B-15.2 Development of AIM/impact Model

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Abstract:

The objective of this project is to develop the AIM/impact model for scenario analysis of global warming impacts on the Asian-Pacific region. AIM/impact is designed to calculate the impacts in primary production - water supply, agricultural production, wood supplies, etc.- and then make predictions of higher-order impacts on the regional economy. AIM/impact is linked to AIM/emission through a GCM experiment which is based on the Greenhouse Gas emission scenarios calculated by AIM/emission. Various economic and environmental data for the region has been gathered and filed in a special data-base. As well simulation models to estimate water resource changes, vegetation changes and Malaria spread caused by global warming have been developed. The climate change scenario was prepared using GCM experiments by GFDL, CCC, and other organizations. Using these scenarios, we have simulated changes in catchment water run-off, the survival status of vegetation and the reproduction rates of Malaria for all special units of water catchments and vegetation types region in the region. These will be linked to higher-order impact models to estimate impacts on the regional economy.

Key Words AIM/impact, Global Warming Impacts, Asian-Pacific Region, Water Resource Changes, Vegetation Changes, Malaria Diffusion

1. Outline of AIM/impact Model

The other main component of AIM is the AIM/impact model, which estimates impacts of global warming in the Asian-Pacific region. AIM/impact is comprised of a Sea Level Rise Model, a Water Balance Model, a Vegetation Change Model, a Health Impact Model, a Natural Disaster Model, an Agriculture Production Model, and an Economic Evaluation Model of global warming damage.

When the AIM/emission model is finally completed, its outputs will be entered into the AIM/climate model which will provide a variety of scenarios used in GCM experiments. Data from the GCM experiments will be used as the basic assumptions for the AIM impact model, and will reflect estimates of regional climate impact. AIM/impact model will calculate the impact on primary production - water supply, agricultural production, wood supplies, etc. - and then make predictions of higher order impacts on the regional economy.

AIM/impact will allow us to analyses and predict all scenarios of the impacts of global warming on the Asian-Pacific region. Over the previous three years, sectors on which the AIM/impact model has focused are a Water Balance Model, a Vegetation Change Model, and a Health Impact Model. The impacts have been estimated on changes in catchment water run-off, the survival status of vegetation and reproduction rate of Malaria. This report the outline of the modeling studies.

2. Geographical Information System and Regional Climate Change Scenarios

To function properly, these models require a high-quality spatial data-base. As such, we are developing the Asian-Pacific Environmental, Social and Economic Geographical Information

System in cooperation with the Center for Global Environmental Research, Japan. This GIS system has a spatial segmentation at the sub-country level as shown in Figure 1. Information which comes from many international organizations, including the UNEP/GRID system as well as individual governments, is integrated with our originally constructed data, and the information is organized in a format useful to support the AIM study.

