B-15.2.1 Collaborative Studies for Developing AIM/Impact Model - Development of Basic Models (Final Report)

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Abstract: Climate impacts will be one of the serious concerns in the Asia-Pacific region. This region will experience dynamic development in the next century so that even without climate change, rapid growth in the demographic and economic situations of this area will cause drastic changes in the local and global environment. Climatic impacts will make the situation even more complex.

The purpose of this research is to develop and improve the model that can assess the impact of global warming on agricultural production, water resources, vegetation, and human health in the region. First, an agricultural impact model was developed to estimate the potential change in yields of major grins caused by climate change in the region, and then it was improved in cooperation with researchers in China and India. A sub-national area-based geographical information database was also established for the impact model application in China and India.

Secondly, using the above and other AIM/Impact modules, we estimated several kinds of direct physical impacts based on the probable range of global temperature increase, and identified the impact response curves of the climate changes. Major outcomes are summarized as follows:

1) Assuming global average temperature increase of 2°C, the median estimations of national average temperature increases ranged between 1.3 ~ 2.7°C in these regions. The precipitation changes ranged between +1~17%. The variance among estimations is large, and the change in runoff ranged between -8~67% .
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 estimations is large. The relation between the impact and global temperature change reveals no discernibly logical pattern by either crops or countries.

Key Words: AIM/Impact, Global Warming Impacts, Asian-Pacific Region, Agricultural Production, Geographical Information System

1. Introduction and Research Objective

Climate impacts will be one of the serious concerns in the Asia-Pacific region. This region will experience dynamic development in the next century so that even without climate change, rapid growth in the demographic and economic situations of these areas will cause drastic changes in the local and global environment. Climatic impacts will make the situation even more complex.

The purpose of this research project is to develop the agricultural impact model of the climate change in country level in cooperation with researchers in China and India and using this model along with the other modules of AIM/Impact model, to evaluate the potential global warming impacts in a comprehensive manner. Since both China and India are now facing very rapid population growth as well as industrialization and urbanization, we selected these two countries as the research fields. We have collaboration with researchers of the Commission for Integrated Survey of Natural Resources (CISNAR) in China and the Indira Gandhi Institute of Development Research (IGIDR) in India. Development and improvement of the impact assessing model have been done in cooperation with them. They were also collecting and archiving the environmental and socio-economic data in the both countries for this work.

The developed agricultural impact model and the other modules of AIM/Impact model such as water resources, vegetation, and human health were used to evaluate the future situation of the Asia-Pacific countries where the impact of global warming is severer than other parts of the world. Since the future environment in this area is filled with uncertainties, it is necessary to consider many unpredictable factors in human activities such as population growth, economic development and technological innovation together with the variables in natural processes. A range of synopses or scenarios needs to be prepared, and various possibilities must be considered in the course of policy development. The AIM/Impact model are major component of the AIM model. The schematic diagram of the AIM/Impact model is illustrated in Fig. 1. In this report, as the summary of the 3-year research project, we concentrate on the estimation of the direct impacts from forthcoming climate change.

