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IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES, CROP PRODUCTION AND NATURAL ECOSYSTEM IN THE ASIA AND PACIFIC REGION

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Abstract

Impacts of climate change will be one of the important concerns in the Asia and Pacific region. The region will experience dynamic development in the next century. Even without climate change, rapid growth in the demographic and economic situations of the area will cause drastic changes in the local and global environment. Impacts of climate change will make the situation even more complex. In order to assess the impact on this dynamic Asian-Pacific region, we first estimate several kinds of direct physical changes to occur within the probable range of global temperature increase, and identify the impact vs. response curves of the climate changes. In this paper, we describe the impacts on water resources, crop production and natural ecosystems focusing on spatial changes. Typical outcomes of the model calculations for the Asian-Pacific region are summarized as follows:

1) Following global average temperature increase of 2℃, the median of estimated national average temperature increases ranges between 1.25～2.76℃ in the region. The precipitation changes range between +1～34%. The variance among the estimations is large, and some estimate show more than a 3.5℃ temperature increase. The medium change in runoff ranged between -7～68%.

2) Slight decrease in rice production is expected in most of the countries. The productivity of wheat will decrease significantly in Bangladesh, India and other tropical countries. The variance in productivity changes among the estimations is large. The relation between the impacts on crop production and global temperature change reveals no discernibly logical pattern by either crops or countries.

KEYWORDS: *Global Environment, Climate Change, Crop Production, Water Resource*

1. Introduction

The future Asian-Pacific environment is full of uncertainties. Together with the variables in natural processes, it is necessary to consider many factors in human activities such as population growth, economic development and technological innovation, and these factors are often difficult to predict. A range of synopses or scenarios needs to be prepared, and

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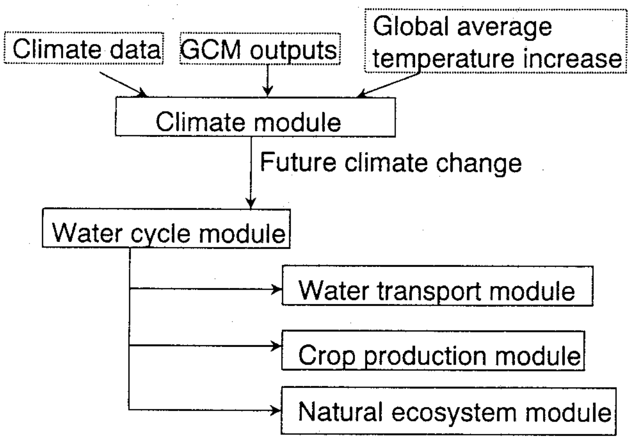

Figure 1. Framework of the assessment

various possibilities must be considered in the course of policy development. In order to tackle such problems, we developed and are using a large-scale integrated assessment model called AIM (the Asian-Pacific Integrated Model, Matsuoka *et al.*, 1995). In this paper, however, we concentrate on the estimation of the direct impacts from future climate change. Even at the level of direct impact assessments, reported results varied considerably with the type of GCM (General Circulation Model) and the assumed climate scenario. In order to obtain a consistent estimate of climate change impacts, which are useful for an international comparison of their significance, a global-wide but spatially high-resolution impact assessment should be conducted under several GCM scenarios. In this paper, having assumed the range of increase in global average surface temperature, we overlaid the spatial climate change patterns from 11 GCMs and calculated their direct influence on water resources, crop productivity and forest suitability using sub-modules of the AIM/Impact. This will provide impact response curves, which should be useful for further assessment on mitigation of and adaptation to climate change impacts.

2. Model Description

The direct impacts of climate change on water resources, crop production and natural ecosystems was evaluated in this paper. To this end, we used part of the AIM/Impact model. Figure 1 shows the framework of this assessment using four sub-modules of the AIM/Impact model, i.e., climate module, water cycle/transport module, crop production module, and natural ecosystem module. The projections were conducted under several global temperature change scenarios with multiple GCM results, and calculated indices were spatially aggregated for each country. Their median as well as maximum and minimum values were then recorded for use in the following analysis.

