3. Potential Impacts of Global Climate Change

Hideo Harasawa[1], Yuzuru Matsuoka[2], Kiyoshi Takahashi[1], Yasuaki Hijioka[1],
Yoko Shimada[3], Yosuke Munesue[4], and Murari Lal[5]

Summary. AIM/Impact model, an integrated assessment model of climate change impacts, has been developed in order to evaluate future climate change impacts and to support decision making on the global/Asia scale. AIM/Impact model consists of sub-models for evaluating impacts on major vulnerable sectors (water, agriculture, ecosystem, human health) and linkages among them. In this chapter, the general framework of AIM/Impact and examples of model outputs are introduced with a brief description of the sub-models.

3.1 Introduction

There is concern that anticipated climate change will cause significant negative damage on ecosystems and various sectors of human life. The degree of climate change and its damage depends on the pattern of future greenhouse gases (GHGs) emissions. The spatial and temporal distribution of climate change impact will be unequal, since the degree of climate change varies spatially and the adaptive capacity in relation to climate change is quite different among those affected according to their physical, economic, and social environments. The direct physical impacts of climate change on each sector may be interrelated and cause higher-order impacts. In order to evaluate alternative policies on GHGs mitigation, the consequent impacts, including higher-order effects, need to be assessed, while analysis on adaptation for the mitigation of future impacts is also important.

The AIM/Impact model, an integrated assessment model of climate change impacts, has been developed in order to evaluate future climate change impacts considering these complicated interrelationships and to support decision making on the global/Asia scale. The AIM/Impact model consists of sub-models for evaluating impacts on major vulnerable sectors (water, agriculture, ecosystem, human health) and linkages among them.

In this chapter, the general framework of AIM/Impact is presented first. Secondly, examples of model outputs are provided with a brief description of the sub-models.

---

[1] National Institute for Environmental Studies, Tsukuba 305-8506, Japan

[2] Kyoto University, Kyoto 606-8501, Japan

[3] Kobe Institute of Health, Kobe 650-0046, Japan

[4] Tokyo Institute of Technology, Tokyo 152-8552, Japan

[5] Indian Institute of Technology, New Delhi 110016, India

3.2 Framework of AIM/Impact Model

Figure 1 shows the linkages between the sub-models developed for the AIM/Impact study. Some sub-models have already been developed and sectoral impacts of climate change are estimated for various future climate scenarios projected using General Circulation Models (GCMs).

The FOOD sub-model consists of a productivity model for 12 crops and an agricultural trade model. The potential productivity changes caused by climate change are estimated using a 5^o x 5^o spatial resolution. Then, based on the estimated changes in crop productivity, the agricultural trade model calculates the allocation of the production of, and demand for, crops and other commodities that maximize social welfare.

The HEALTH sub-model examines the impact of malaria infection. It evaluates the suitability of climatic factors for the malaria mosquito to reproduce, and estimates the extent of different possible levels of malaria infection.

The VEG sub-model estimates the impact of climate change on several forest and other vegetation types. The model simulates forest collapse in regions where the rate of climate change is too high for the existing vegetation patterns to continue. The VEG sub-model also determines the value of human services provided by forests that are lost due to climate change. Work to modify the model so that it simulates dynamic changes to the vegetation is continuing.

The HYDRO sub-model uses information on climate, soil and terrain to simulate surface runoff and river discharges. The WATER sub-model estimates the future water demand at the national level and assigns that demand to each grid block, so creating a spatial distribution of water demand. Sub-models of the AIM/Emission model and of the AIM/Climate model such as the ENERGY and the CLIMATE ones are also interrelated with the sub-models of AIM/Impact in various ways. For example, the CLIMATE sub-model provides future climate scenarios for the sub-models of AIM/Impact with processing of the spatial GCM projections and observed climatology.

The sub-models that have been developed and will be developed are now related in a complex way. This complexity did not exist during the initial development stage of the project and the reasons for this are as follows:

1. It was necessary and efficient to consider long-term climate change problems simultaneously with other short-term environmental problems to develop realistic policies, especially for emissions abatement and impact adaptation. Initially, using individual sub-models with future climate scenarios was sufficient for estimating the damage caused solely by climate change in each region for each sector. However, the problems have become more complicated and recent policy requirements meant that the sub-models developed in the earlier stages had to be revised.
2. Since the initial stage, the significance of the feedback effect caused by changes in vegetation patterns and other sectors affected by climate change has been recognized. Nevertheless, due to the limited computer resources and

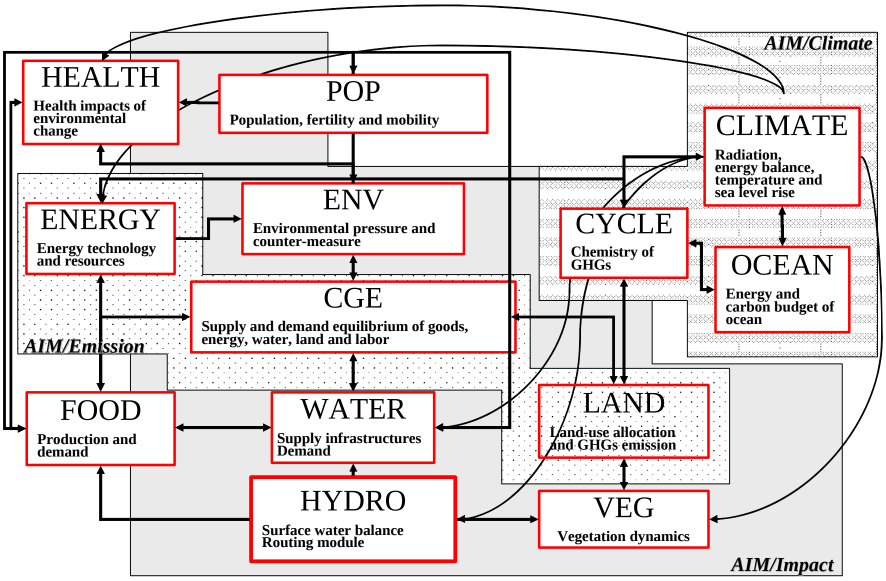


Fig. 1. Framework of AIM/Impact model (see color plates)

the complexity of the feedback processes, this issue had not received much detailed attention when reassessing the model. As climate models are refined and computer technology improves, it is becoming easier and more feasible to consider the feedback processes for carbon and other GHGs within GCM simulations. The importance of studies on the impact of climate change on vegetation is growing.