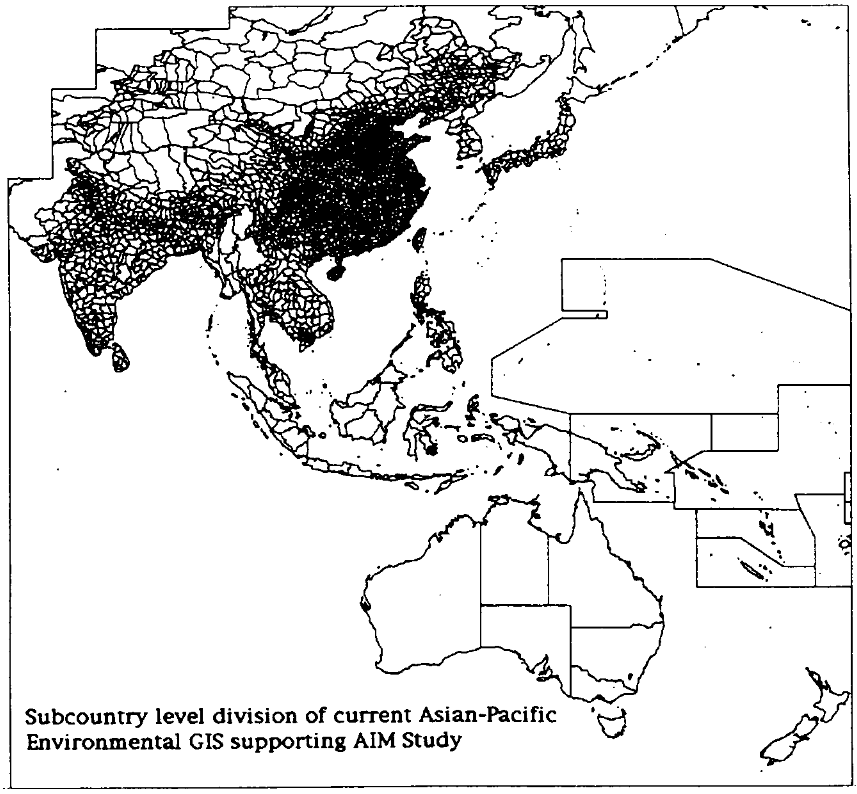

Fig.1 Subcountry Level Division of Current Asian-Pacific GIS Supporting the AIM Study

The regional climate change scenarios to be used in AIM/impact are mainly prepared by the GCMs (General Circulation Models). In order to apply these GCM experiments, their outputs were normalized by dividing them by the difference between the global means of the equilibrium $2xCO_2$ experiment and the $1xCO_2$ experiment. This procedure eliminates equilibrium sensitivities of different models, and also allows the normalized result to be applied to time-dependent scenarios of global mean warming produced by the AIM/emission model. These normalized climate change patterns are basically prepared in the GCMs' spatial resolutions. However, they are subsequently interpolated to a finer grid in order to correspond with the regional impact models of each sector. As the sub-grid interpolation of GCM outputs has a lot of problems, we are also intensively examining methods based on statistical relationships between broad-scale climatic data and small scale observations from regional climate records.

3. Impacts on water resources

Hydrological impacts are one of the most important aspects of the coming climate change. Changes in the magnitude, frequency and duration of hydrological factors influence the availability of water resources, flooding intensity as well as agricultural and natural terrestrial ecosystems. A rainfall-runoff process submodel was developed as one of the basic submodules of AIM/impact model. This submodule consists of water balance and water transport components, and it is intended to provide critical hydrologic information to the impacts models of other sectors. Specifically, it creates gridded high resolution datasets of surface runoff, soil moisture, evapotranspiration and river discharge.

The inputs to the hydrological model are elevation, soils, vegetation as well as precipitation, temperature, and potential evapotranspiration. Except for the first three, these parameters are endogenous variables of the total AIM system. As the coupling of the total system is not complete, we set soil and vegetation characteristics as well as elevation conditions at their current situations.

The water balance component of the model is based primary on the models of Thornthwaite and Mather (1955) and their successors. Bookkeeping of the water balance among precipitation, snowmelt, evapotranspiration and streamflow is calculated for each grid cell in the simulated region. A number of climatological and geographical data sets were prepared from various sources. Precipitation and temperature values were taken from interpolated results of GCM experiment by the Geophysical Fluid Dynamics Laboratory. Soil moisture capacities were estimated using current vegetation classes and soil textures (Vorosmarty et al.,1989, Webb et al., 1993).

In the water transport component, the network topology of streams was determined from digital elevation data and modified with various hydrological maps of analyzed regions. Modeling of surface water retention time in each cell followed Vorosmarty's model (1989). Figure 2 is a result of estimating annually-averaged accumulated runoff under current climate conditions. The calculation was conducted with 1/4 degree grid cells. Climatic data was taken from the monthly average data sets of Legates and Willmott (1989) with 1/2 degree resolution. The degree of shading in the Figure expresses the intensity of discharge from a cell to the next one downriver. Black indicates the highest flow areas, and white indicates the areas of lowest flow.

