Journal of Global Environment Engineering, Vol. 2, pp. 23–37, 1996

ESTIMATION OF THE CHANGE IN PRECIPITATION OVER JAPAN DUE TO GLOBAL CLIMATE CHANGE BY THE WEATHER PATTERN ANALYSIS

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Abstract

The purpose of this study is to predict the effects of greenhouse-induced global warming on precipitation at river basin scale in Japan. We applied a weather pattern - precipitation analysis to the outputs of a GCM under the present concentration of carbon dioxide (CO_2) ($CO_2 \times 1$ scenario) and under the doubled concentration of CO_2 ($CO_2 \times 2$ scenario). We found that under $CO_2 \times 2$ scenario, frequency of typhoon decreases and frequency of North Pacific anticyclone increases in summer season. It was shown that in Kanto, Chubu and Seinan outer belt area, where most of precipitation in summer is caused by typhoon, annual precipitation decreases, while in Hokkaido and Tohoku area, annual precipitation almost does not change.

KEYWORDS: *climate change, prediction of precipitation, weather pattern analysis*

1. Introduction

By-products of industrial and agricultural activities, such as carbon dioxide (CO_2), were recognized as potential cause for climate change. It is mentioned that global warming due to greenhouse-gases has been already starting to occur. In order to cope with change in hydrological cycle due to global warming, it is necessary to study its potential long term climate and hydrological impacts.

To predict the effects of greenhouse-induced climate change, we often use General Circulation Models (hereinafter called GCMs). However, the grid-size of GCMs is too coarse to estimate the change in precipitation by global warming on Japanese river-basin scale, i.e. 10^2-10^3km^2. One possible approach to fulfill this gap is to use a small-grid-model, i.e. meso-scale model, nested in a GCM. The other approach is to look at the relation between weather patterns and precipitation. As a latter approach, we used a weather pattern - precipitation analysis proposed by Hay and McCabe (Hay *et al.*, 1991) and estimated the amount of precipitation over Japan under $CO_2 \times 1$ scenario and $CO_2 \times 2$ scenario. This study has been

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proceeded under the umbrella of joint research project between the Public Works Research Institute (PWRI) and the United States Geological Survey (USGS).

2. Characteristics of weather pattern in Japan

Weather pattern in Japan is classified into 15 categories on the basis of low and high pressure systems by Yoshino (Yoshino, 1978) as shown in Table 1. Using this categorization, daily weather charts in 1961-1985 were classified into these weather patterns. Results are shown in Table 2. The pressure pattern of type I, i. e. anti cyclone at west side and low pressure system at east side of Japan, appears in winter season and type V, i. e. north Pacific anticyclone, is typical in summer season. Type IV mainly represents a stationary front in a rainy season like Bai-u front and type VI represents typhoon. It often rains in type IV and type VI, which are particular weather patterns in Japan and characterize Japanese climate. Type II and III, i.e. atmospheric depression and anticyclone, are general weather patterns and appear in all season, but in summer have relatively low frequency.

Then, we draw weather charts, using outputs of the MRI-GCM, which has been developed by the Meteorological Research Institute (MRI), Japan Meteorological Agency (JMA). Based on the calculated atmospheric pressure and temperature distribution for 3 years, each day's weather chart was drawn with a pressure pattern and fronts, which were then classified into 15 weather patterns under $CO_2 \times 1$ scenario and $CO_2 \times 2$ scenario. The grid-size of the MRI-GCM is 4 degrees in longitude and 5 degrees in latitude. Number of layer in vertical direction is 5. Tropical cyclones formed in the equatorial area and moving northward were considered as typhoon, though their growth might not be expressed in the GCM. In Fig. 1, frequency of each weather pattern is shown. For the annual data, the frequency of each weather pattern under $CO_2 \times 1$ scenario and $CO_2 \times 2$ scenario is almost same except type V. The simulated frequency distribution of each weather pattern under $CO_2 \times 1$ scenario shows relatively good agreement with the observed tendency in 1961-1985, except type V from May to June and type IV from July to November. In the following discussions, the simulated results under $CO_2 \times 1$ and $CO_2 \times 2$ scenario were compared to evaluate the impact of CO_2 doubling on the precipitation pattern.

In respect with monthly data shown in Figs. 2(a), 2(b), 2(c) and 2(d), following changes can be seen under $CO_2 \times 2$ scenario.

