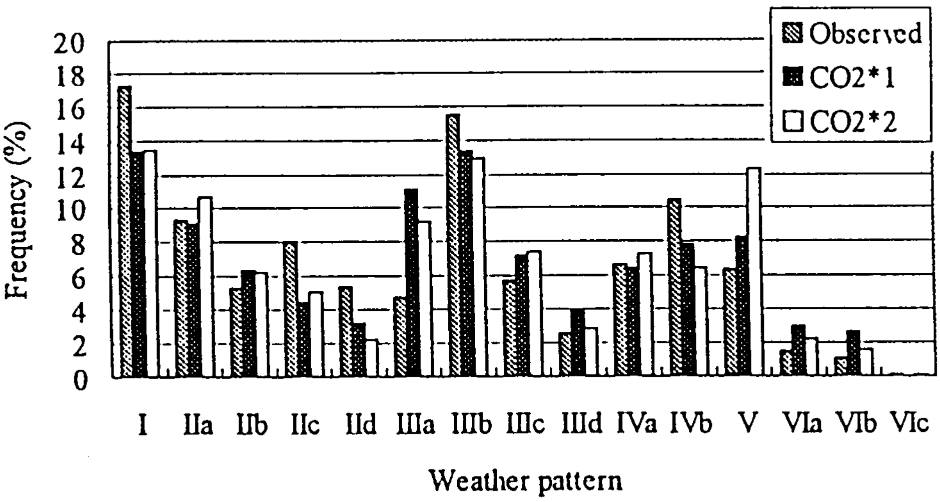


Figure 1. Frequency of each weather pattern under each scenario

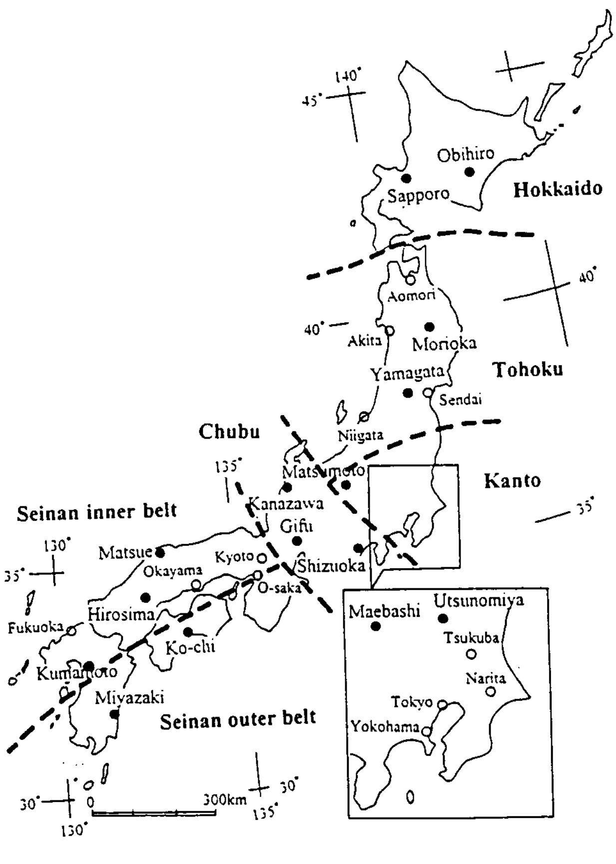


Figure 2. Location of the selected stations for analysis (black circle)