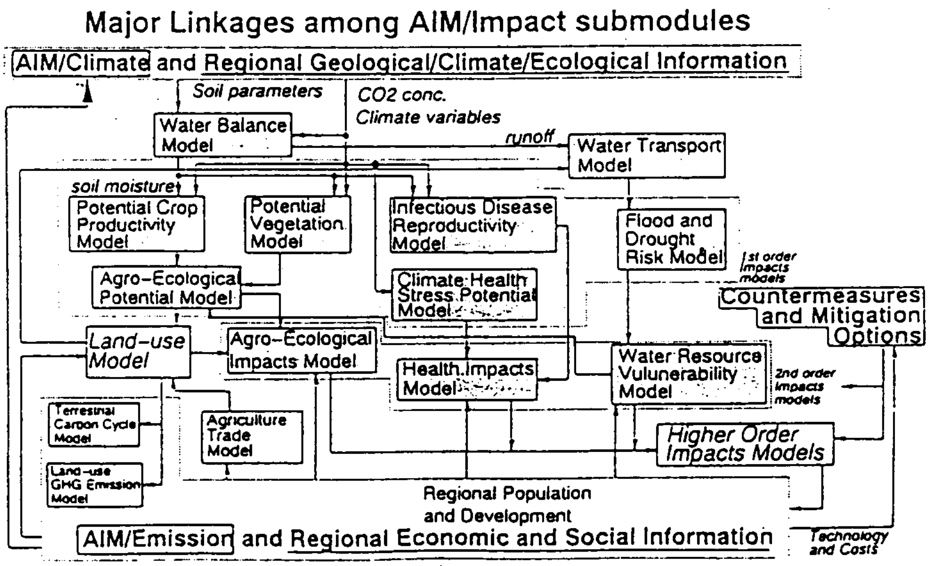

Fig. 1 Framework of AIM/Impact model

2. Research Method

2.1 Development and improvement of Agricultural impact model for China and India

Agriculture is the most important industry in the Asia-Pacific region except Japan and South Korea. In addition, the population in this area is rapidly increasing, so that food production must be increased to feed growing population in this region. Considering restrictions to which many developing countries are now facing such as land use change, environmental degradation, and so on, the global warming will affect the agricultural production in the future. Development of models are necessary to estimate future impacts of global warming on agriculture in each country for better response strategy. We selected China and India as the research fields in this work mainly because both countries are currently two of the most important crop production countries and they are now facing rapid population growth and urbanization and industrialization. Considering agricultural inputs such as fertilizer, chemicals, and irrigation, the agricultural impact model was greatly improved. Figs.2 and 3 shows predicted results by the original model and the improved model respectively.

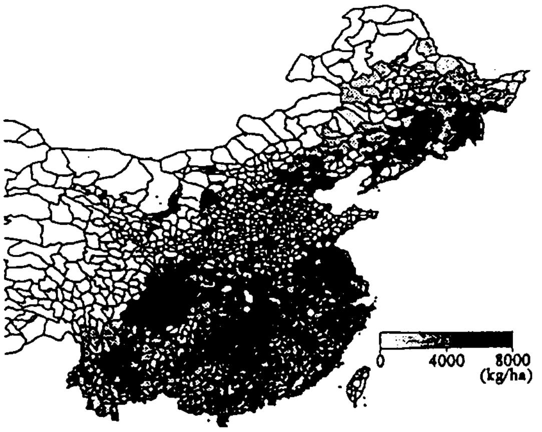

Fig. 2 Actual rice yield (1987)

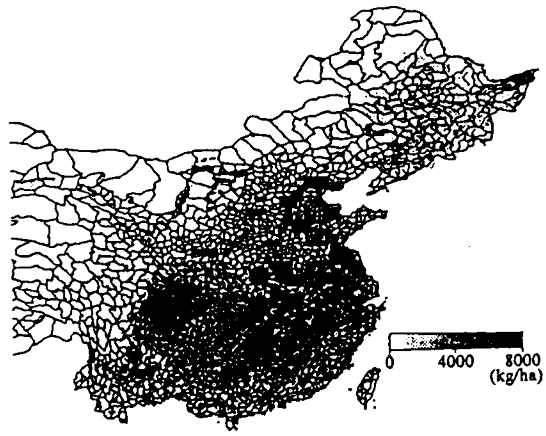

Fig.3 Estimated crop yield by the improved model

2.2 Integrated Assessment of Global Warming Impacts in the Asia-Pacific Region

We applied the developed model and the sub-modules of the AIM/Impact model to the Asia-Pacific region. Even in the case of direct impact assessments, reported results varied considerably with the overlaid GCM, the climate scenario and the model used. To get a consistent image of climate impacts, which are useful for an international comparison of their significance, a global-wide but spatially high-resolution impact assessment should be conducted under alternative GCM scenarios. Assuming the range of global average surface temperature increase (climate sensitivity), we overlaid 11 GCMs' spatial climate change patterns and calculated their direct influence on runoff discharges, crop productivity and forest suitability using sub-modules of the AIM/Impact.