3. In order to investigate efficient strategies for mitigating and adapting to the impacts of climate change, it is necessary to estimate and compare the monetary value of the damage caused by climate change, the monetary value of the damage alleviated by various adaptation strategies, and the cost of adaptation strategies. A framework for this economic assessment, mainly relying on the CGE model, is required to quantitatively assess the various impacts of climate change in financial terms.

3.3 Agriculture

The productivity of agricultural land will be greatly influenced by future environmental changes. For example, climate-induced changes are expected to have profound impacts on potential crop yields, and so influence the distribution of cropping patterns in the Asia-Pacific area.

In order to assess the impact of climate change on agriculture, studies are necessary using a framework that can evaluate related direct and indirect effects.

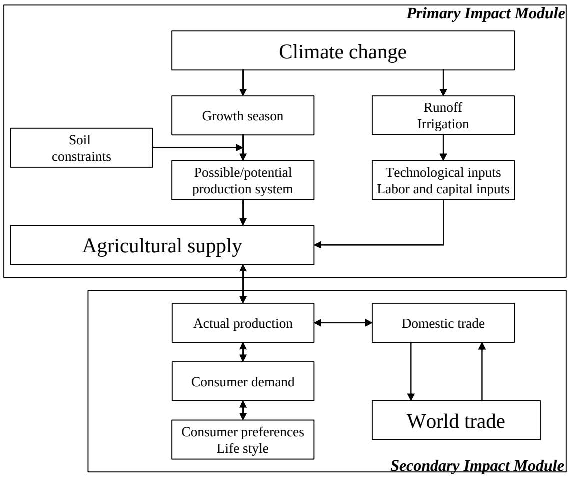


Fig. 2. Framework of agricultural impact model

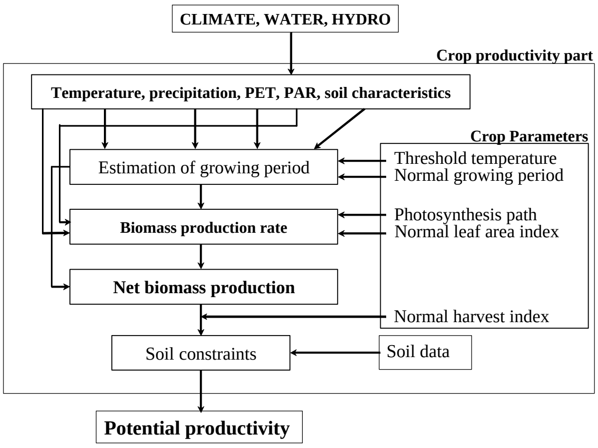


Fig. 3. Model used to estimate potential crop productivity

Figure 2 shows the framework of the agricultural impact study (Takahashi *et al.* 1997). The two basic assumptions for this study are: (1) climatic change will directly affect land and water resources (the primary effects); and (2) changes in land and water resources will affect economic activities (the secondary effects).

A potential crop productivity model was developed and linked to regional climate and environmental soil data to illustrate the first assumption. The method used for estimating potential crop productivity is based on that used by the Food and Agriculture Organization (FAO 1978-1981). The number of days suitable for crop cultivation (the growing period) are counted using climate data, then the crop growth during the growing period is simulated using the growth parameters for

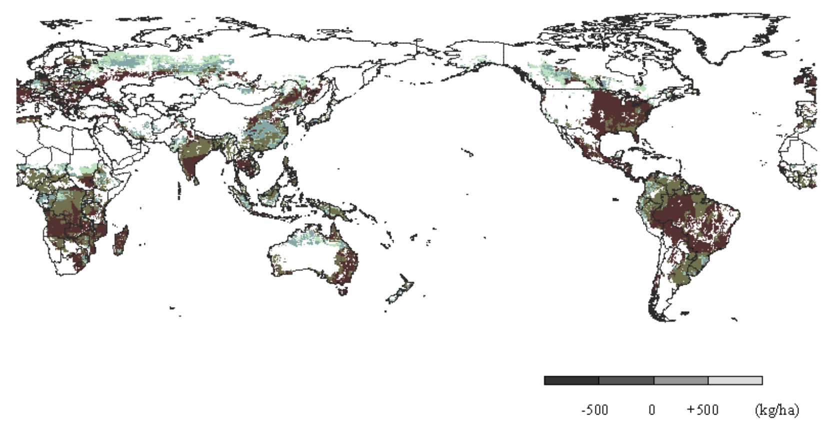


Fig. 4. Change in the potential productivity of rice from 1990 to 2050 under the climatic conditions projected using the CCSR/NIES GCM (see color plates)

each crop. Figure 3 shows the framework for estimating potential crop productivity. This model requires data for: daily mean temperatures; mean daytime temperatures; precipitation; potential evapotranspiration (PET); photosynthetically active radiation; and soil characteristics. The physical and chemical properties of soil such as soil texture and soil slope were used to estimate the suitability of land areas for agriculture. The calculations used data for these properties on a 5-minute resolution grid to account for their high spatial variability. Figure 4 shows the change in the potential productivity of rice from 1990 to 2050 under the climate conditions projected with CCSR/NIES GCM. In general, the productivity of rice crops will increase in areas of high-latitude and decrease in areas of low-latitude.

An agricultural trade model based on the GTAP general equilibrium model developed at Purdue University (Hertel 1997) was used to assess the impact of climate change on the economy through changes in crop productivity within each region (Takahashi *et al.* 1999). Regions and production sectors treated in the model are shown in Tables 1 and 2. In the agricultural trade model, potential changes in the productivity of rice, winter wheat, tropical maize and other crops - as estimated in the potential crop production model - are taken as the changes in the Hicks-neutral technology parameters for their respective production sectors.