1) The frequency of type I decreases in early winter, but increases in late winter.
2) The frequency of type IV decreases in May, July and September, and decreases a little in June, while increases in August.
3) The frequency of type V increases in May and July.

Concerning typhoons, it seems that typhoon frequency decreases in September. However, we have to keep in mind the limitation of the present GCM to predict the change in frequency and intensity of typhoon.

As a result, according to the analysis using scenarios based on GCM's output, changes in the frequency of each weather pattern due to climate change occur especially in summer season. It is found that the typical summer day (type V) increases in May and July due to global warming.

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.

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.

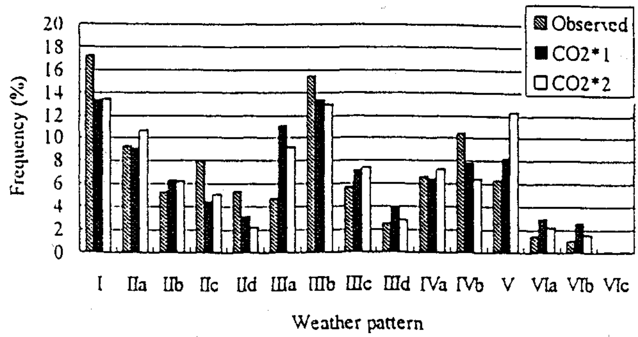


Figure 1. Frequency of each weather pattern under each scenario for the annual data.

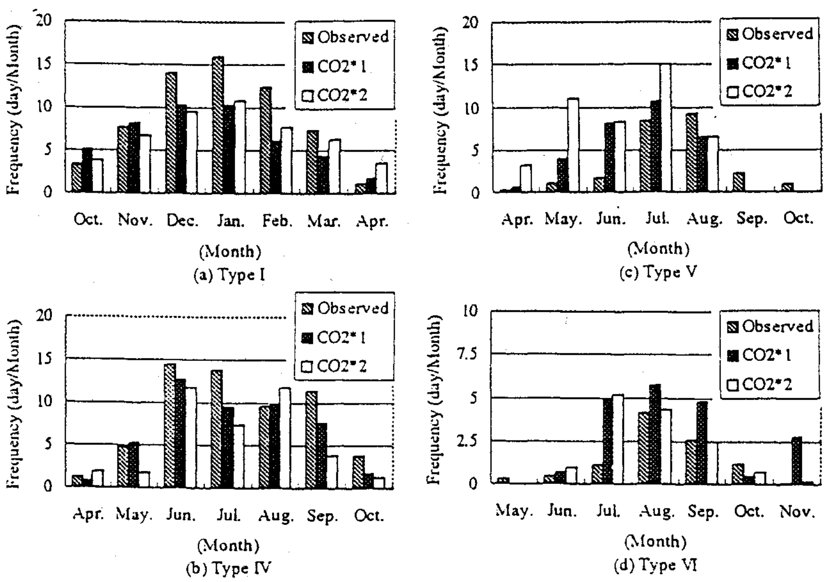


Figure 2. Distribution of monthly frequency under each scenario.