The direct impact of climate change on water resources, crop production and natural ecosystems was evaluated. Fig. 2 shows the brief flow of this direct impact assessment using sub-modules of the AIM/Impact model. Four modules are relevant to this analysis: climate module, water cycle/transport module, crop production module, and natural ecosystem module. The projections were conducted under alternative global temperature change scenarios, and calculated indices were averaged for each country. Their median as well as maximum and minimum values were then recorded for use in the following analysis. (1) CLIMATE MODULE

The basic part of Fig. 4 is the climate module (Fig. 5) in which present temperature and precipitation and a perturbed climate change profile from GCM outputs are integrated and processed to produce the information required in the downstream part of the analysis. Global mean surface temperature changes are assumed to be 0.5～4.0℃. For the spatial distribution of climate data, we used outputs of various General Circulation Models (GCMs).

The 11 GCMs used are listed in Table 1. Since spatial resolution of GCM outputs is not fine enough for 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. The $1/r^2$ -weighted interpolation method was employed for precipitation. 0.5 degree latitude×0.5 degree longitude resolution was used. After the interpolation of GCM outputs, the following formulas are used to calculate future climate data in each grid for each month.

Table 1 GCM outputs used in this research

Climate Model	Calculated Date	lat. x long.(°)	Δ T (℃)	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	1.1	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

Δ T =Equilibrium surface temperature change on doubling CO_2

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

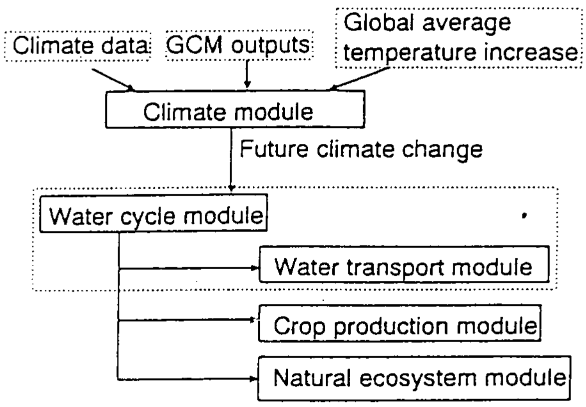

Fig. 4 Brief Flow of Impact Assessment using modules of the AIM/Impact model

For temperature: $$T(t) = T(present) + (T(perturbed) - T(base)) \times \frac{T_{mean}(t) - T_{mean}(base)}{\Delta T} \quad (1)$$

For precipitation: $$\log P(t) = \log P(present) + \frac{T_{mean}(t) - T_{mean}(base)}{\Delta T} \times \log\left[\frac{P(perturbed)}{P(base)}\right] \quad (2)$$

Here, $T(t)$ [℃] and $P(t)$ [mm/month] are the temperature and the precipitation in year t, respectively. $T(perturbed) - T(base)$ [℃] is the temperature difference, and $P(perturbed)/P(base)$ [-] is the precipitation ratio between perturbed and base calculation at the grid as obtained from GCM experiments. ΔT [℃] is a global average temperature change in the GCM experiment. $T_{mean}(t) - T_{mean}(base)$ [℃] is a global annual mean temperature increase between the base year and year t, which we assumed as 0.5, 1.0, 1,5, 2.0, 2.5, 3.0 and 4.0 ℃ (written as ΔT_{assume}, hereafter). As a result, in this paper, 8 (assumed temperature levels) × 11GCM cases = 88 cases of impact projections were executed for each kind of assessment.