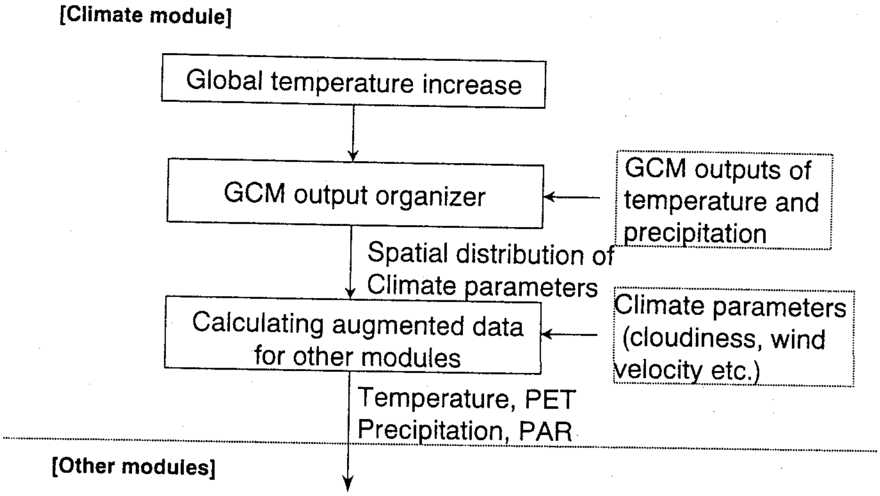

Figure 2. Framework of climate module

2.1 Climate module

The basic part of the assessment framework shown in Fig. 1 is the climate module (Fig. 2) in which present temperature and precipitation, and the change of temperature and precipitation from GCM outputs are integrated and processed in order to produce the information required in the downstream part of the study. Changes in global mean surface temperature are assumed to be 0.5~4.0℃. For the current climate, we used the Legates and Willmott's monthly mean temperature (Legates and Willmott, 1990a) and precipitation (Legates and Willmott, 1990b). For the spatial distribution of climate data, we used outputs of various GCMs. The 11 GCMs used are listed in Table 1 (IPCC, 1990). Since spatial resolution of GCM outputs is not fine enough for the use in impact studies, the "GCM output organizer" interpolates the outputs spatially by methods appropriate to each climate parameter, combines these outputs with the assumed global mean temperature, and generates future climate data. As for temperature, the spline interpolation method was used, while the $1/r^2$-weighted interpolation method (r: radius) was employed for precipitation. The spatial resolution for the present study is 0.5 ° in the longitude latitude. After the interpolation of GCM outputs, the following formulas were used to calculate future climate data in each grid for each month.

For temperature,

$$T(t) = T(present) + (T(2 \times CO_2) - T(1 \times CO_2)) \times \frac{T_{mean}(t) - T_{mean}(present)}{\Delta T} \quad (1)$$

For precipitation

$$P(t) = P(present) + P(present) \times \left\{ \frac{P(2 \times CO_2)}{P(1 \times CO_2)} - 1 \right\} \times \frac{T_{mean}(t) - T_{mean}(present)}{\Delta T} \quad (2)$$

Here, $T(t)$ [°C] and $P(t)$ [mm/month] are the temperature and the precipitation in year t, respectively. $T(2\times CO_2) - T(1\times CO_2)$ [°C] is the temperature difference and $P(2\times CO_2)/P(1\times$

Table 1. GCM outputs used in this study

Climate Model	Calculated Date	lat. x long.(°)	ΔT (℃)	Reference
CCC	Nov-89	3.75x3.75	3.5	Boer et al., 1989
GISS	1982	7.83x10.0	4.2	Hansen et al., 1984
GFDL	1984-85	4.44x7.50	4.0	Wetherald & Manabe, 1986
GFDL R30	May-89	2.22x3.75	4.0	Wetherald & Manabe, 1989
GFDL Q-flux	Feb-88	4.44x7.50	4.0	Wetherald & Manabe,1989
OSU	1984-85	4.00x5.00	2.8	Schlesinger & Zhao, 1989
UKmet	Jun-86	5.00x7.50	5.2	Wilson & Mitchell, 1987
UIUC	Sep-96	4.00x5.00	3.4	Schlesinger, 1996
MRI	1994	4.00x5.00	2.5*	Tokioka et al., 1995
GISS	1995	4.00x5.00	3.6*	Miller and Russell, 1995
GFDL100	1991	4.50x7.50	3.2*	Manabe et al., 1992

ΔT=Equilibrium surface temperature change on doubling CO_2

ΔT*=Warming surface temperature change at the getting out period for this study

CO_2) [-] is the precipitation ratio between $2\times CO_2$ and $1\times CO_2$ at the grid, which are calculated by GCMs. ΔT [°C] is the equilibrium surface temperature change on $2 \times CO_2$ (Table 1). $T_{mean}(t) - T_{mean}(present)$ [°C] is the global annual mean temperature increase between the base year, 1990, and year t, which is assumed as 0.5, 1.0, 1,5, 2.0, 2.5, 3.0, 3.5 and 4.0 [°C] (written as ΔT_{asm}, hereafter). As a result, in this paper, 8 (assumed temperature levels) × 11GCM outputs = 88 cases of impact projections were practiced for each kind of impacts.

2.2 Water resources

Hydrological impacts are one of the basic factors in the climate change. Changes in the magnitude, frequency and duration of hydrological factors influence the availability of water resources, flooding intensity, and agricultural and natural terrestrial ecosystems. A rainfall-runoff process sub-module of the AIM/Impact model consisting of water balance and water transport components plays a role to provide basic hydrologic information for the impact models of other sectors (AIM Project Team, 1996). Specifically, it creates gridded high-resolution data sets of surface runoff, soil moisture, evapotranspiration, and river discharge. Soil moisture capacities were estimated using current vegetation classes and soil textures by a one-layer soil water model. To estimate potential evapotranspiration (PET), two optional modules were prepared. They are based on the FAO24 and Thornthewaite methods (FAO, 1992) respectively, with the choice depending on data availability.

2.3 Crop production

The productivity of cropland may be strongly affected by climate change. In order to evaluate such impact, we estimated the changes in potential crop production (Takahashi *et al.*, 1997).

