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Impact of climate change on natural vegetation in China and its implication for agriculture

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Abstract. Climate change scenarios due to human activity in East Asia and China by 2050 have been estimated by means of a simple global social-economic-climate-impact model combined with seven general circulation models (GCMs). These climate change scenarios show that annual mean temperatures might increase by about 1.4°C, and annual total precipitation might increase by about 4% over the whole of China in comparison with the present climate. The change in precipitation might be much smaller than that of temperature.

The potential impacts of human activity-induced climate change on natural vegetation in China were estimated using the vegetation-climate model developed particularly for Chinese vegetation types and different climate change scenarios derived from seven GCMs for 2050. All scenarios suggest a large change in natural vegetation, although details of predicted types vary between the scenarios. There will be a northward shift of vegetation types, with an increase in the areal extent of tropical rain forests and decrease of cold temperate coniferous forest and tundra.

China has a high population. During the historic development of several thousand years large areas of forest and grassland have been converted into arable lands; at present agriculture is a very important element of vegetation cover. Consequently, considering all these changes and situations, especially in combination with the probable negative balance between precipitation and evapotranspiration (that is, increase of moisture stress) the possible influences of climate change on Chinese agriculture are assessed briefly in this paper.

As a result of the above-described analyses it is extremely difficult to draw general conclusions of the potential implications of climate change for Chinese vegetation because of scientific uncertainties both of investigation of climate change and of its vegetation response.

Key words. Climate change scenarios, natural vegetation, vegetation-climate model, shift, social-economic climate-impact model.

INTRODUCTION

As presented by working group I (Houghton, Jenkins & Ephraums, 1990; Houghton, Callander & Varney, 1992), global warming of about 0.3–0.6°C for the last 100 years has been found. Warming of about 0.6–0.8°C in East Asia for the last 100 years has been shown by Hulme et al. (1992). Climate change is divisible into two parts: natural change and man-made change (human activity-induced). Global climate change scenarios due to human activity have indicated that global temperature and precipitation might increase (Houghton et al., 1990, 1992). Regional climate change scenarios for East Asia and China have been estimated in this paper. It is noted that temperature and precipitation in East Asia might also increase due to human activity (Hulme et al., 1992). For studying the corresponding change of the natural vegetation, climate change in different parts of China should be estimated.

At a global scale, the formation and distribution of natural vegetation are largely controlled by climate. They are also significantly magnified by other factors, such as soil conditions and moisture availability. Nevertheless, climate can be used to define characteristic vegetation patterns and to assess future changes in these patterns as a result of greenhouse warming. Currently, with the rapid development of science and technology throughout the world, the anthropogenic impact on environment and climate is becoming increasingly serious. It means that the changes of global climate caused by increased emissions of CO₂ and other greenhouse gases to the atmosphere can, potentially, change the current distribution of vegetation patterns. Therefore, studies of these problems are of profound significance.

At present, a number of bioclimatic models have been used to assess the potential impacts of climate change on the distribution of major ecosystem complexes on a global scale (Holdridge, 1967; Budyko, 1974; Emanuel, Shugart & Stevenson, 1985; Prentice et al., 1992). However, all these global models have significant limitations for recog-
TABLE 1. Ranges of the climatic parameters used to define nature vegetation distribution in China.