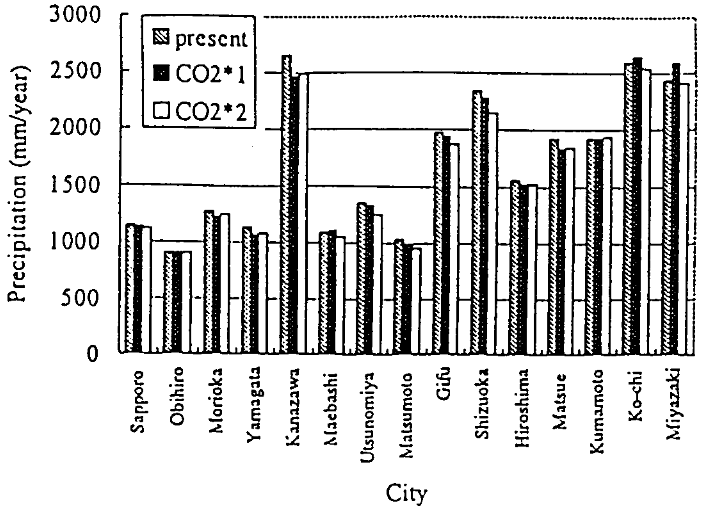


Figure 3. Annual precipitation at each city under each scenario

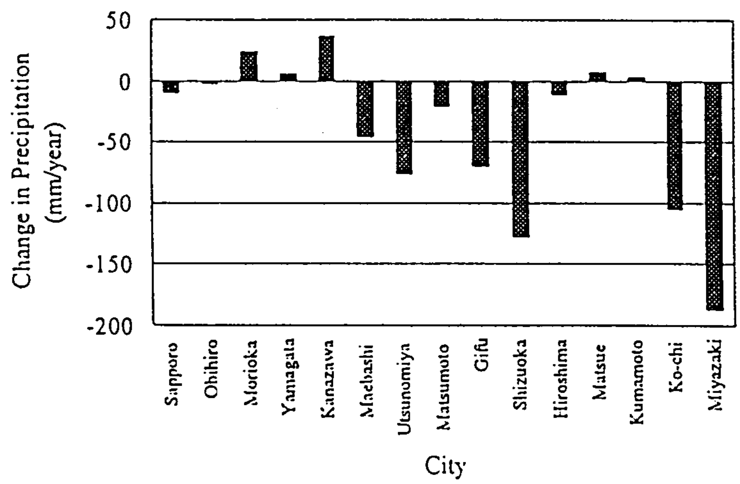


Figure 4. Precipitation change due to CO_2 doubling

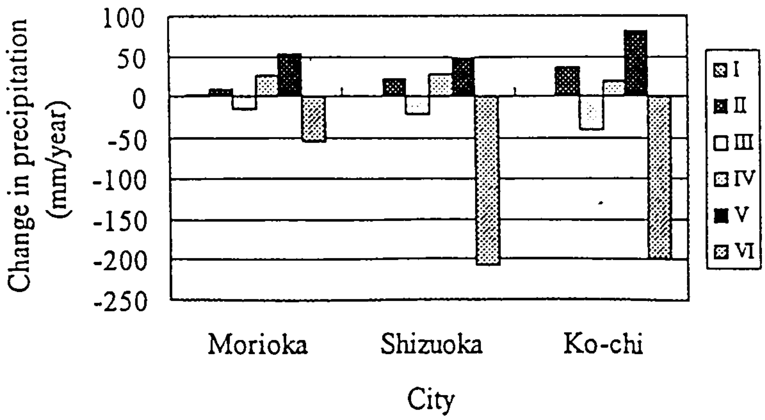


Figure 5. Precipitation change under each weather pattern

pattern, precipitation under type Ⅳ and Ⅴ increases and that under type Ⅳ decreases. At Shizuoka and Kochi, the precipitation change due to typhoon explains most of the change in the annual precipitation.

But, we have to keep in mind that the above analysis is under the following limitations. They are : 1) since the growth of typhoon is not well modeled in the present version of GCM, the change of intensity and size of typhoon due to climatic change might not be well estimated. 2) we assumed that Yoshino's weather pattern classification can be applicable and the relationship between the weather pattern and precipitation does not change even under the warming condition, that the statistical equation to generate daily rainfall intensity holds for any weather pattern and location of the station and that the weather pattern transition matrix is statistically reliable.