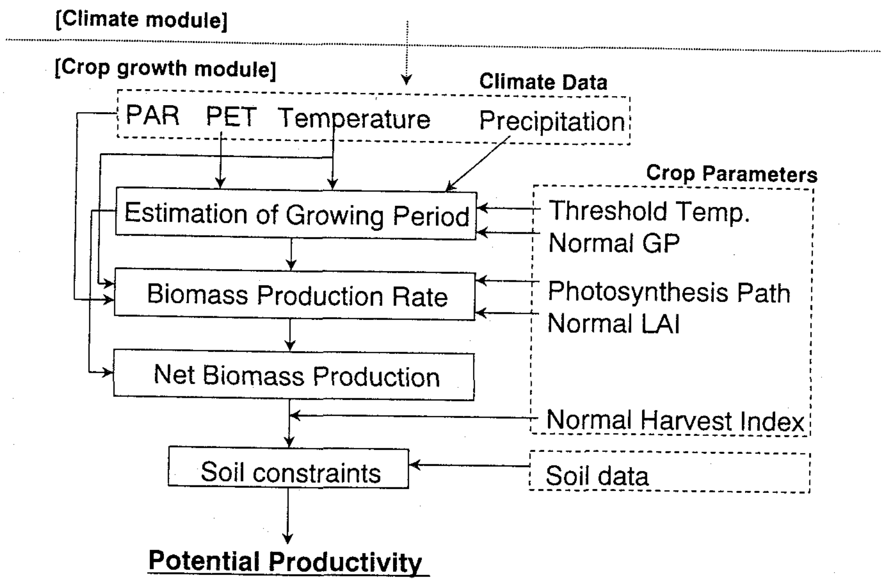

Figure 3. Framework of crop production module

Days suitable for crop cultivation (growing period) are counted using climate data, and the crop growth during the growing period is simulated according to the growth characteristic parameters of each crop. Figure 3 shows the framework for estimating potential crop productivity. This module requires daily mean temperature, mean daytime temperature, precipitation, PET, photosynthetically active radiation, and soil characteristics. Most of these are deduced from the climate and water resources modules. Fertilizing effect of carbon dioxide concentration on crop growth is not considered in this paper. Four properties of soil were taken into account to represent a suitability of land resource: soil units, soil phase, soil texture and soil slope. To consider the high spatial variability of these constraints, soil data on a 5-minute resolution grid were used for this calculation. Potential productivity of rice, winter wheat, and maize were selected as indices of crop production.

2.4 Natural ecosystems

The Holdridge method was used to assess climate change impacts on natural ecosystems (Ohkita, 1995). This model is a climate classification scheme that relates the distribution of ecosystem complexes to the climate variables of bio-temperature, precipitation, and the ratio of PET to precipitation. Two climate variables, bio-temperature and annual precipitation, determine the classification. Bio-temperature is calculated in the following equiation.

$$T_{BIO} = \frac{\sum_{m=1}^{12} \max(T(m), 0)}{12} \tag{3}$$

Here, T_{BIO} [°C] is the bio-temperature, and $T(m)$ [°C] is the monthly mean temperature. Climate is first classified into 7 divisions by this bio-temperature, then divided by average total annual precipitation. The complete classification includes 39 climate zones. The map produced by the Holdridge model represents the potential distribution of vegetation determined by the

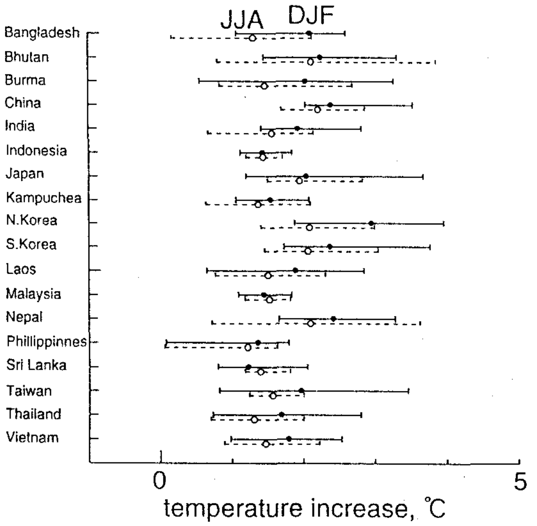

Figure 4. Country average temperature change, ΔT_{asm}=2°C

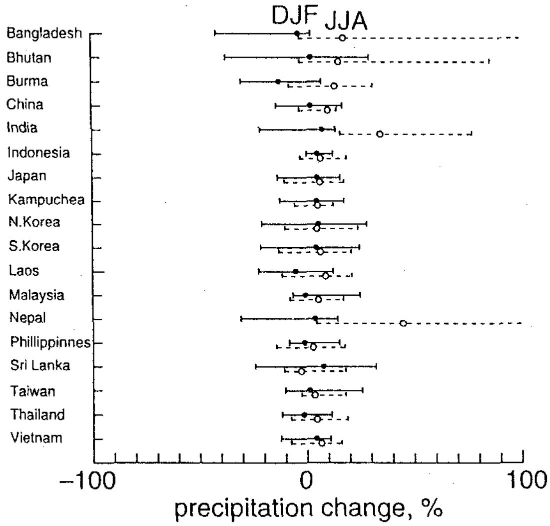

Figure 5. Country average precipitation change, ΔT_{asm}=2°C

climate. The changes in temperature and precipitation projected by eqs.(1) and (2) are used to estimate the changes in the climate zones, which shows the potential impacts on natural ecosystems.