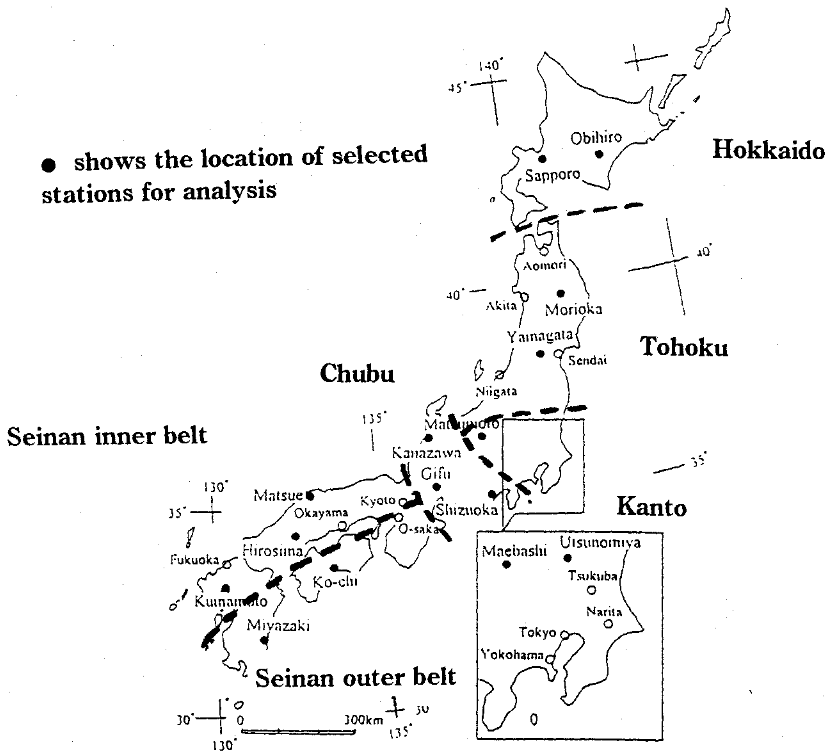


Figure 3. Location of meteorological observatory of J.M.A.

3. Analysis on the relationship between precipitation and weather pattern in Japan

To examine the present characteristics of precipitation in Japan, we surveyed the daily rainfall intensity measured at the selected meteorological observation stations of JMA during 1961-1985. The locations of these stations are shown in Fig. 3. Each station is selected to represent the typical climate characteristics judged from several meteorological parameters, which include temperature, precipitation, humidity and vegetation.

To relate probability of daily precipitation with weather pattern, we analyzed the probability and mean rainfall intensity on rainy day in each weather pattern using the observed daily precipitation data. The expected value of daily rainfall intensity at each station is shown in Fig. 4. In Hokkaido and Tohoku (north-eastern) area, rainfall intensities due to typhoon (Type VIc) are relatively high, while not so high in rainy season. In Kanto area, most of rainfall is caused by typhoon, front, and depression. Expected values of rainfall intensity to these weather patterns are almost the same. In Chubu and Seinan outer belt area, expected values of rainfall intensity due to typhoon, front, and depression are larger than those in Kanto and Seinan inner belt. In Seinan inner belt, expected values of rainfall intensity due to typhoon are not high exceptionally and rainfall intensity due to front-line is larger than those under other weather patterns.

Relationships between distribution of rainfall intensity and each weather pattern (II, IV and VI) at Shizuoka, which is located nearly at the center of Japan Island, are shown as an example in Fig. 5. In order to see the effect of average temperature on the rainfall amount, we classified the 25 years into 3 groups based on the annual average temperature of high, low and middle values and compared the tendency. Number of years classified as High and Low annual mean temperature case is 7 respectively, and those classified as Middle is 11. The difference in temperature between each group is about 0.5°C. The evident change on the distribution of frequency due to difference in the annual temperature cannot be seen. It is a common feature of rainfall pattern for the area facing the Pacific Ocean that most of rainfall under type II and type IV is weak and under type VI frequencies of rainfall intensity over 30 mm/day is almost same. It seems that there are different characteristics in the distribution of frequency between typhoon and other weather patterns. It can be considered that the rainfall intensity by typhoon depend on its course, speed, size and intensity.

4. Simulation of precipitation in $CO_2 \times 1$ scenario and $CO_2 \times 2$ scenario

4.1 Method of simulation

At first, daily-transition-probability-matrix M_{ij}, which shows the transition probability of weather pattern from j to i for each month under $CO_2 \times 1$ scenario and $CO_2 \times 2$ scenario, is obtained from the observed data and GCM's output for 3 years. By applying Monte-carlo simulation method using a transition-matrix M_{ij}, we made a weather-pattern-calendar for 200 years under each scenario.

As a next step, we estimated the daily rainfall intensity for 200 years, using the relation between precipitation and weather pattern from the observed data shown in the previous section. Whether a rainfall occurs or not is judged from the probability of rainfall event corresponding to the weather pattern on that day. When it was judged to rain, daily rainfall intensity is evaluated from the following equation proposed by L. E. Hay and G. J. McCabe (1991). The performance of this equation has been evaluated using the precipitation data at Ura-Tsukuba experimental basin (Fujikane et. al., 1993).

$$R = R_{ai} \times (-ln(Rnd_1)) \times (1 + Rnd_2) \quad (1)$$

R_{ai} :mean rainfall intensity at station a under weather pattern i
Rnd_1: uniform random variable (0, 1]
Rnd_2: uniform random variable [-1, 1]
As a result, we can get daily precipitation time series for each station under each scenario, which can be used for evaluating the change of rainfall pattern characteristics under the warming condition.