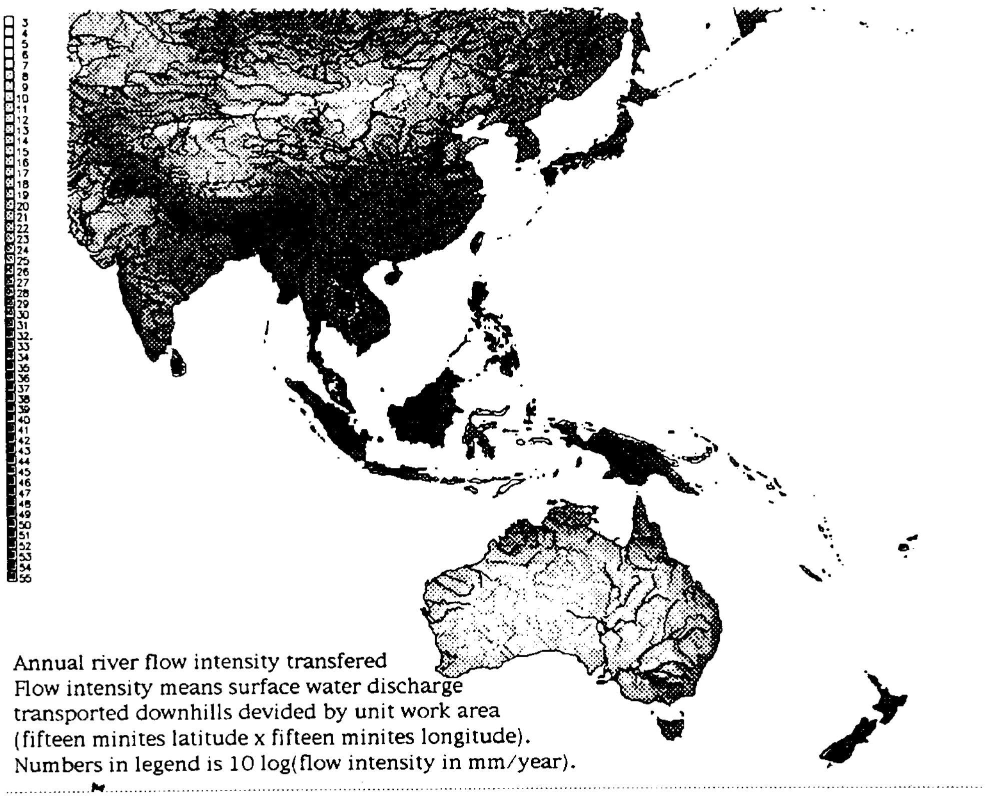

Fig.2 Estimates of Current River Flow Intensity

Using this model as the base condition, we then applied outcomes of GCM experiments (GFDL Q-flux experiment as the perturbed climate scenario), which provide precipitation, temperature and soil humidity data. These experiments were based on a future CO2 level which is twice that of the Pre-industrial Revolution level. After interpolating the daily and monthly results of the GCM experiment, so they could be overlaid with Legates' climatic pattern which has a higher resolution than GCM outputs, these input conditions were used to prepare simulations of variability in the water discharge of each river basin. These simulations were conducted for a 10 year period after a 2 year initial simulation under each condition, and then the probability distributions of the monthly simulated discharges were identified in each grid cell. Based on these distributions, we estimated flood levels and drought levels over a 10 year period in the $2xCO_2$ condition.

Figure 3 shows an output of such a simulation for flood discharge. The light gray shading indicates the areas where the highest flow discharge level for a 10 year return period may be expected to exceed twice the current level. Parts of India, China, and Japan could experience much higher flood levels. Figure 4 shows the changes in low flow conditions over a 10 year period. The dark shading indicates areas where the lowest flow levels decrease by 40 or 50%. As shown in the figure, large areas of the region are forecasted to experience much drier dry periods. The spatial pattern of influence was not sensitive to the selection of a return period. Intensification of flood discharge does not mean the relief of drought, and in fact, an increase in the incidence of both events is anticipated for some regions.