4. Meso scale hydro-meteorological model

As a second approach to predict the effect of global warming on the hydrological cycle over Japan, we used a hydrologic model coupled with a meso scale atmospheric model, which utilizes the output of GCM as a boundary condition and can simulate the change of precipitation and temperature under the condition of doubled concentration of CO_2. The meso scale hydro-meteorological model, developed in cooperation with Prof. Kavvas of the University of California at Davis, can describe the interrelationship between the land surface and the atmosphere and can simulate hydro-meteorological variables such as precipitation, evapotranspiration and soil moisture over Japan main island. There are two types of model, one is 60km mesh and the other one is 20 km mesh. 20 km mesh model, which uses the output of 60 km mesh model as boundary conditions and land surface characteristics. The domain of 20 km mesh model is as shown in Fig. 6. The important land surface conditions include the surface roughness, the amount of heat transfer and evapotranspiration, which are much more comprehensive than for ocean. The scale of the physical phenomenon at the boundary between the land and the atmosphere is much smaller than the atmospheric model, which requires the parameterization of the variables based on the physics of the phenomenon. So, we developed the land surface hydrological process model, which can consider the interruption of rainfall by plants and surface soil moisture conditions. We used the output of MRI-GCM. Evaluation of the model was executed for January 1989, which showed relatively good agreement for daily precipitation, daily average temperature and daily average relative humidity at the ground surface level at selected points. Fig. 7, as an example, shows the comparison of daily observed and simulated precipitation pattern at Tsukuba. Fig. 8 shows the comparison of observed and simulated aerial distribution of monthly precipitation. Comparing the simulated results under the condition of present and doubled CO_2 concentration, it was shown that, in the warming world due to doubled CO_2, the annual precipitation amount tend to decrease over simulated domain, especially at the mountainous area of central main island as shown in Fig. 9. It was also shown that the relative humidity at the ground level would slightly decrease and that the annual average surface soil moisture would decrease about 5%. It should be noted that this approach is also under the limitation of the accuracy of GCM.

5. Conclusion

Weather pattern analysis method and meso-scale hydro-meteorological model were developed as methodologies to evaluate the effect of global warming on the hydrological cycle over Japanese river catchment scale. Simulated results of both approaches using the output of MRI-GCM can be summarized that the annual precipitation amount in the warming world would decrease in the most part of Japan Island, though we have to keep in mind the limitation of the ability of the present GCM to simulate the growth of typhoon.