4.2 Results of simulations

We calculated the annual precipitation at the selected 15 stations. Fig. 6 shows the annual precipitation under $CO_2 \times 1$ scenario and $CO_2 \times 2$ scenario, and also one using the past observed data. Fig. 7 shows the difference in the annual precipitation between each scenario. At Kanto, Chubu and Seinan outer belt area, precipitation decreases about 2-5%. On the contrary, at Hokkakido, Tohoku and Seinan inner belt area, precipitation increases about 1-2% or slightly decreases.

These changes are due to the change in frequency of some weather patterns. Fig. 8 (a), (b) and (c) show the distribution of the annual precipitation under each weather pattern at Morioka, Shizuoka and Kochi, respectively. In general, the precipitation under type V and type IV increases and under type VI decreases according to the fluctuation in frequency of the weather-pattern. At Morioka, however, decrease of precipitation due to typhoon is less than those at Shizuoka and Kochi. This difference causes the change in annual precipitation. It can be seen from Fig. 7 and Fig. 9, that where the precipitation due to typhoon in summer is large under $CO_2 \times 1$ scenario, the annual precipitation decreases under $CO_2 \times 2$ scenario, while it does not show decrease where precipitation due to typhoon is not large under $CO_2 \times 1$ scenario. Fig. 9 shows the change in precipitation under each weather pattern. Precipitation under Type IV and V increases and that under Type VI decreases. At Shizuoka and Kochi, the change in precipitation due to typhoon explains most of the change in the annual precipitation.

Fig. 10 shows the change in frequency of heavy rainy day due to climate change. Pattern of change shown in Fig. 10 almost corresponds to that in Fig. 7. Number of heavy rainy days decreases mainly in Kanto, Chubu and Seinan outer belt area. As shown in Fig. 7, Fig. 9 and Fig. 10, fluctuation in the number of heavy rain decides change in annual precipitation and most of these change are due to decrease of the number of typhoon coming to Japan, except for Kanazawa where it snows heavily in winter. It can be said that typhoon's effect on the change of precipitation is large and therefore it is very important to know the change in behavior of typhoon due to climate change for evaluating change in precipitation.

Fig. 11(a), (b) and (c) show monthly precipitation at Morioka, Shizuoka and Kochi, respectively. In general, precipitation in May decreases and precipitation in summer season decreases because of the above mentioned reason.

From the above analysis, it was shown that a number of typical summer days as represented by weather pattern type V increases and the precipitation decreases in summer season due to global warming. But we have to keep in mind that 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 in intensity and size of typhoon due to climate change might not be well