Table 3 shows the changes in producer prices, agricultural production and social welfare in some regions under changed climatic conditions (IS92a emissions for 2100). Comparing the changes in social welfare per capita, India is found to be the country likely to suffer the most damage. This reflects the significant decline in the productivity of wheat in India and the comparatively large share of agricultural products purchased using private funds. Whilst a rich country can use trade to mitigate the economic damage caused by decreases in crop productivity, a poor country cannot adapt in the same way, as a result, its social welfare deteriorates.

Table 1. The thirty countries and regions in the agricultural trade model

Country	Code
Australia	AUS
New Zealand	NZL
Japan	JPN
Korea, Republic	KOR
Indonesia	IDN
Malaysia	MYS
Philippines	PHL
Singapore	SGP
Thailand	THA
China	CHN
Hong Kong	HKG
Taiwan (China)	TWN
India	IDI
Other South Asia	RAS
Canada	CAN
U.S.A.	USA
Mexico	MEX
Central America and Caribbean	CAM
Argentina	ARG
Brazil	BRA
Chile	CHL
Other South America	RSM
EU	E_U
Austria, Finland, Sweden	EU3
European Free Trade Area	EFT
Central European Associates	CEA
Former USSR	FSU
Middle East and North Africa	MEA
South Africa	SSA
Rest of the world	ROW

Table 2. The eight production sectors in the agricultural trade model

Sectors	Description
Paddy	Paddy
Wheat	Wheat
Other grains	Other grains
Other crops	Non-grain crops
Livestock	Wool Other livestock
Other agricultural products	Processed rice Meat products Milk products Other food products Beverages and tobacco Textiles Leather
Manufacture	Apparel Lumber Pulp paper Petroleum and coal Chemicals, rubbers and plastics Nonmetallic minerals Primary ferrous metals Nonferrous metals Fabricated metal products Transport industries Machinery and equipment Other manufacturing
Services	Electricity, water and gas Construction Trade and transport Other private services Other governmental services Ownership of dwellings

Table 3. Changes in producer prices, agricultural production and social welfare in some regions under changed climate (IS92a emissions, the year 2100 compared to 1990)

	JPN	CHN	IDI	CAN	USA	E_U
Producer price change (%)						
Rice	-0.01	-1.58	17.96	-40.16	-0.06	-4.93
Wheat	4.91	8.47	125.11	-13.10	4.76	8.92
Other grains	1.81	0.79	1.80	-43.59	-1.46	-3.36
Other crops	-0.01	-0.28	1.90	2.76	-0.10	-0.05
Livestock	-0.19	-0.09	2.84	-1.22	-0.59	-0.04
Other agricultural products	-0.15	-0.01	0.30	-0.35	-0.07	0.04
Manufacture	0.03	-0.12	-1.10	0.61	0.03	-0.02
Services	0.03	-0.16	-0.93	0.69	0.02	-0.02
Production change (%)						
Rice	0.11	-0.25	-1.76	105.99	0.23	2.03
Wheat	-6.60	-3.97	-7.64	115.07	2.87	-3.64
Other grains	-15.56	-1.39	-1.33	89.41	-4.04	-6.50
Other crops	0.11	-0.07	-4.25	-2.26	0.25	-0.03
Livestock	0.09	-0.24	-2.27	0.94	0.03	-0.22
Other agricultural products	0.11	-0.27	-4.73	0.69	0.04	-0.22
Manufacture	-0.01	0.31	-0.37	-1.62	0.03	0.05
Services	0.00	0.00	-2.62	-0.02	0.01	0.01
Consumer price index (%)	0.001	0.001	6.047	0.513	0.017	-0.010
Income change per capita (%)	0.026	-0.236	-0.617	0.833	0.026	-0.009
Social welfare change (%)	0.022	-0.219	-4.892	0.343	0.009	0.003

3.4 Vegetation

Figure 5 shows the process used to account for the economic impact of forest loss caused by climate change (Munesue *et al.* 2000). The impacts of climate change on several forest types and other vegetation types are projected. These vegetation types are based on the vegetation climate-zones classified according to the Holdridge scheme (Holdridge 1947) under current and future climatic conditions and an assumed maximum rate for vegetation transfer that follows the shift in suitable climatic conditions due to climate change. The model simulates forest collapse in regions where the rate of climate change is too great to allow the existing vegetation types to shift. The black cells (cells are classified to a forest type under the present climate and to a non-forest type under the future climate) and gray cells (cells are classified to a forest type under the present climate and to a different forest type under the future climate, but the shift cannot occur smoothly) in Fig. 6 indicate forests that collapse under situations of low, medium or high rates of climate change. The global mean temperature increases between 1990 and 2100 under these scenarios are 0.85°C, 2.08°C, and 3.52°C. The maximum rate of forest transfer is assumed to be 1 km/yr in this model trial. The forest area will shrink by 2%, 5% and 9% of the total land area, and the replacement of forest types at risk of shrinking will be 3%, 7% and 12% of the total land area. The most damaged forests are in the northern parts of Eurasia and North America.

The economic value of the loss due to forest collapse caused by climate change is estimated using values from the National Center for Ecological Analysis and Synthesis (Costanza *et al.* 1997), and comes to US$49.7 billion, $US126.4 billion, and $US219.5 billion at 1994 dollars respectively under the three scenarios.