In order to assess the more direct impact of hydrological changes on the human dimension, we have to consider the effect of water control and management devices, as well as the intensity and style of water consumption. So far, we have estimated only population-weighted average values of drought and flood intensities. It is still too incomplete to comprehend the overall

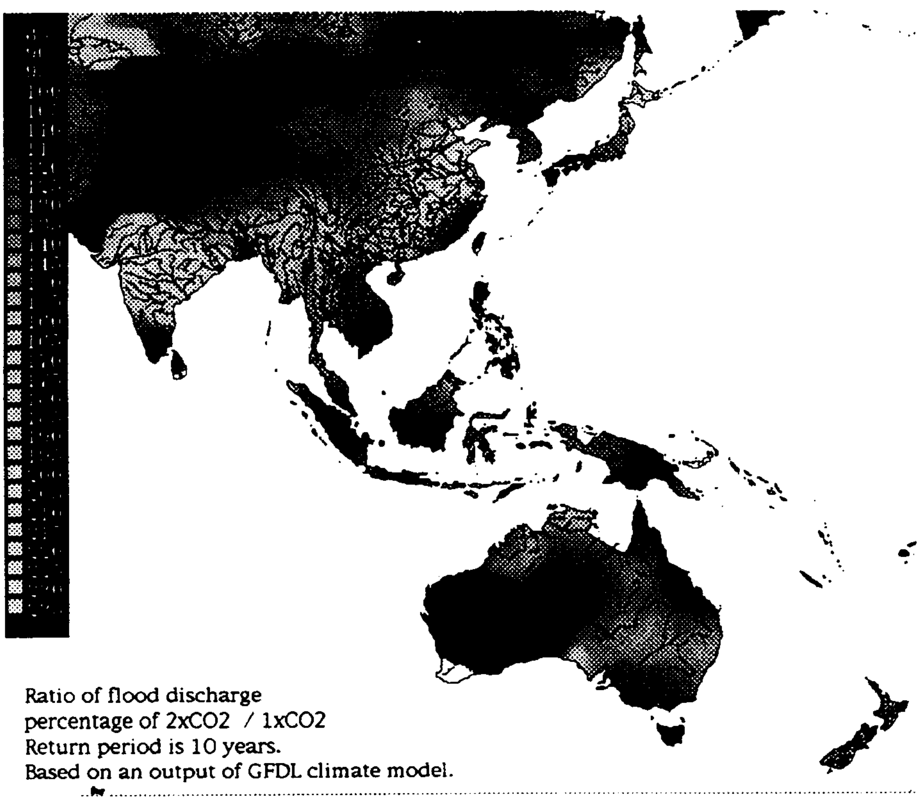

Fig.3 Prediction of Monthly High-flow Discharge for a 10 Year Return Period

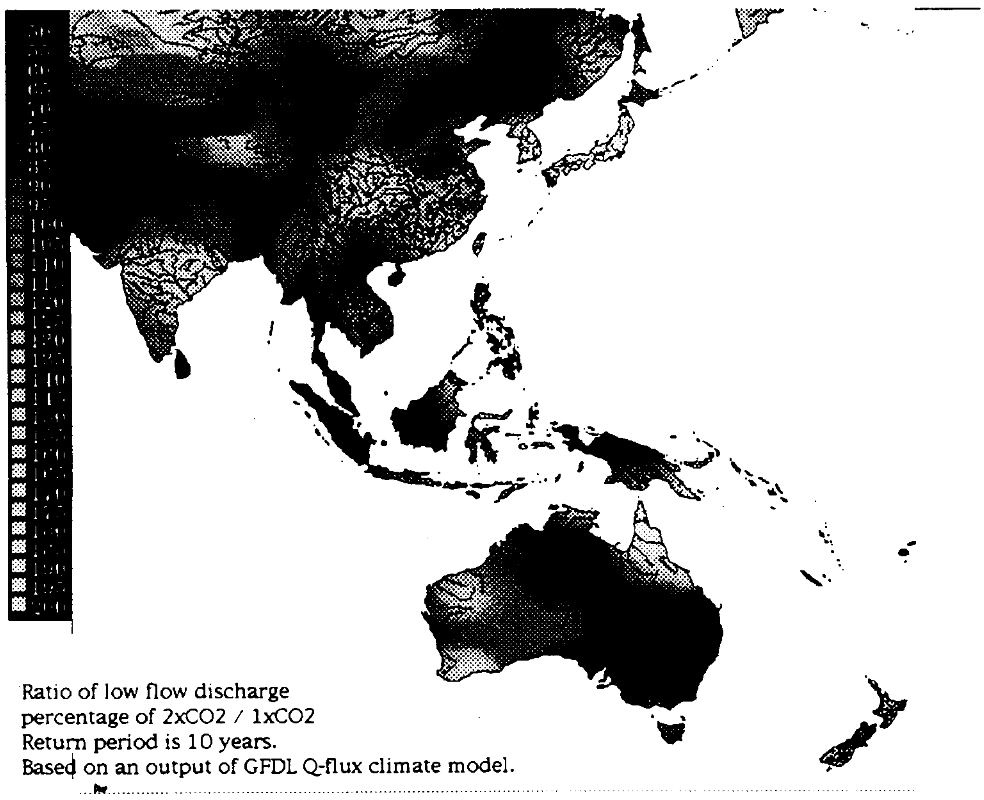

Fig.4 Prediction of Monthly Low-flow Discharge
for a 10 Year Return Period

impacts of hydrological changes on human society. To clarify these impacts, we are now accumulating information about vulnerabilities to water related factors at the regional and subcountry levels.

4. Impacts on Natural Ecosystems

The spatial distribution of natural vegetation is strongly controlled by climate. Future climate change should have profound impacts on the distribution of vegetation patterns in the Asia-Pacific area. As a preliminary assessment of this impact, we established a simple model of global vegetation change caused by the change of related climate elements. In this model, a vegetation type is assumed to change if any climate element in