3. Climate Impact Assessment using AIM/Impact Model

Changes in temperature and precipitation averaged in the countries are shown in Figs. 4 and 5. These are the cases in which global average temperature change (ΔT_{asm}) is 2°C, and ● corresponds to a 3 month average of DJF (December, January and February) and ○ to JJA (June, July and August). These circles indicate the median values of 11 GCMs. Maximum and minimum values for these GCMs are shown as the edges of horizontal errorbars. The median temperature changes in Asian countries range from 1.25 to 2.76°C, but they might range from 0.06 to 3.59°C according to the errorbars in Fig. 4. While the median precipitation changes range from +1~34% in Asian countries, there is an uncertainty because of the difference of spatial distribution among GCMs (Fig. 5). The DJF's temperature increase is larger than the JJA's. However, the JJA's precipitation increase is larger than the DJF's. The precipitation increase is larger in the Indian subcontinent, including India, Nepal and Bangladesh, compared with other regions.

Based on the outputs of these national climate changes, changes in mean surface runoff were calculated for the countries as shown in Fig. 6. ΔT_{asm} was 2°C for this figure. The median of the runoff change ranges from -7~68%. India, Nepal and Bangladesh will experience more than a 30% increase. The runoff in Burma will increase 20%, and other countries will have relatively small changes almost within ± 5%. Figure 7 shows the relation between ΔT_{asm} and average runoff for some countries. Table 2 shows the median runoff change for each temperature increase scenario.

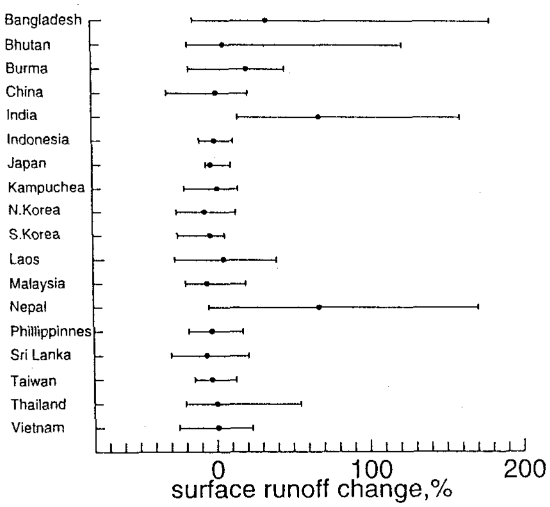

Figure 6. Country average runoff change, ΔT_{asm}=2°C

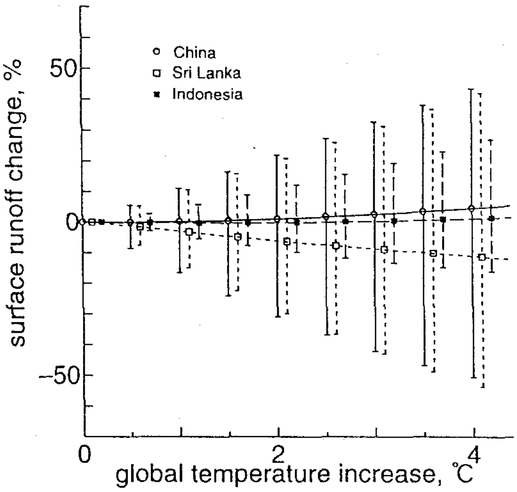

Figure 7. Country average runoff change, Relation with ΔT_{asm}

Table 2. Median of runoff change (%), Relation with ΔT_{asm}

	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0 (℃)
Bangladesh	8.3	16.9	25.6	34.6	43.7	53.0	62.5	72.1
Bhutan	1.6	3.2	4.7	6.4	8.0	9.8	11.7	13.8
Burma	5.2	10.4	15.7	21.2	26.7	32.2	37.9	43.7
China	0.1	0.3	0.7	1.3	2.0	2.9	3.8	4.9
India	13.9	30.3	48.7	68.4	88.8	109.8	131.2	153.0
Indonesia	-0.1	-0.2	-0.1	0.1	0.4	0.7	1.2	1.7
Japan	-0.5	-1.1	-1.8	-2.7	-3.6	-4.7	-5.8	-6.8
Kampuchea	0.1	0.4	0.8	1.6	2.6	3.5	4.5	5.7
N.Korea	-0.8	-2.3	-4.4	-6.8	-9.4	-12.4	-15.3	-18.3
S.Korea	-0.6	-1.5	-2.4	-3.4	-4.4	-5.8	-7.1	-8.5
Laos	1.1	2.3	3.7	5.4	7.4	9.6	11.5	13.4
Malaysia	-2.0	-3.6	-4.6	-5.6	-6.5	-7.2	-7.8	-8.3
Nepal	16.8	33.8	50.7	67.5	84.4	101.3	118.3	135.2
Phillippinnes	-1.2	-2.0	-2.5	-2.6	-2.3	-1.7	-0.8	-0.2
SriLanka	-1.6	-3.1	-4.8	-6.1	-7.5	-8.7	-9.9	-11.1
Taiwan	-0.6	-1.3	-2.0	-2.7	-3.4	-4.2	-5.0	-5.8
Thailand	-0.4	-0.4	-0.1	0.4	1.2	2.2	3.5	5.2
Vietnam	0.0	-0.1	0.2	0.7	1.3	2.2	3.2	4.3