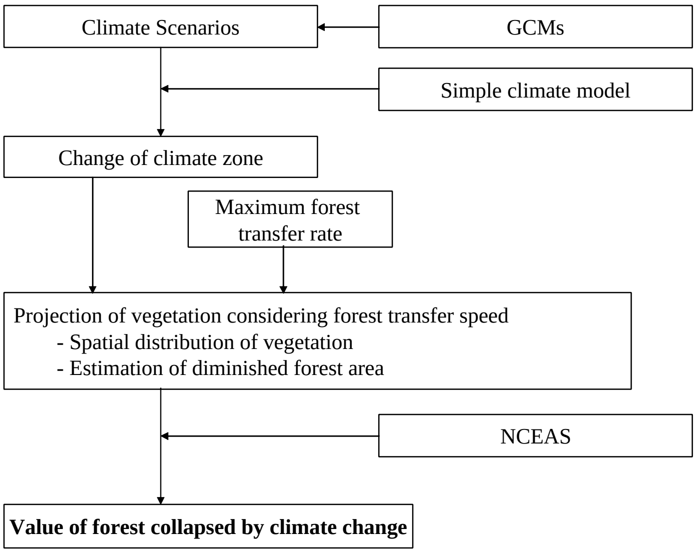
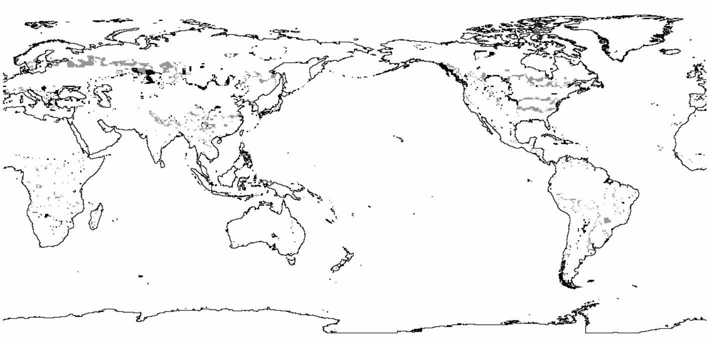
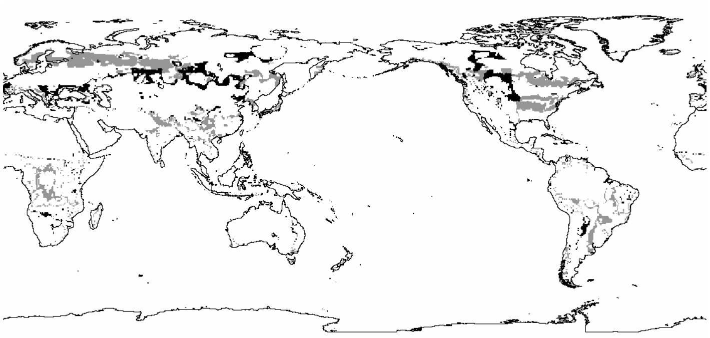


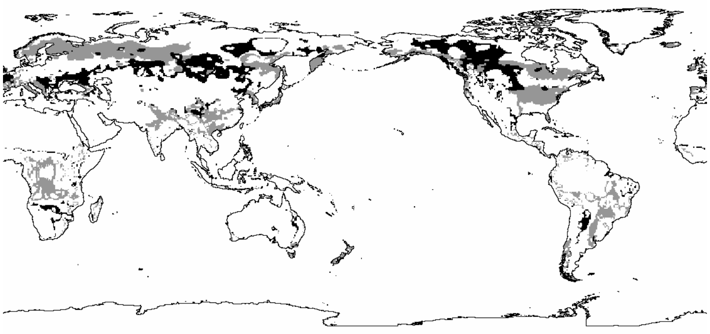
Fig. 5. Process of estimating the economic cost of forest loss from climate change



IS92c scenario with low climate sensitivity



IS92a scenario with medium climate sensitivity



IS92e scenario with high climate sensitivity

■ Cells are classified to a forest type under the present climate and to a non-forest type under the future climate (diminishment of forest).

▨ Cells are classified to a forest type under the present climate and to a different forest type under the future climate, but the shift cannot occur smoothly (replacement of the forest type with the risk of diminishment).

Fig. 6. Forest collapse under low, mid, high-climate change scenarios (IS92c emissions with low climate sensitivity, IS92a emissions with medium climate sensitivity, IS92e emissions with high climate sensitivity) (see color plates)

3.5 Health

Air and water pollution, as well as solid and hazardous wastes, impact directly on human health. Global climate changes will also affect human health in many ways. For example, global warming will change the vegetation distribution and increase ground temperatures. This will allow the habitat of the Anopheles mosquito, which is the malaria vector, to expand. In addition, the time taken for the development of the malaria protozoan will shorten and its reproductive potential will increase. As a result, the risk of malaria outbreaks on a global scale is predicted to increase. A sub-model of the AIM/Impact model was developed to quantitatively estimate this risk (Matsuoka *et al.* 1995).

Figure 7 shows the assessment framework used in this study. The two major components of the framework are the relationship between sporogony and temperature, and the eco-climatic index model which shows the climatic response of vectors. These components are supported by the soil moisture sub-model and outputs from the equilibrium experiments of GCMs. The primary climatic variables of this framework are surface temperature and precipitation distributed spatially and temporally for both the current situation and that expected under $2xCO_2$ climate conditions.

Figure 8 shows the potential for malaria infection calculated under current and expected future climate conditions. The yellow indicates areas where the risk of malaria is mesoendemic and the red highlights areas where it is hyperendemic (see color plates).

Table 4 shows the predicted expansion of the population living under endemic malaria when the global mean temperature increases by 2.0°C. The risk of malaria in China, Indonesia and India increases due to this change. It is concluded that the population expected to be at risk of malaria infection in the Asia-Pacific region will increase by 30%.