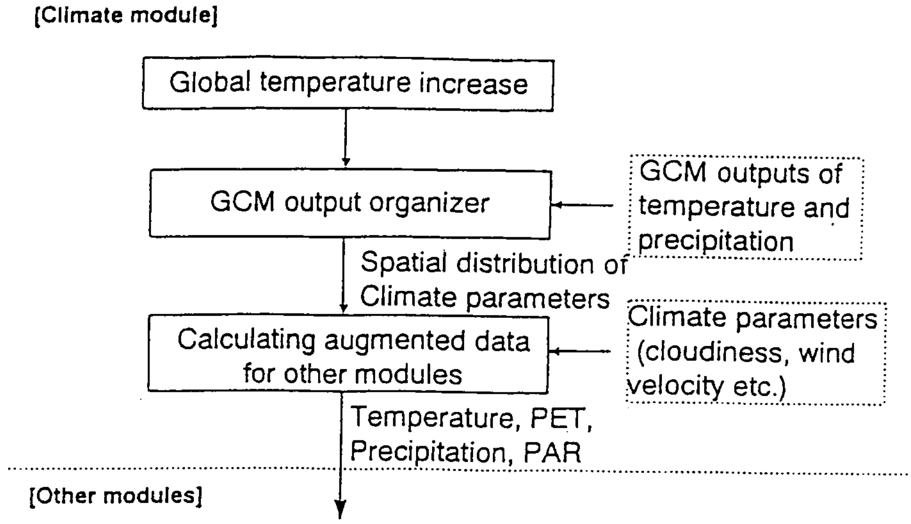

Fig. 5 Framework of climate module

(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 is intended to provide basic hydrologic information for the impact models of other sectors. Specifically, it creates gridded high-resolution data sets of surface runoff, soil moisture, evapotranspiration, and river discharge. A number of climatological and geographical data sets were required and organized from local and international institutes. 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 respectively, with the choice depending on data availability. In the water transport component, network topology of streams was determined from digital elevation data, and checked and modified using various information sources.

(3) CROP PRODUCTION

The productivity of crop land may be strongly controlled by climate change. To evaluate the impact, we estimated the influence on potential crop production. Days suitable for crop cultivation (growing period) are counted using climate data, and the crop growth during the growing period is simulated biophysically according to the growth characteristic parameters of each crop. Fig. 6 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 climate and water resources modules. The direct impact of CO_2 concentration on crop growth is not considered in this paper. Potential productivity of rice, winter wheat, and maize were selected as indices of crop production. In this estimation, four kinds of soil constraints were considered, i.e., cultivation suitabilities classified by soil units, soil phase, soil texture, and soil slope. To consider the high spatial variability of these constraints, 5-minute resolution gridded soil data were used for this calculation.

(4) NATURAL ECOSYSTEMS

The Holdridge method was used to assess climate change impacts on natural ecosystems.

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 defined as the temperature sum over a year with monthly temperatures greater than 0℃ divided by 12. Climate is classified into 7 divisions by this bio-temperature. Climate zones are also divided by average total annual precipitation. The complete classification includes 37 life zones. The map based on the Holdridge model represents the potential distribution of vegetation based on climate. The changes in climate classification caused by temperature and precipitation changes projected by eq.(1) and (2) are used to assess the potential impacts on natural ecosystems.

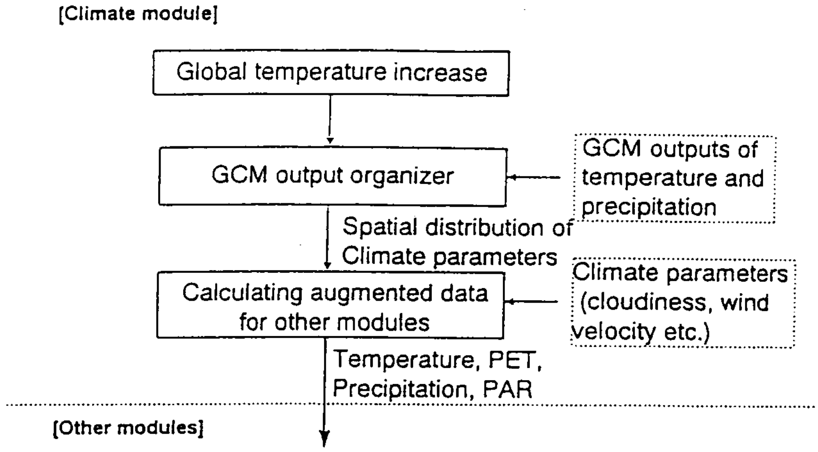

Fig. 6 Framework of crop production module

3. RESULTS

Country average temperature and precipitation changes are shown in Figs. 7 and 8 These are the cases in which global average temperature change (ΔT_{assume}) is 2℃, and ○ corresponds to a 3 month average of DJF and ● to JJA. These circles are plotted at the median values of 11 GCMs. Maximum and minimum values of these GCMs are written as small tics at the edge of horizontal bars.