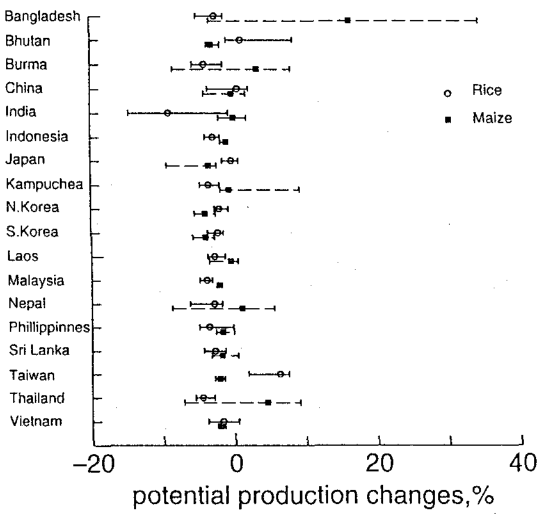

Figure 8. Potential production change of rice and maize, ΔT_{asm}=2°C

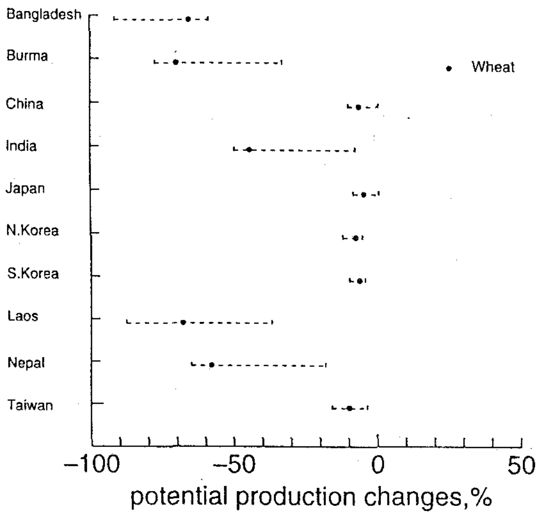

Figure 9. Potential production change of winter wheat, ΔT_{asm}=2°C

Potential crop production changes are shown in Fig. 8 for rice and maize, and Fig. 9 for wheat, where ΔT_{asm} is 2°C. A little decrease of rice production is expected in most countries, while slight increase is expected in Bhutan and Taiwan. The productivity of wheat will decrease significantly in Bangladesh, India and other tropical countries. China may not be affected so seriously by this climate change. As for maize (tropical variety), Bangladesh is expected to have a large productivity increase. The impacts on other countries are within $\pm$ 5%, when ΔT_{asm} is 2°C. The variance in the productivity change among GCMs is large. However, the tendencies toward productivity gain or loss are roughly the same for each country, showing that such trends are in close agreement for different GCMs. There is no consistent dependency on ΔT_{asm} among the kinds of crops and countries. Tables 3, 4 and 5 show the dependencies of rice, wheat and maize, respectively, on ΔT_{asm}. Figures 10, 11 and 12 show the same dependencies in some countries with errorbars. Potential productivity in some countries decreases monotonously in proportion to the global temperature increase, while a threshold of temperature increase can be found in other non-sensitive countries. Moreover, there are contries where productivity increases first with the temperature increase of 1~2°C, then it begins to decrease with the more severe temperature increase.

As for natural ecosystems, changes in present forest regions were analyzed. Figure 13 shows changes in the forest area. The forests in some countries in Fig. 13 are presently temperate/boreal forests and change to other classifications under future conditions. In Japan and China, 35% of forest area is expected to change by ΔT_{asm}=2°C, and more than a 50% by ΔT_{asm}=4°C . Most of the changes take plece toward tropical forest.

Table 3. Median of potential production change of rice (%), Relation with ΔT_{asm}

	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0 (℃)
Bangladesh	-0.4	-0.9	-1.6	-2.4	-3.1	-4.2	-5.5	-6.0
Bhutan	0.8	1.7	1.2	1.1	1.0	0.4	1.4	2.8
Burma	-0.8	-1.7	-2.8	-4.0	-5.1	-6.3	-7.6	-8.9
China	0.7	1.3	1.3	0.7	-0.1	-1.4	-2.7	-4.5
India	0.0	-0.6	-3.3	-9.0	-16.2	-21.5	-27.9	-35.9
Indonesia	-0.6	-1.4	-2.0	-2.8	-3.3	-4.2	-5.0	-5.4
Japan	0.5	0.6	0.2	-0.2	-0.7	-1.2	-1.7	-2.4
Kampuchea	-0.8	-1.6	-2.5	-3.5	-4.5	-5.6	-6.8	-7.9
N.Korea	-0.5	-0.9	-1.4	-2.0	-2.6	-3.3	-4.1	-4.8
S.Korea	-0.5	-1.0	-1.6	-2.2	-3.0	-3.8	-4.7	-5.7
Laos	-0.5	-1.2	-1.9	-2.7	-3.7	-4.7	-5.8	-6.9
Malaysia	-0.9	-1.8	-2.8	-3.8	-4.9	-6.0	-7.0	-7.6
Nepal	-0.3	-0.8	-1.9	-2.8	-3.9	-5.0	-6.0	-12.8
Phillippinnes	-0.8	-1.7	-2.7	-3.5	-4.5	-5.5	-6.5	-7.7
SriLanka	-0.4	-0.9	-2.0	-2.7	-3.5	-2.4	-3.5	-4.7
Taiwan	0.0	3.9	6.3	6.3	6.0	5.6	5.6	4.6
Thailand	-0.9	-2.0	-3.2	-4.4	-5.7	-7.1	-8.5	-10.2
Vietnam	-0.6	-1.1	-1.8	-1.6	-1.9	-2.5	-3.8	-5.1