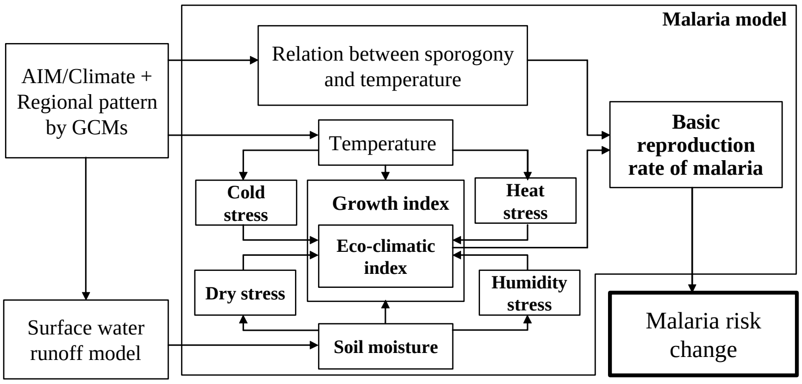


Fig. 7. Framework of malaria impact model

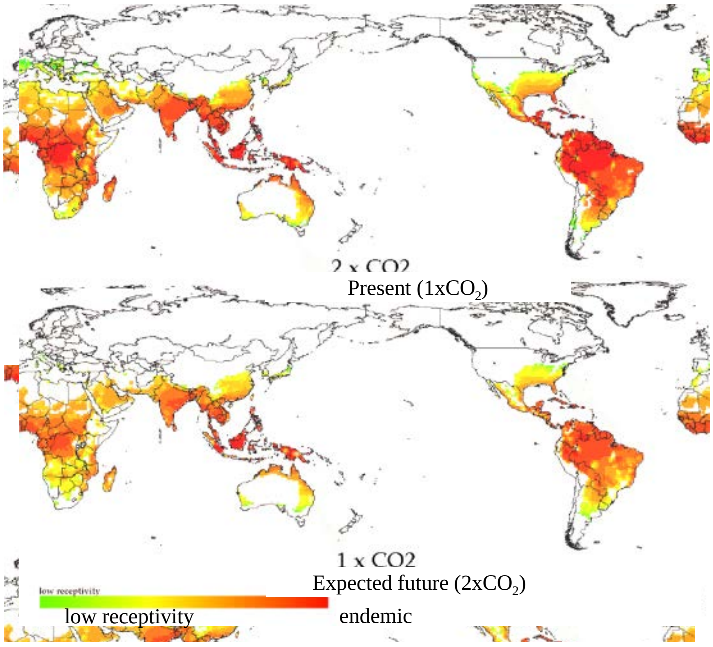


Fig. 8. Expansion of the area affected by malaria (Upper: current climate, Lower: 2xCO$_2$ climate change, GCM: GFDL q-flux equilibrium experiment) (see color plates)

Table 4. Population at risk of malaria (millions)

	Reported values		Present climate		Future climate	
Country	Country Population	Malarious Area	Low Risk	High Risk	Low Risk	High Risk
Afghanistan	18.14	10.39	3.65	0.00	18.14	0.00
Bangladesh	98.66	2.29	64.16	64.16	64.16	64.16
Bhutan	1.42	0.18	0.79	0.73	0.79	0.79
Cambodia	7.28	2.36	5.76	5.76	5.76	5.76
China	1059.52	975.82	646.93	54.60	807.30	132.33
India	750.90	728.33	721.40	522.31	731.45	648.04
Indonesia	163.39	155.63	122.00	74.76	138.17	107.62
Iran	44.21	34.83	12.92	0.00	29.76	0.00
Iraq	15.90	15.90	9.39	0.00	15.90	0.00
Laos	4.12	3.30	3.79	3.64	3.79	3.79
Malaysia	15.56	15.44	13.14	12.16	13.14	12.16
Myanmar	37.15	33.22	30.93	23.25	36.06	29.39
Nepal	16.63	10.76	14.09	4.76	14.95	10.22
Oman	1.24	1.24	0.92	0.00	0.48	0.00
Pakistan	96.18	96.18	91.89	0.00	95.86	0.00
Philippines	54.38	16.82	30.55	30.55	30.55	30.55
Saudi Arabia	11.54	4.51	8.68	0.00	7.97	0.00
Sri Lanka	15.84	11.51	12.67	9.17	12.67	12.67
Syria	10.27	6.38	1.91	0.00	10.27	0.00
Thailand	51.30	46.09	44.61	43.98	44.61	43.98
Turkey	49.27	49.27	14.78	0.00	49.27	0.00
U.A.E.	1.33	1.33	1.07	0.00	1.07	0.00
Viet Nam	59.61	44.03	45.96	41.37	45.96	45.96
Yemen	6.85	3.01	1.08	0.00	2.38	0.00
Papua New guinea	3.33	3.33	2.97	2.14	3.15	2.81
Solomon	0.27	0.27	0.08	0.00	0.00	0.00
Vanuatu	0.14	-	0	0.00	0.00	0.00
Total	2594.43	2272.42	1906.12	893.34	2183.61	1150.23

3.6 Water

Figure 9 shows the model used to predict changes in water resources (Takahashi *et al.* 2001). In the surface runoff model, the runoff volume is calculated using grid climate information and surface information, as a result, the volume of water potentially available for use within river basins can be estimated. In the water demand model, the future water demand in each river basin is calculated using estimates of the current water demand and population distribution together with economic development scenarios. Moreover, with the changes in the water available for use relative to water demand, future qualitative changes in the balance between water supply and demand can be understood. An assessment of the balance between supply and demand was carried out for each river basin.

Water demand was estimated for the household, industrial, and agricultural sectors (Fig. 10). For each sector, water demand was first estimated for each country based on population changes and growth in economic activities as well as scenarios for improvements in water use efficiency. Next, the spatial distribution of the water demand was estimated using estimates of population and land use distribution (cropland density). Finally, the estimated spatial values were aggregated to provide a total value for water demand in each river basin.

To estimate the surface runoff in each grid, one of the bucket-type models (Vorosmarty *et al.* 1989) was used with inputs of monthly mean climate data and surface data at a 0.5^o x 0.5^o spatial resolution. Surface runoff was calculated as the amount of effective precipitation (precipitation minus evapotranspiration, but including consideration of snow coverage during periods of low temperatures) exceeding the maximum amount of water able to be retained in the soil. Evapotranspiration was calculated as a function of the monthly mean PET using the method of Penman (FAO 1992) and the level of soil-water saturation.