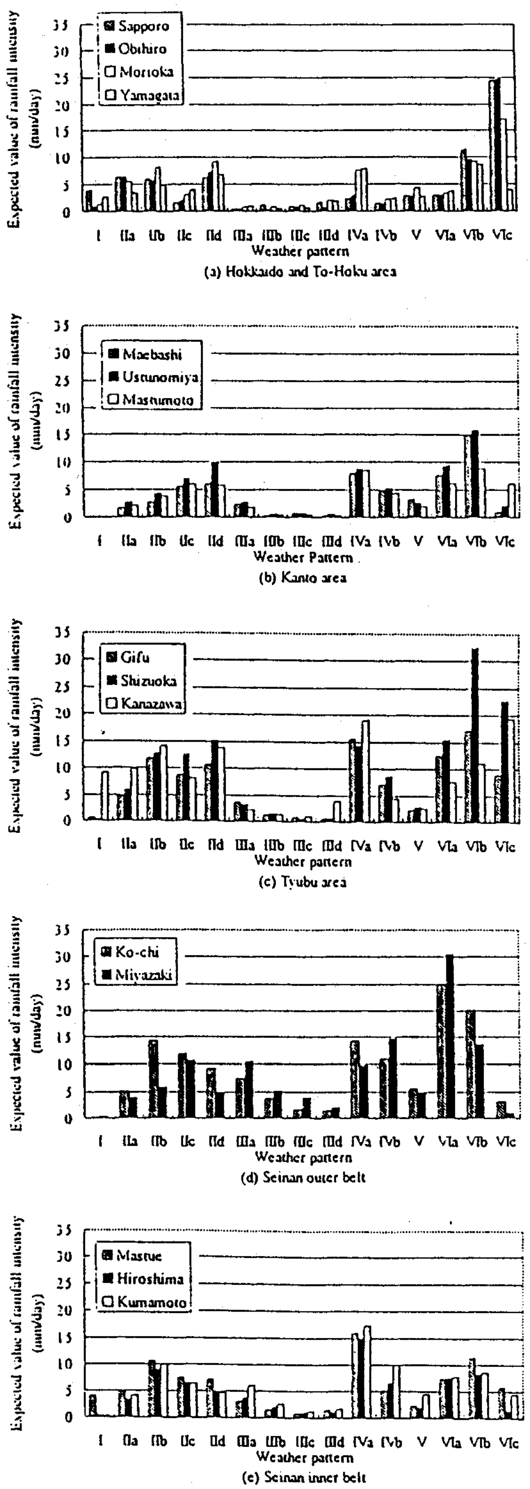


Figure 4. Expected value of rainfall intensity observed at each city under each weather pattern.

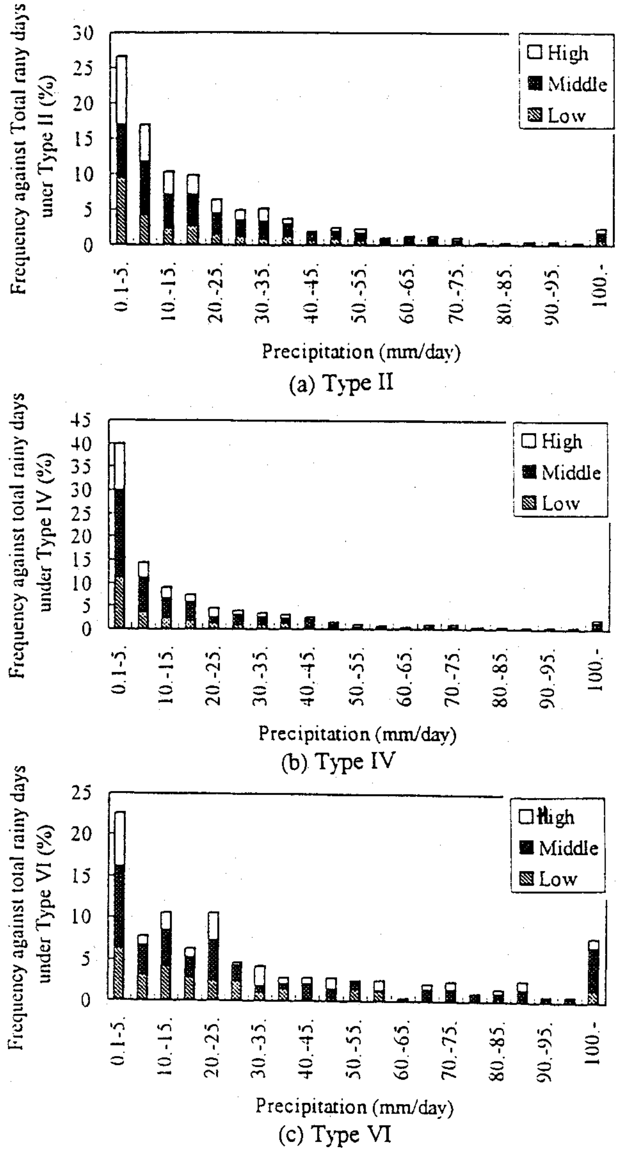


Figure 5. Distribution of frequency of rainfall intensity at Shizuoka.

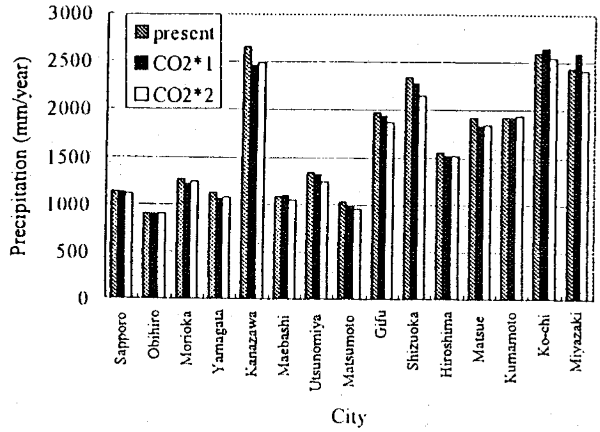


Figure 6. Annual precipitation at each city under each scenario.