Table 4. Median of potential production change of winter wheat (%), Relation with ΔT_{asm}

	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0 (℃)
Bangladesh	-23.1	-40.4	-54.6	-65.1	-80.6	-87.4	-89.6	-98.2
Bhutan	-	-	-	-	-	-	-	-
Burma	-19.4	-44.5	-60.0	-69.7	-74.4	-80.2	-84.0	-86.6
China	-0.4	-1.4	-3.4	-6.4	-9.9	-14.3	-18.4	-22.5
India	-12.4	-24.9	-35.0	-44.2	-52.2	-59.6	-65.8	-70.8
Indonesia	-	-	-	-	-	-	-	-
Japan	-1.0	-1.6	-2.7	-4.6	-5.9	-7.2	-8.6	-10.6
Kampuchea	-	-	-	-	-	-	-	-
N.Korea	-1.0	-3.5	-5.5	-7.5	-10.2	-12.8	-15.8	-18.8
S.Korea	-1.4	-3.0	-4.6	-6.2	-8.2	-10.8	-13.2	-15.3
Laos	-13.9	-32.5	-57.0	-67.8	-76.4	-89.8	-94.8	-97.1
Malaysia	-	-	-	-	-	-	-	-
Nepal	-17.6	-28.5	-42.7	-57.8	-67.6	-72.0	-76.9	-82.1
Phillippinnes	-	-	-	-	-	-	-	-
SriLanka	-	-	-	-	-	-	-	-
Taiwan	-2.2	-4.2	-5.3	-9.7	-15.4	-19.9	-23.0	-27.9
Thailand	-	-	-	-	-	-	-	-
Vietnam	-	-	-	-	-	-	-	-

Table 5. Median of potential production change of maize (%), Relation with ΔT_{asm}

	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0 (℃)
Bangladesh	−0.1	7.2	8.9	16.2	23.7	26.5	33.8	40.4
Bhutan	−0.6	−1.6	−2.3	−3.0	−3.5	−4.1	−4.5	−5.0
Burma	1.8	3.4	3.6	3.4	3.0	2.4	2.4	1.7
China	0.7	0.7	0.5	−0.2	−1.1	−2.5	−5.0	−6.5
India	0.3	0.4	0.2	0.1	−0.3	−0.9	−1.8	−2.7
Indonesia	−0.3	−0.6	−1.0	−1.0	−1.1	−1.6	−1.7	−1.9
Japan	−0.5	−1.6	−2.6	−3.5	−5.0	−8.5	−9.8	−11.0
Kampuchea	−0.3	−0.4	−0.5	−0.6	−0.4	0.0	1.2	1.6
N.Korea	−1.0	−1.9	−3.0	−4.0	−5.0	−6.1	−7.1	−8.2
S.Korea	−1.0	−1.9	−2.9	−4.0	−5.0	−6.1	−7.4	−8.8
Laos	−0.2	−0.2	−0.3	−0.5	−0.8	−0.9	−1.2	−1.6
Malaysia	−0.5	−1.0	−1.5	−2.1	−2.6	−3.1	−3.4	−3.7
Nepal	0.0	0.3	1.6	1.1	1.4	1.8	3.3	2.4
Phillippinnes	−0.5	−0.9	−1.4	−1.7	−2.1	−2.5	−2.8	−3.2
SriLanka	−0.5	−0.5	−1.3	−1.8	−1.8	−0.4	−1.8	−2.2
Taiwan	−0.5	−1.1	−1.6	−2.1	−2.4	−2.9	1.3	2.0
Thailand	2.0	3.7	4.7	4.6	4.4	4.2	3.8	3.6
Vietnam	−0.3	−0.9	−1.4	−2.0	−2.7	−3.0	−3.4	−3.9