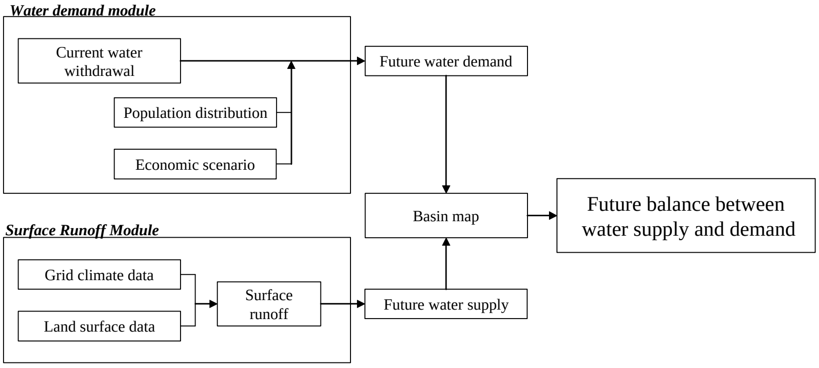


Fig. 9. Model used to estimate water resources

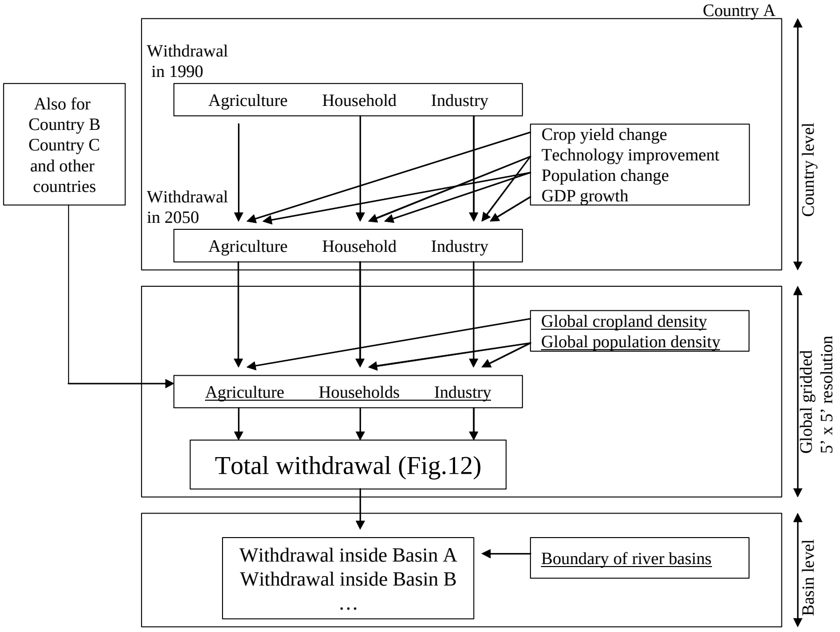


Fig. 10. Model used to estimate water demand

Figure 11 shows the spatial distribution of water demand density (mm/year, a total of three sectors) with a 5^o x 5^o resolution in 1990 and 2050. Areas with a very high density of water demand exist in various regions, including eastern China, Southeast Asia, India, Japan, eastern USA and Europe. Of these, eastern China and India will have extremely high demand due to the rapid increases in demand during the first half of the 21st century.

When the potential trends for change from the current situation are examined, it is seen that in the industrialized countries where population should be stable, water demand will increase only in the industrial sector. It will not change significantly in the household sector, and should decline in the agricultural sector. In contrast, increases will occur simultaneously in all three sectors in the developing countries, reflecting the trends of both population growth and economic development. The increase in the industrial sector will be the largest.

Figure 12 shows changes in the calculated runoff based on the results of the transient experiments (atmospheric CO_2 concentration is assumed to increase at an annual rate of 1%) of the CCC, ECHAM4, and CCSR/NIES climate models. This is equivalent to [mean runoff for the 10 years from 2050 to 2059] minus [mean runoff for the 10 years from 1980 to 1989]. Thus, it can be seen that some increases in runoff will occur throughout the whole of Siberia. Large increases in runoff in southern China and the Indian subcontinent are also common features. On the other hand, completely opposite change patterns are shown by the climate models for central Africa and northern South America. This shows that the choice

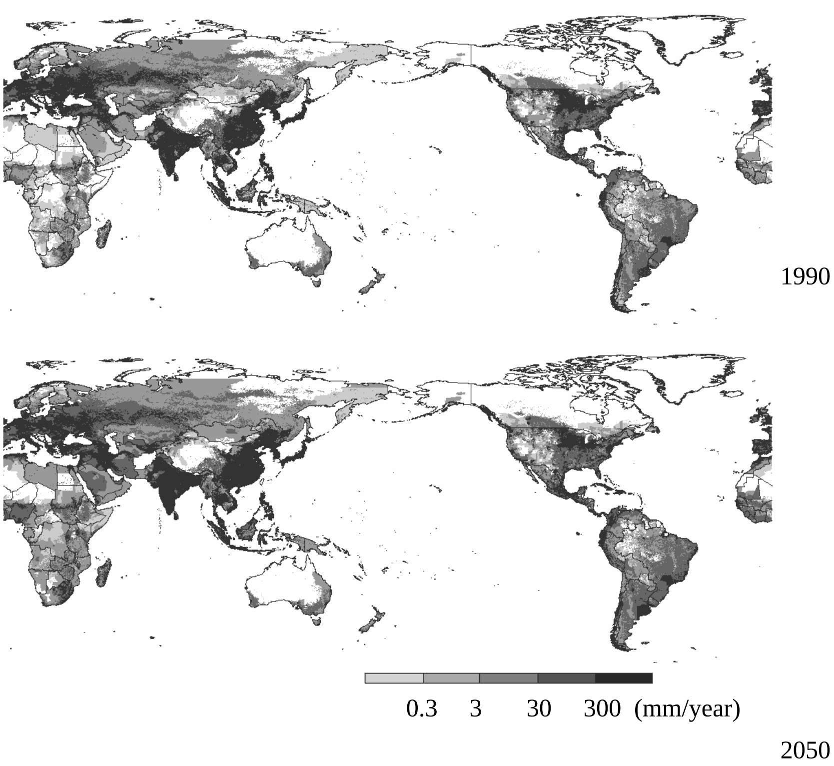


Fig. 11. Water demand per unit area in 1990 and 2050 (see color plates)

of climate model significantly influences the spatial distribution of changes in runoff.