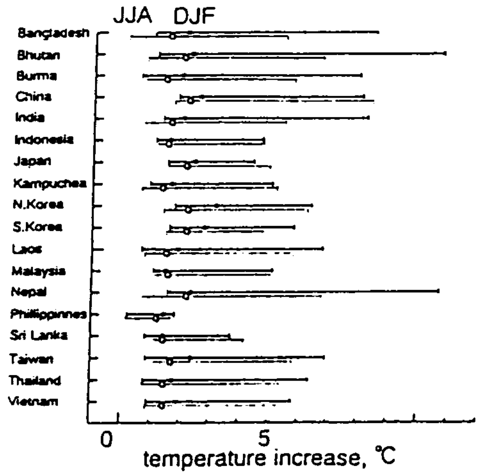

Fig. 7 Country average temperature change ΔT_{assume}=2℃

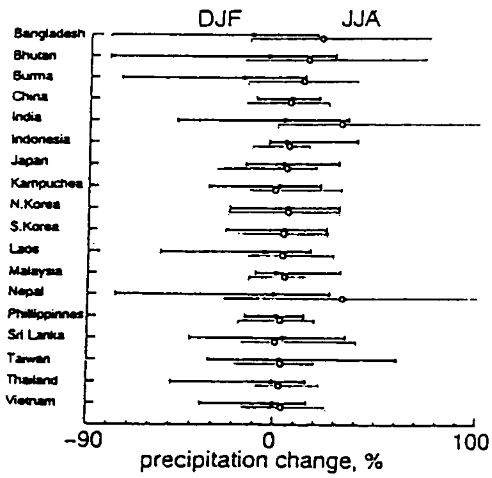

Fig.8 Country average precipitation change ΔT_{assume}=2℃

The median temperature changes are 1.3～2.7 ℃, but the range is 0.1～3.6℃ for all GCMs. The median precipitation changes are from +1～17% and range from -14～+47% for all GCMs. 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, than in other regions.

Based on the outputs of these national climate changes, Fig. 9 shows the country averaged surface runoff change . ΔT_{assume} was 2℃ in this figure. The median change in runoff ranges from -8～67%. India, Nepal and Bangladesh will experience more than a 30% increase.

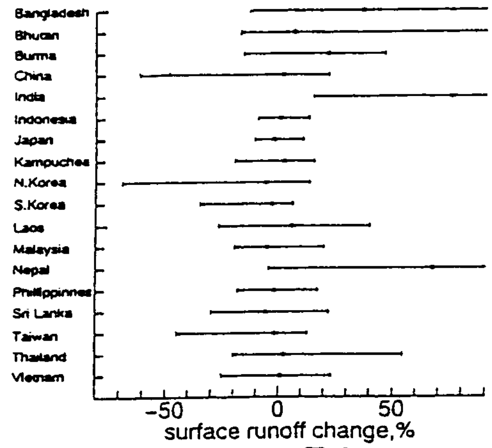

Fig.9 Country mean runoff change (ΔT_{assume}=2℃)

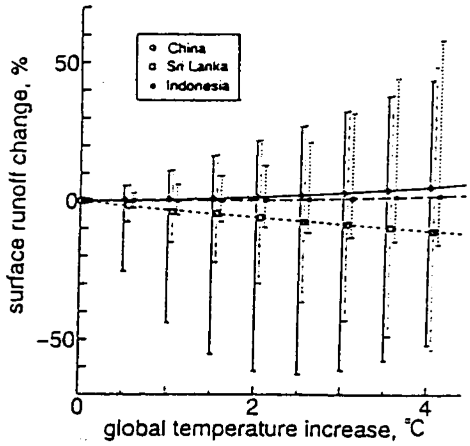

Fig.10 Country mean runoff change (Relation with ΔT_{assume})