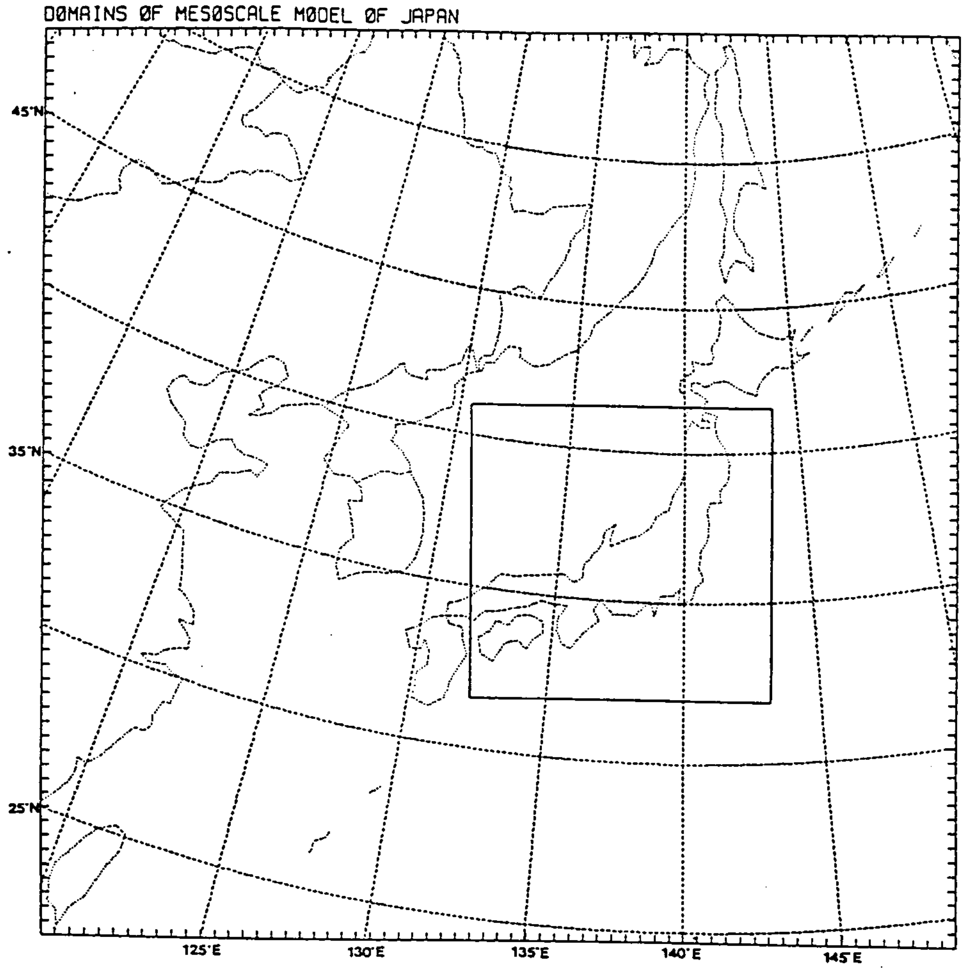
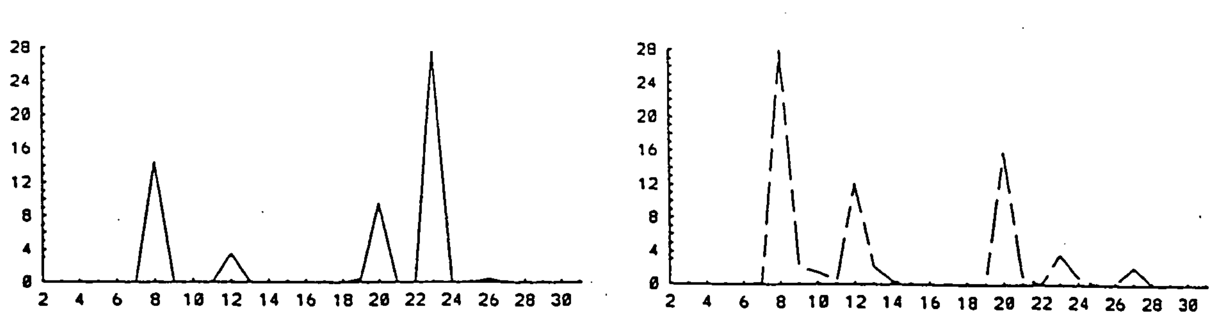


Figure 6. Simulated domain of the 20 km mesh model



Observed (mm/day) Simulated (mm/day)

Figure 7. Observed and simulated precipitation pattern at Tsukuba for January 1989