As an example of the comparison between water supply and demand, Figure 13 shows the annual changes in the supply and demand balance from 2050 to 2059 for the Ganges and Mekong river basins. For the Ganges river basin, the ratio will not change greatly since the increase in runoff is expected to match the increase in water demand due to population growth and economic development. However, the CCSR/NIES model shows a different behavior for the Ganges river basin compared with the other two models. For the Mekong river basin, the supply - demand ratio will increase with the increasing water demand, but the value of the ratio will not be high compared to other basins where water is scarce.

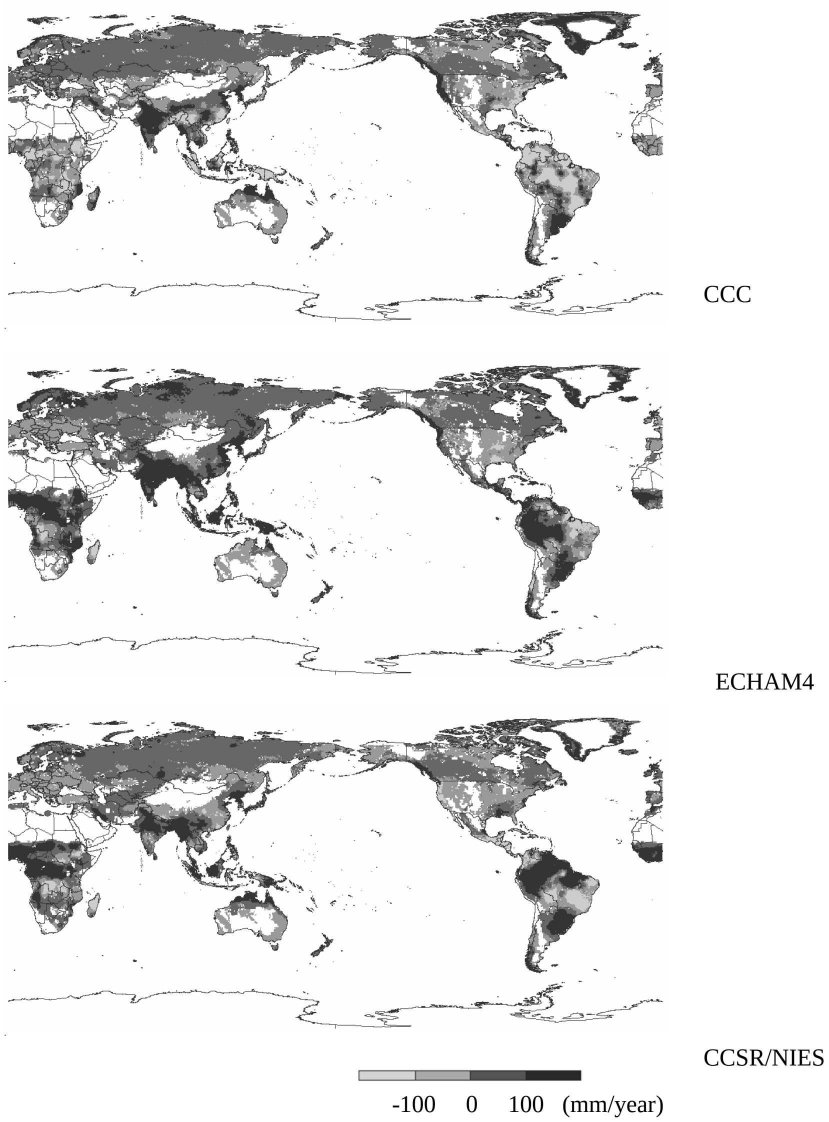


Fig. 12. Changes in runoff calculated based on the results of the transient experiments of the CCC, ECHAM4, and CCSR/NIES climate models (mean runoff for the 10 years from 2050 to 2059 minus mean runoff for the 10 years from 1980 to 1989) (see color plates)

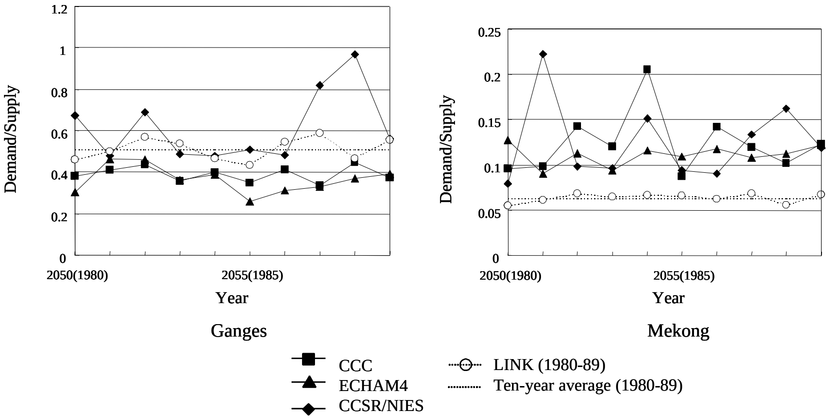


Fig. 13. Annual change in the supply and demand ratio for water from 2050 to 2059 for the Ganges and Mekong river basins

3.7 Climate Change Scenarios used in AIM/Impact

The impacts of climate change have been assessed using climate scenarios based on the latest GCM experiments at each research stage. Currently, the transient experiments with the GCMs listed in Table 5 are mainly used for creating future climate scenarios (Takahashi *et al.* 2001). To compensate for the disadvantages of GCMs, such as the coarse spatial resolution, historically observed data provided by LINK (New *et al.* 1998) is amalgamated with the simulated results of GCMs. The development of climate scenarios based on regional climate models or statistical downscaling methods have also been investigated, although they have not yet been used for practical impact assessment.