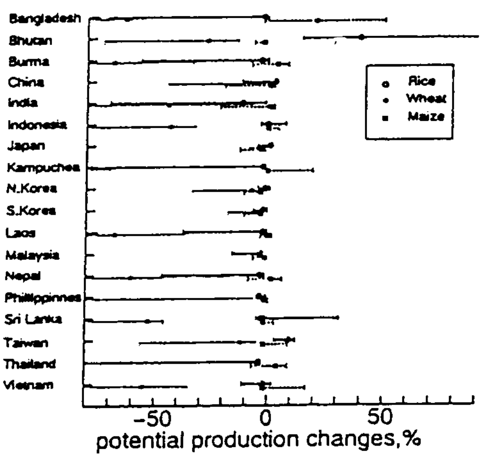

Fig. 11 Potential crop production changes (ΔT_{assume}=2℃)

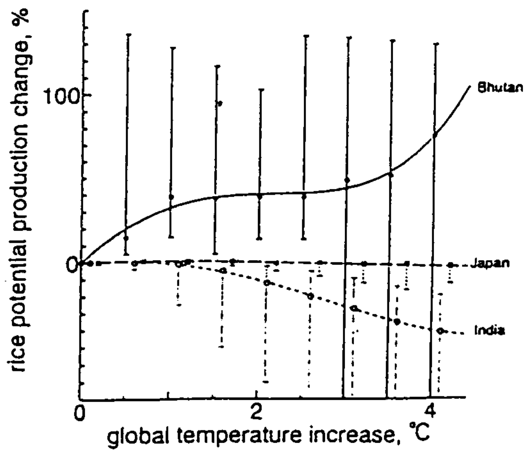

Fig. 12 Potential rice production changes (Relation with ΔT_{assume})

Burma will increase 20%, and other countries will be within ±5%. Fig. 10 shows the relation between ΔT_{assume} and country average runoff for some countries. Although the median changes monotonously in proportion as ΔT_{assume}, however, the ranges do not.

Crop production changes are shown in Fig. 11 where ΔT_{assume} is 2℃. A little decrease on rice production is expected in most of the countries. Except for significant increase 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 variance), Bangladesh is expected to show a large productivity increase. The Impact on other countries is within ±5%. The variance in 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 among different GCMs. The dependency on ΔT_{assume} does not show a consistent shape among the kinds of crops and countries. Figs. 12, 13 and 14 show the dependencies of rice, wheat and maize, respectively. Some responses registered monotonously, others showed a threshold response in a non-sensitive region, and still others had an initial increase followed by a decrease in proportion to the increase in global warming temperature.

As for natural ecosystems, changes in present forest regions were analyzed. Fig. 15 shows the forest area change, which is presently temperate/boreal forest and changes to other classifications under future conditions. In Japan and China, 35% of forest area is expected to change by ΔT_{assum}=2℃, and more than a 50% by ΔT_{assum}=4℃ . Most of the changes are to tropical forest.

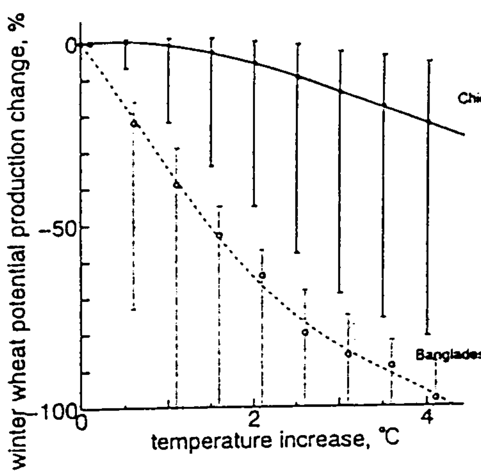

Fig. 13 Potential wheat production changes (Relation with ΔT_{assume})

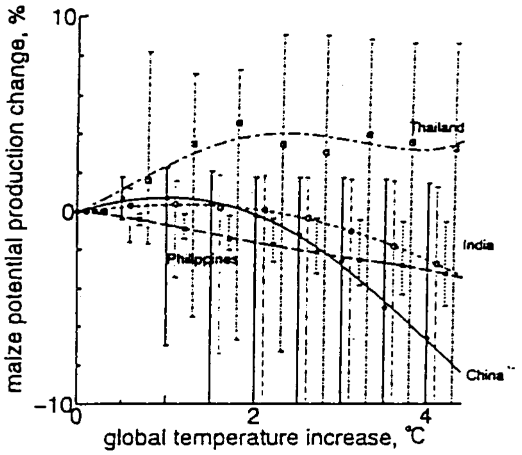

Fig. 14 Potential maize production changes (Relation with ΔT_{assume})