its habitat exceeds the current global minimum or maximum level found in that vegetation habitat. As for climate elements, we used mean annual precipitation, mean annual temperature, coldest monthly temperature, hottest monthly temperature, and degree-days above 5 ℃.

Figure 5 shows the potential changes in vegetation under the several scenarios described in B-15.3, coupled with the results of the GFDL-R30 GCM experiment. Significant changes in northern China are observed. Boreal conifer forests and larch taiga in this area are predicted to be significantly influenced. Tibetan and Himalayan alpine tundra would also be influenced.

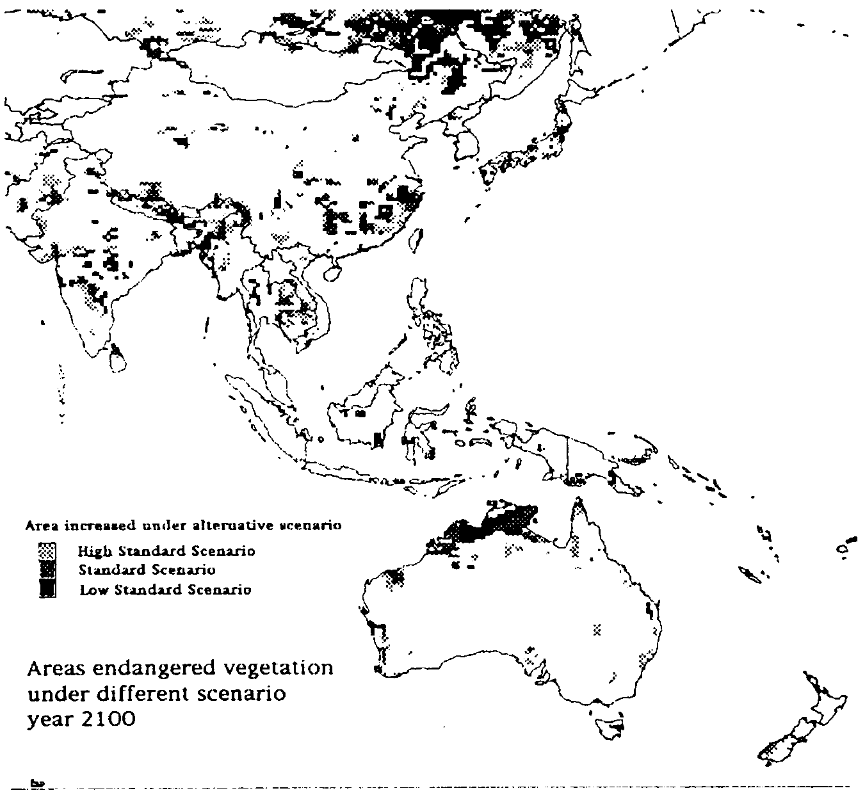

Fig.5 Potential Changes in Vegetation under Different Scenarios

Evergreen-deciduous areas in Southeast China, drought-deciduous forests in India, Indo-China Peninsula and Northern Australia would also adversely affected by climate change. These changes should be considered as potential shifts under equilibrium assumptions.
The actual mechanism of succession is far more complex and dynamic. For a preliminary analysis, the above method is useful. However, we consider such a static model to be unsatisfactory and of limited use, so we are preparing dynamic population-based succession models.