Research collaboration with the GCM modeling project inside NIES has been promoted to take advantage of the fact that NIES has both the impact analysis project and the climate modeling project. AIM/Impact not only receives projections of future climatic conditions from GCM experiments, but it also provides the results of the impact modeling to GCM modelers so feedback processes can be depicted.

Table 5. Transient experiments of the GCMs currently used to create climate scenarios

	CCSR	CCCma	CSIRO	GFDL	HADCM2	ECHAM4	NCAR
Institution, country	Tokyo University and National Institute for Environmental Studies, Japan	Canadian Center for Climate Modelling and Analysis	Australia's Commonwealth Scientific and Industrial Research Organization	Geophysical Fluid Dynamics Laboratory, USA	Hadley Centre for Climate Prediction and Research, UK	Deutsches Klimarechenzentrum, Germany	National Centre for Atmospheric Research, USA
Resolution (A-GCM)	5.6°×5.6° 20layer	3.7°×3.7° 10layer	3.2°×5.6° 9layer	4.5°×7.5° 9layer	2.5°×3.75° 19layer	2.8°×2.8° 19layer	4.5°×7.5° 9layer
Resolution (O-GCM)	2.8°×2.8° 17layer	1.8°×1.8° 29layer	3.2°×5.6° 21layer	4.5°×3.75° 12layer	2.5°×3.75° 20layer	2.8°×2.8° 11layer	1°×1° 20layer
CO_2 concentration (control run)	345ppmv	295ppmv	330ppmv	300ppmv	323ppmv	354ppmv	330ppmv
CO_2 concentration (transient run)	1%/yr	1%/yr	0.9%/yr	1%/yr	1%/yr	1%/yr	1%/yr
Simulated period (control run)	1890-2099 210yr	1900-2100 200yr	1881-2100 219yr	1958-2057 100yr	1860-2099 240yr	1860-2099 240yr	1901-2036 136yr
Climate sensitivity	3.5°C	3.5°C	4.3°C	3.7°C	2.5°C	2.6°C	4.5°C
Reference	Emori *et al.*, 1999	Reader and Boer, 1998	Hirst *et al.*	Manabe and Stouffer, 1996	Johns *et al.*, 1997	Roeckner *et al.*, 1996	Meehl, 2000

3.8 Future Direction for Model Improvement

The role of studies on the assessment of climate change impacts on a global scale has been changing in recent years. The main purpose of impact assessments on a global scale was to alert people to the seriousness of climate change and to prompt the promotion of policies to mitigate GHG emissions by identifying the regions that could suffer severe damage as a result.

Nowadays, however, the roles that impact studies on a global scale are being expected to fulfill has become diversified. In order to investigate the feasibility and effectiveness of strategies for dealing with climate change problems in a more realistic way, the impact on the natural environment and human wellbeing as a consequence of choices regarding alternative paths to future socioeconomic development should be assessed by taking into account not only climate change itself, but also the wider contributing factors, such as the socioeconomic background and the state of the natural environment. The framework of analysis to achieve a more comprehensive approach is expected to be developed and applied to the ongoing international activities for comprehensive policy evaluation that focus on wider contexts, such as sustainable development and ecosystem conservation. Moreover, since it is possible for the natural environment and human system altered by climate change to affect the climate system itself through feedback mechanisms, impact assessment is expected to be closely linked with climate systems analysis and to provide the information required for considering the consequences of feedback effects.

Taking into consideration the expected role for impact assessment on a global scale, our best efforts are being directed towards the creation of linkages among sectoral assessment models, as explained in section 3.2, as well as to refine the following aspects of the AIM/Impacts model:

- Development of impact and adaptation assessment methods that consider not only climate change, but also future changes in socioeconomic and other environmental factors.
- Extension of data collection on adaptation strategies and the development of methods of evaluating the cost-benefit ratio of the strategies.
- Closer collaboration with climate system modelers to take into account feedback effects.

Adding to these refinements, in order to analyze adaptation strategies in more realistic and effective ways, top-down analysis on a global scale that considers international trade, technology transfer, climate change, and the bottom-up analysis on a national scale that considers concrete adaptation measures, will be linked by maintaining consistency in the socioeconomic background in addition to the physical and monetary variables.

References

Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P, van den Belt M (1997) The value of the world's ecosystem services and natural capital. Nature 387: 253-260

FAO (1978-1981) Report on the Agro-Ecological Zones Project, Vol.1-4, World Soil Resource Report 48, Food and Agriculture Organization of the United Nations, Rome

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

Hertel TW (1997) Global trade analysis, Cambridge University Press

Holdridge LR (1947) Determination of world plant formations from simple climatic data. Science 105: 367-368

Matsuoka Y, Kai K (1995) An estimation of climatic change effects on malaria. Journal of Global Environmental Engineering 1: 43-47

Munesue Y, Takahashi K (2000) Evaluation of climate chnage impact on vegetation and its economic value. Environmental Science 13(3): 329-337

New M, Hulme M, Jones P (1998) Representing twentieth century space-time climate variability. I: Development of a 1961-1990 mean monthly terrestrial climatology. J. Climate 12: 829-856

Takahashi K, Harasawa H, Matsuoka Y (1997) Climate change impact on global crop production. Journal of Global Environmental Engineering 3: 145-161

Takahashi K, Harasawa H, Matsuoka Y (1999) Impacts of climate change on food production. - An Economic Assessment -. Journal of Global Environmental Engineering 5: 1-9

Takahashi K, Matsuoka Y, Shimada Y, Harasawa H (2001) Assessment of water resource problems under climate change - considering inter-annual variability of climate derived from GCM calculations-. Journal of Global Environmental Engineering 7: 17-30

Takahashi K, Matsuoka Y, Okamura T, Harasawa H (2001) Development of climate change scenarios for impact assessment using results of General Circulation Model simulations. Journal of Global Environmental Engineering 7: 31-45

Vorosmarty CJ, Morre III B, Grace AL, Gildea MP (1989) Continental scale model of water and fluvial transport: an application to South America. Global Biogeochemical Cycle 3: 241-256