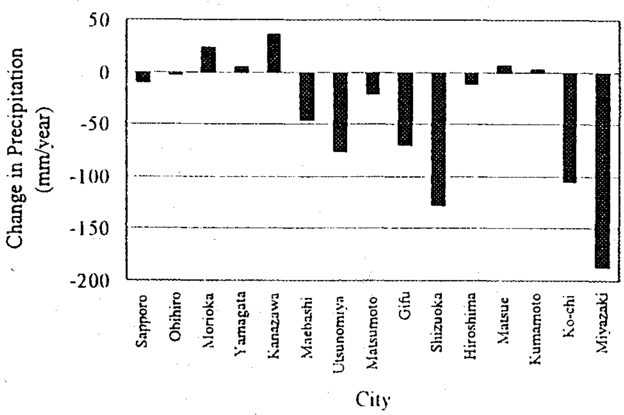
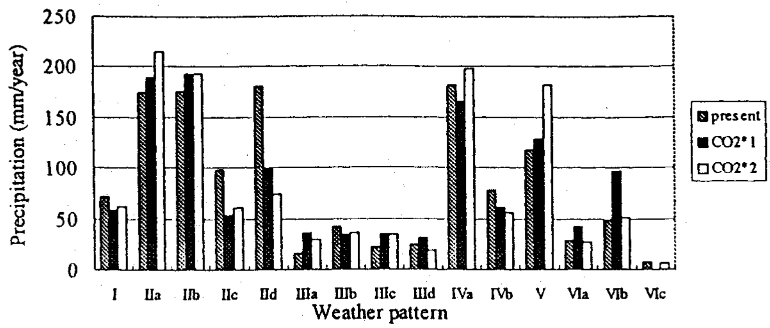
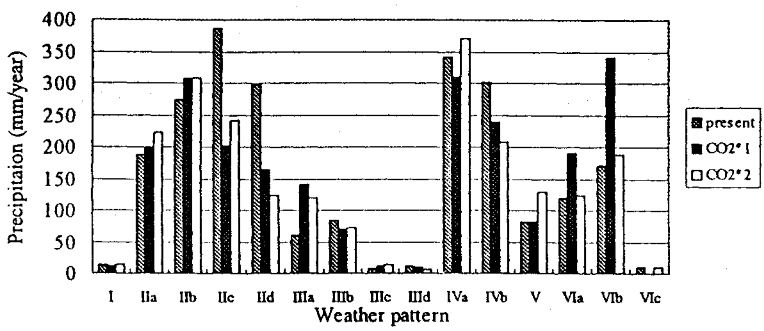


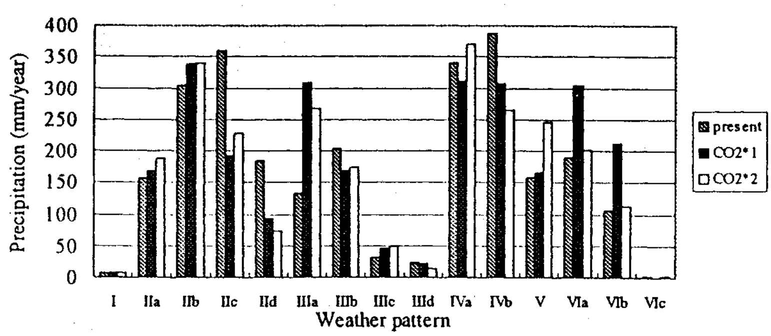
Figure 7. Change in precipitation due to climate change.



(a) Morioka



(b) Shizuoka



(c) Ko-chi

Figure 8. Precipitation under each weather pattern.

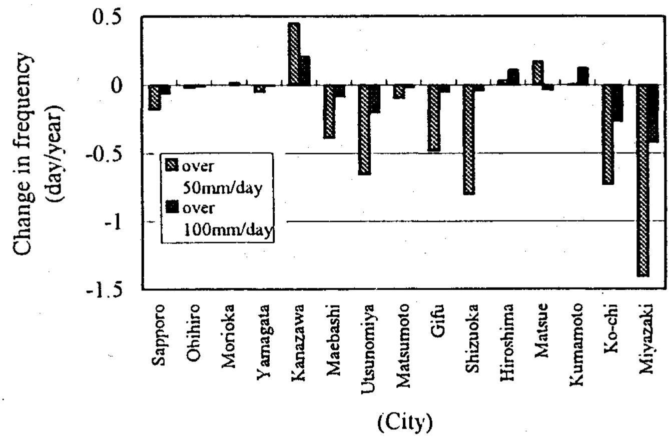


Figure 9. Change in precipitation for each weather pattern.