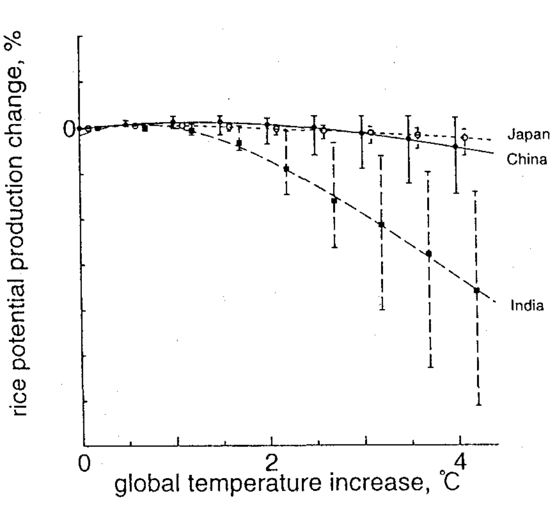

Figure 10. Potential production change of rice, Relation with ΔT_{asm}

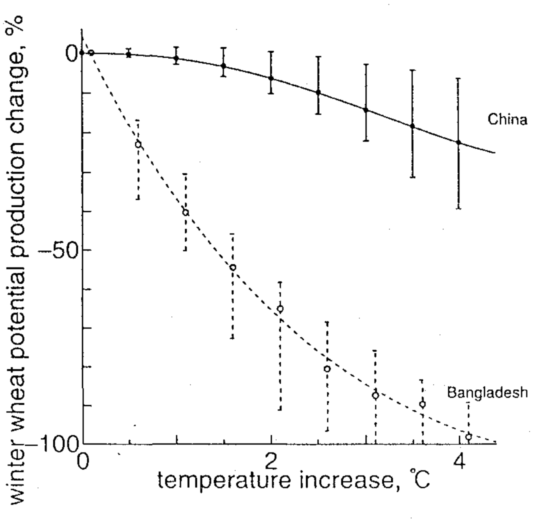

Figure 11. Potential production change of winter wheat, Relation with ΔT_{asm}

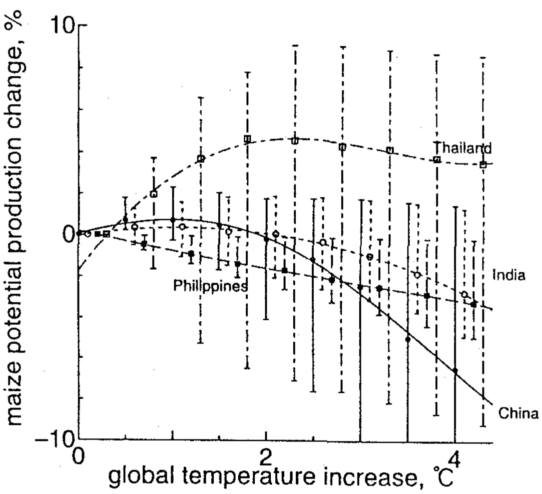

Figure 12. Potential production change of maize, Relation with ΔT_{asm}

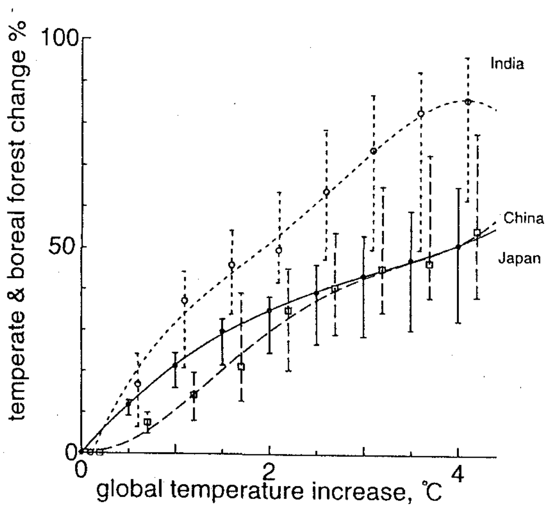

Figure 13. Decrease in temperate/boreal forest, Relation with ΔT_{asm}

4. Conclusions and Future Prospects

In order to assess the impact of climate change in the Asian-Pacific region, we estimated several kinds of direct physical changes to occur within the probable range of global temperature increase. As the results of the analysis, Table 6 summarizes the impacts for ΔT_{asm}=2°C, in which the significance of the impacts was evaluated subjectively. From Table 6, the Indian subcontinent seems to suffer from various direct impacts of climate change, such as losses of areas suitable for wheat production and temperate forest. It can be concluded that the Indian subcontinent should be studied more intensively in future. Other regions such as the East Asia are expected to be affected less seriously compared with the Indian subcontinent. Some parts of the region may experience a bad yield of wheat, but the national impact is not significant in this calculation. Suitable conditions for temperate or boreal forest will decrease by 40% in the East Asia as a result of a ΔT_{asm}=2°C global temperature increase. As the temperature increase becomes large, the impacts are accelerated in a complex fashion. These are illustrated in Figs. 10～12 for crop production.

In this study, we used 11 GCMs to obtain a spatial climate change pattern, then estimated impacts of climate change with each climate change pattern. The median value of impacts estimated with 11 GCMs was taken as a representative index of the impact. The variance in responses among GCMs is huge even if the global average temperature increases are adjusted to the same value. Moreover these GCM results still include poor representations of typical climatological phenomena, such as monsoonal circulation and ENSO events. These problems may cause crucial effects on the results.