5. Impacts on Malaria Incidence

Global warming will result in increases in the temperature and changes to the vegetation close to the ground. This will allow the habitat of the ANOPHELES mosquito, which is the malaria vector, to expand. As well, the development period of the malaria protozoan will shorten and its reproductive potential will increase. As a result, it is predicted that the global malaria risk will increase. In order to estimate the risk quantitatively, a global model has been developed.

The malaria risk increase is estimated in the model using the following steps:
1) The adaptability of Anopheles to basic eco-climate parameters, such as annual and daily temperature variability plus soil moisture is identified.
2) The future temperature variability based on GCM outputs, as well as soil moisture based on the water resource impact model developed in this project is estimated.
3) Using the values predicted in 2, the changes in the habitat area of Anopheles is calculated.
4) The rate of transfer of the disease between patients (the rate of spread of the disease in each

climatic grid) is calculated taking into account the shortening of the sporozyte's development phase within the mosquito. The risk based on the reproduction rate in each region, as well as at the national and global levels is estimated. The sensitivity of GCM outputs in relation to risk outcomes is then determined.

Figure 6 shows the predicted expansion of the area in which malaria will be endemic if the atmospheric CO_2 concentration doubles. Parts of northern, central and southern America, Australia, China and south-east Asia, India and Africa will have an increased risk of malaria infection. It was concluded that the area in which malaria will become endemic will increase by 6 - 20% (i.e. there will be a 6 - 20% increase in the human population at risk of malaria infection).

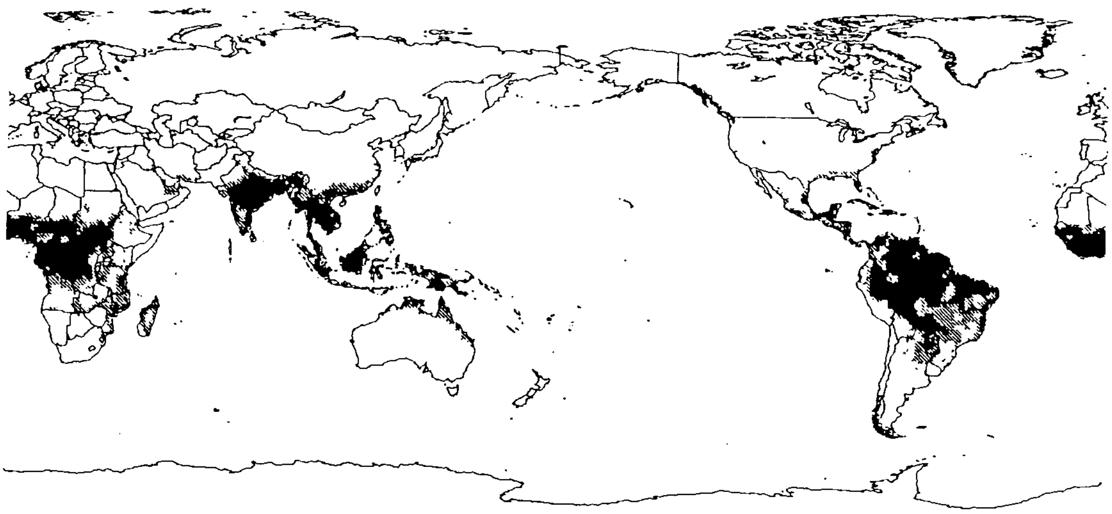

Fig.6 Predicted Expansion of Areas in whick Malaria will become Malaria Endemic

6. Concluding Remarks

During these past three years, we developed a Water Resource Change Model, a Vegetation Change Model, and a Health Impact Model. These models and the database used for simulation need to be improved to explain the complex and dynamic process of real mechanisms. It is also necessary to develop some models to estimate other primary impacts caused by global warming. Based on these primary impact estimates, we plan to estimate higher order impacts on regional economies while taking into account the effects of international relations.

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