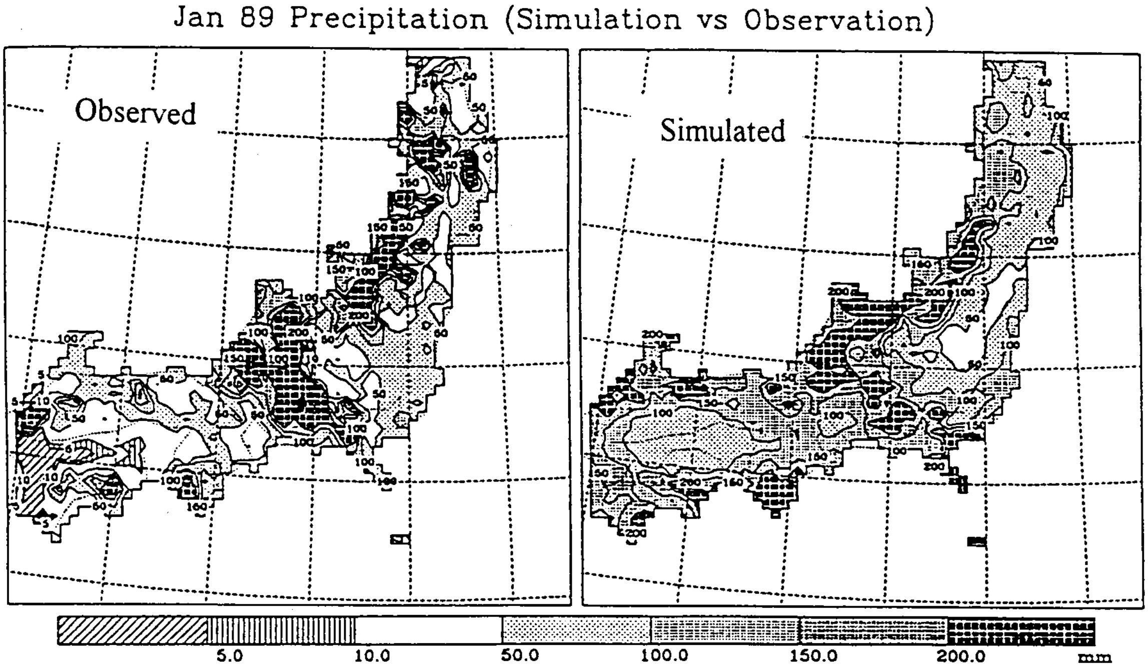


Figure 8. Observed and simulated aerial distribution of monthly precipitation for January 1989

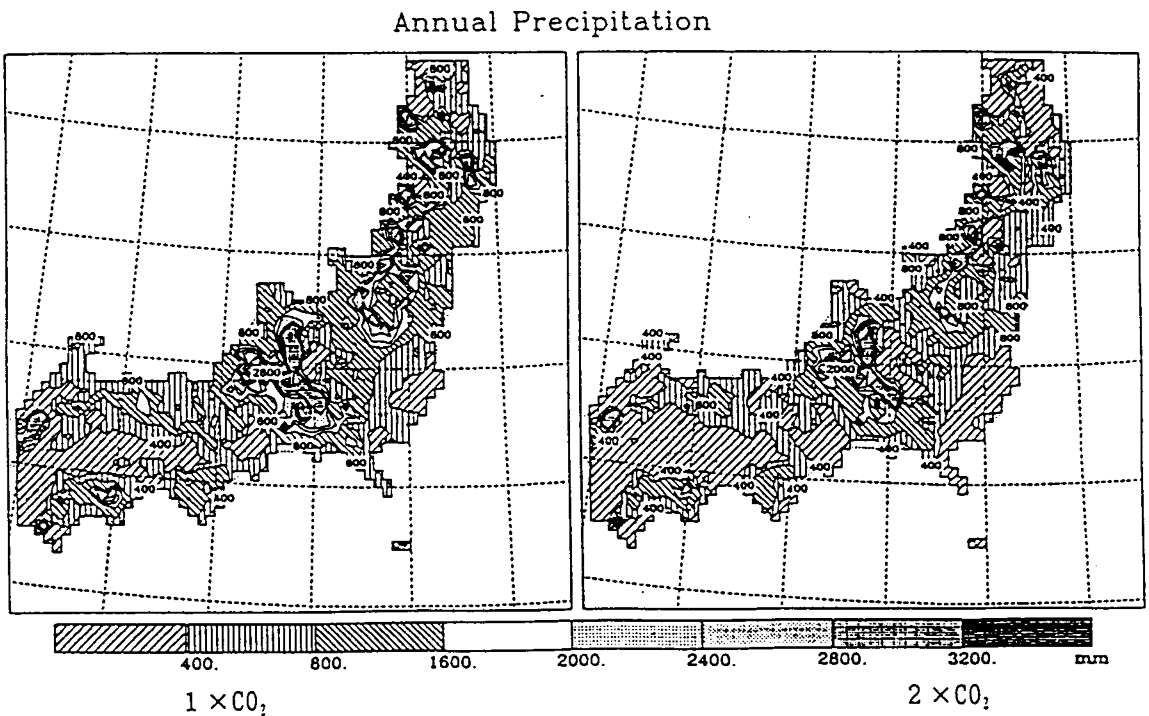


Figure 9. Simulated change of aerial precipitation under the warming condition

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