Recently, many direct impact studies have been done in the Asia and Pacific region (e.g. Asian Development Bank 1994, Erda et al. 1996). They revealed a wide range of uncertainties in the impact assessment even if the analysis is restricted to the direct impacts. Geographic resolution is one crucial factor, and the integration and scaling-up of basic physical and bio-

Table 6. Climate change impacts on the Asia and Pacific region

	Climate		Water resource	Crop production			Vegetation
country	temp.	precip.	runoff	rice	wheat	Maize	Temp.Forest
Bangladesh	0	+	+ +	0	− − −	++	
Bhutan	+	0	0	0		0	−
Burma	0	0	+	0	− − −	0	
China	+	0	0	0	−	0	−
India	0	+ +	+ + +	−	− − −	0	− −
Indonesia	0	0	0	0		0	
Japan	0	0	0	0	0		−
Kampuchea	0	0	0	0		0	
N.Korea	+ + +	0	0	0	−	0	0
S.Korea	0	0	0	0	−	0	0
Lao_PDR	0	0	0	0		−	
Malaysia	0	0	0	0		0	
Nepal	+	+ +	+ + +	0	− − −	0	
Philippines	0	0	0	0		0	
Sri_Lanka	0	0	0	0		0	
Taiwan	0	0	0	+	−	0	
Thailand	0	0	0	0		0	
Vietnam	0	0	0	0		0	

notation	− − −	− −	−	0	+	+ +	+ + +	note
Temperature				<2.25	2.25~2.5	2.5~2.75	>2.75	Increase,℃
Precipitation	<-45	-45~-30	-30~-15	-15~15	15~30	30~45	>45	percent change
Runoff	<-45	-45~-30	-30~-15	-15~15	15~30	30~45	>45	percent change
Crop production	<-20	-20~-10	-10~-5	-5~5	5~10	10~20	>20	percent change
Forest change	<-60	-60~-40	-40~-20	-20~0				percent change
Malarial area	>+20	+20~10	+10~+5	+5~0				percent change

logical responses are other problems. In order to render an integrated assessment model more realistic and predictable, especially for impact assessments, process-based models with reliable geographic resolution should be used as sub-modules of the whole model. With such models, we can analyze the differences in climate change impacts under alternative emission scenarios, and compare the spatial differences in climate impacts.

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References

Asian Development Bank (1994): *Climate change in Asia*, Manila, Philippines.

AIM Project Team (1996): Technical structure of AIM/impact model, AIM Interim Paper, IP-95-06, Tsukuba, Japan.

Boer, G.J., N. McFarlane and M. Lazane (1989): Equilibrium response studies with the CCC climate model, Pers, Com.

Lin Erda, W.C. Bolhofer, S. Huq, S. Lenhart, S.K. Mukherjee, J.B. Smith and J. Wisniewski (1996): *Climate change vulnerability and adaptation in Asia and Pacific*, Kluwer

FAO (1992): *Crop water requirements*, Irrigation and Drainage Paper-24, Food and Agriculture Organization of the United Nations, Rome.

Hansen, J., A. Lacis, D. Rind, L. Russel, P. Stone, I. Fung, R. Ruedy and J. Lerner (1984): Climate sensitivity analysis of feedback mechanisms, In: Climate processes and climate sensitivity, (ed. J. Hansen and T. Takahashi), *Geophys. Monogr.*, Ser.29, pp.130-63.

IPCC (1990): *Climate Change: The IPCC Scientific Assessment*, Cambridge University Press, Cambridge, UK.

Legates, D.R. and C.J. Willmott (1990a): Mean seasonal and spatial variability in global surface air temperature, *Theor. Appl. Climatol.*, 41, pp.11-21.

Legates, D.R. and C.J. Willmott (1990b): Mean seasonal and spatial variability in gauge corrected, global precipitation, *Int. J. Climatol.*, 10, pp.111-127.

Manabe, S., M.J. Spelman and R.J.Stouffer (1992): Transient responses of a coupled ocean-atmosphere model to gradual changes of atmospheric CO_2, *J. Climate*, 5, pp.105-126.

Matsuoka, Y., M. Kainuma and T. Morita (1995): Scenario Analysis of Global Warming Using the Asian Pacific Integrated Model (AIM), *Energy Policy*, 23(4/5), pp. 357-371.

Miller, J.R. and G.L. Russell (1995): Climate change and the arctic hydrologic cycle as calculated by a global coupled atmosphere-ocean model, *Ann. Glac.*, 21, pp.91-95.

Ohkita, Y. (1995): Climate change impact on natural environment, Master's thesis at Kyoto University, Japan.

Schlesinger, M.E. and Z.C. Zhao (1989): Seasonal climatic change introduced by doubled CO_2 as simulated by the OSU atmospheric GCM/mixed-layer ocean model, *J. Climate*, 2, pp.429-495.

Schlesinger, M.E. (1996): Development of the geographical climate scenarios for the impact analyses of Energy Modeling Forum 14, Proceedings for Energy Modeling Forum 14 workshop, IIASA, Laxenburg, Austria.

Takahashi, K., H. Harasawa and Y. Matsuoka (1997): Climate change impact on global crop production, *J. Global Environment Engineering*, 4, pp.145-161.

Tokioka, T., A. Noda, A. Kitoh, Y. Nikaidou, S. Nakagawa, T. Motoi, S. Yukimoto and K. Takata (1995): A transient CO_2 experiment with the MRI CGCM, *J. Met. Soc. Japan*, 74(4), pp.817-826.

Wetherald, R.T. and S. Manabe (1986): An investigation of cloud cover change in response to thermal forcing, *Climatic Change*, 8, pp.5-23.

Wetherald, R.T. and S. Manabe (1988): Cloud feedback processes in a general circulation model, *J. Atmos. Sci.*, 45, pp.1397-1415.

Wilson, C.A. and J.F.B. Mitchell (1987): Simulated climate and CO_2 induced climate change over western Europe, *Climatic Change*, 10, pp.11-42.