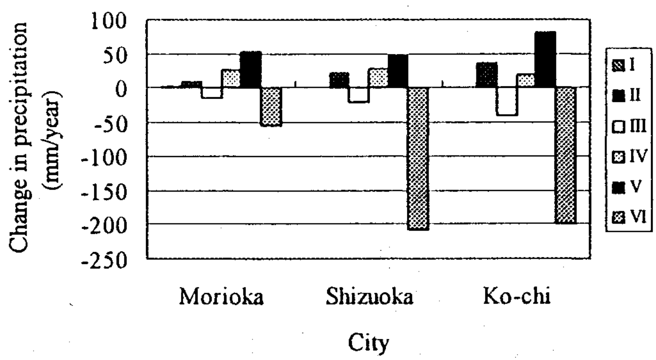


Figure 10. Change in frequency of heavy rain.

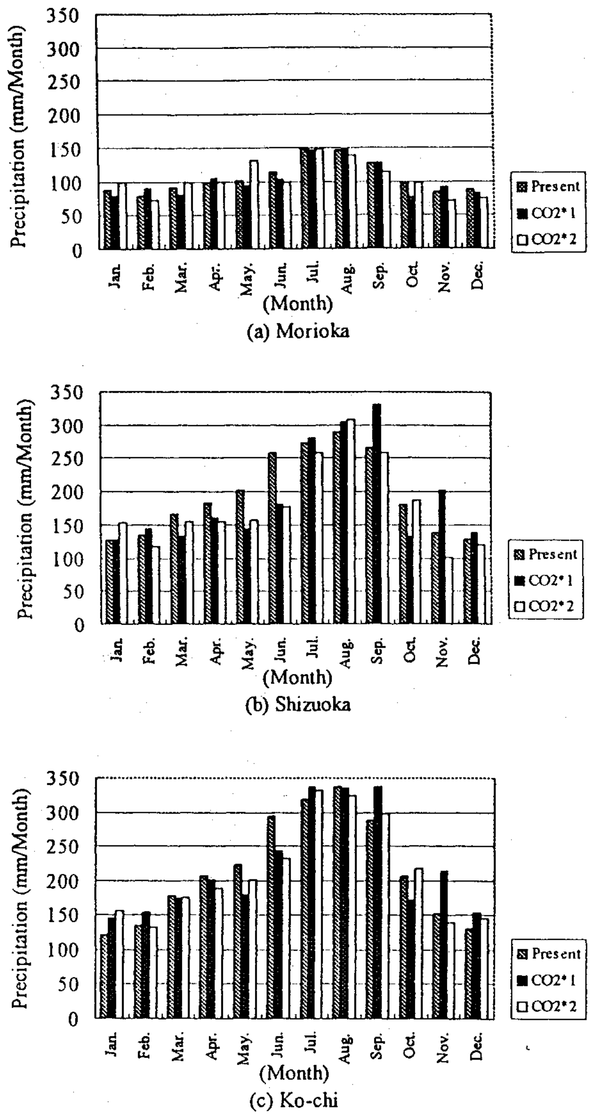


Figure 11. Monthly precipitation under each scenario.

estimated. 2) We assumed that the 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. 3) It is still not easy to evaluate the accuracy of the output of the present GCM for the warming world.

5. Conclusion

A weather pattern - precipitation analysis method was applied to evaluate the effect of global warming on the precipitation pattern in Japan. The main results are summarized as follows. 1) In summer season, the number of typical summer day, i.e. type V, increases. 2) In Kanto, Chubu and Seinan outer belt area, annual precipitation decreases. 3) Number of heavy rainy days decrease at the above mentioned areas. 4) These changes are mainly due to decrease of the number of typhoon coming to Japan, though we have to understand the limitation of the present GCM for modeling typhoon growth.

Acknowledgment

We would like to express our heartfelt thanks to Dr. Tokioka, who kindly provided us with the output of the MRI-GCM, and also to Dr. Yamakawa, who gave us useful advice to classify the daily weather pattern based on the output of the GCM.

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