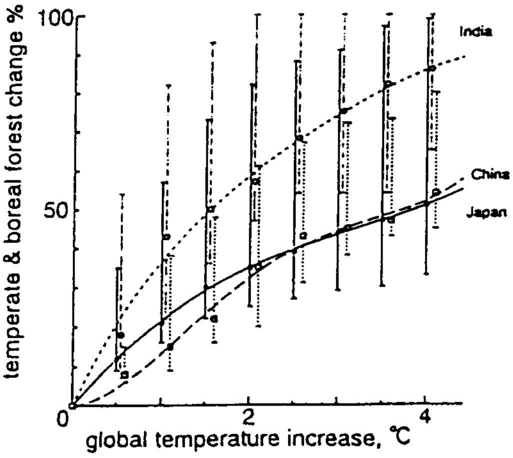

Fig. 15 Decrease in temperate/boreal forest

3. Discussion

Table 2 summarizes the above results. The column of malarial impacts is incorporated from Matsuoka and Kai[1, 2]. In this table, the impacts are evaluated at ΔT_{assum}=2℃, their significance was classified subjectively. From Table 2, the Indian subcontinent suffers from various direct impacts of climate change.

Table 2 Climate impacts on the Asia and Pacific regions (The meanings of -/0/+ are shown below)

	Climate		Water resource	Crop production			Vegetation	Health
country	temp.	precip.	runoff	rice	wheat	Maize	Temp.Forest	Mararia
Bangladesh	0	++	++	0	———	+++		0
Bhutan	0	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	
Lao_PDR	0	0	0	0		0		0
Malaysia	0	0	0	0		0		0
Nepal	0	+++	+++	0	———	0	———	———
Philippines	0	0	0	0		0		0
Sri_Lanka	0	0	0	0		0		-
Taiwan	0	0	0	+	—	0		
Thailand	0	0	0	0		0		0
Vietnam	0	0	0	0		0		-

notation	———	—	-	0	+	++	+++	note
Temperature				−0.5～0.5	0.5～1.0	1.0～1.5	>1.5	Additional 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

These are losses of areas suitable for wheat production and temperate forest, and an increase in malarial areas. Other regions such as East Asia are expected to suffer less compared with the Indian subcontinent. Some parts of the region may experience bad wheat, but the national impact is not significant in this calculation. Suitable conditions for temperate or boreal forest will significantly diminish in East Asia by as much a 40% as a result of a 2℃ global temperature increase. As for a greater temperature increase, the impacts are accelerated in a complex fashion. These are illustrated in Figs. 12～14 for crop production.

In this research, we used 11 GCMs for a spatial climate change pattern, and sampled their median responses 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 faults may cause crucial effects on the results.

Recently, many direct impact studies have been done in the Asia and Pacific regions (e.g. Asian Development Bank[3], Erda et al.[4]). They reveal a wide range of uncertainties in the impact assessment even if the analysis is restricted to direct impacts. Geographic resolution is one crucial factor, and the integration and scaling-up of basic physical and biological responses is another. Limited present knowledge makes it very difficult to aggregate such response simply using a few sampled estimations or spotted assessments. In order to render IAM 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.

4. Conclusion

Using the 4 modules of the AIM/Impact in an integrated manner, we have assessed the future impacts of global warming in the Asian-Pacific region based on the probable range of global temperature increase, and identified the impact response curves of the climate changes. Typical outcomes of the model calculations in the Asian-Pacific region are summarized as follows:

1) Following global average temperature increase of 2℃, the median estimations of national average temperature increases ranged between 1.3～2.7℃ in these regions. The precipitation changes ranged between +1～17%. The variance among estimations is large, and some estimate show more than a 3.5℃ temperature increase. The change in runoff ranged between -8～67% .
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 estimations is large. The relation between the impact and global temperature change reveals no discernibly logical pattern by either crops or countries.

5. References

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