<table>
<thead>
<tr>
<th>Vegetation types</th>
<th>Mean ann. temp. (°C)</th>
<th>Temp. of cold. m.</th>
<th>Temp. of warm. m.</th>
<th>AAT* above 10°C</th>
<th>Number of days &gt; 10°C</th>
<th>Ann. precip. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold temp. conif. forest</td>
<td>-8 - 2</td>
<td>-38 - 25</td>
<td>12 - 20</td>
<td>750 - 2500</td>
<td>50 - 175</td>
<td>250 - 750</td>
</tr>
<tr>
<td>Temp. mix. conif. &amp; broadif.</td>
<td>2 - 9</td>
<td>-25 - 10</td>
<td>16 - 24</td>
<td>1500 - 3500</td>
<td>100 - 200</td>
<td>&gt; 490</td>
</tr>
<tr>
<td>Warm temp. decid. broadif.</td>
<td>9 - 14</td>
<td>-14 - 4</td>
<td>20 - 28</td>
<td>2500 - 3500</td>
<td>175 - 275</td>
<td>&gt; 500</td>
</tr>
<tr>
<td>Subtrop. everg. broadif.</td>
<td>14 - 22</td>
<td>2 - 14</td>
<td>&gt; 24</td>
<td>4000 - 8000</td>
<td>&gt; 200</td>
<td>&gt; 750</td>
</tr>
<tr>
<td>Trop. &amp; monsoon rain forest</td>
<td>22 - 26</td>
<td>14 - 21</td>
<td>&gt; 24</td>
<td>&gt; 7500</td>
<td>&gt; 350</td>
<td>&gt; 1200</td>
</tr>
<tr>
<td>Temperate steppe</td>
<td>5 - 8</td>
<td>-30 - 5</td>
<td>16 - 28</td>
<td>1500 - 3500</td>
<td>100 - 200</td>
<td>150 - 500</td>
</tr>
<tr>
<td>Temperate desert</td>
<td>2 - 12</td>
<td>-30 - 5</td>
<td>&gt; 18</td>
<td>2000 - 4500</td>
<td>100 - 250</td>
<td>&lt; 200</td>
</tr>
<tr>
<td>Tundra alpine vegetation</td>
<td>&lt; 8</td>
<td>&lt; 0</td>
<td>&lt; 16</td>
<td>&lt; 2500</td>
<td>&lt; 175</td>
<td>no limits</td>
</tr>
</tbody>
</table>

*AAT*: the active accumulated temperature (the sum of daily mean temperatures above a given threshold temperature).

TABLE 2. Climate change scenarios for East Asia and China in future (1991–2100) compared with the present climate (1951–80) (DT: the change of temperature, and DP: the change of precipitation).

<table>
<thead>
<tr>
<th>Years</th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
<th>2060</th>
<th>2070</th>
<th>2080</th>
<th>2090</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>DT (°C)</td>
<td>0.20</td>
<td>0.35</td>
<td>0.65</td>
<td>0.88</td>
<td>1.06</td>
<td>1.40</td>
<td>1.64</td>
<td>2.01</td>
<td>2.30</td>
<td>2.66</td>
<td>2.95</td>
</tr>
<tr>
<td>DP (%)</td>
<td>0.6</td>
<td>1.1</td>
<td>1.9</td>
<td>2.6</td>
<td>3.2</td>
<td>4.2</td>
<td>4.5</td>
<td>5.5</td>
<td>6.3</td>
<td>7.2</td>
<td>8.9</td>
</tr>
</tbody>
</table>

FIG. 1. Distributions of annual mean temperature and annual total precipitation at the present time (1951–80, solid lines) and 2050 (dashed lines) (unit: °C for temperature and mm for precipitation). The data for temperature and precipitation obtained from the stations in East Asia have been interpolated as the grid points (5°×5°).

FIG. 2. Changes in monthly temperature and precipitation in East Asia (compared doubled CO₂ × CO₂) (unit: %).

| TABLE 3. Change of annual and seasonal temperatures (unit: °C) in north east China, east China, west China and the whole of China (comparing the year 2050 with the present time). |
|----------------|--------|--------|--------|--------|
|                | ANN    | DIF    | MAM    | JJA    |
| North east China | 1.47   | 1.53   | 1.47   | 1.37   | 1.52   |
| East China      | 1.42   | 1.43   | 1.37   | 1.42   | 1.45   |
| West China      | 1.57   | 1.48   | 1.44   | 1.49   | 1.53   |
| Whole China     | 1.49   | 1.48   | 1.44   | 1.49   | 1.53   |

| TABLE 4. Change of annual and seasonal precipitation (unit:%) in north east China, east China, west China and the whole of China (comparing the year 2050 with the present time). |
|----------------|--------|--------|--------|--------|
|                | ANN    | DIF    | MAM    | JJA    |
| North east China | 3.7    | 5.0    | 4.1    | 3.0    | 4.3    |
| East China      | 3.3    | 4.2    | 4.5    | 2.9    | 2.2    |
| West China      | 4.9    | 8.0    | 5.8    | 2.4    | 3.4    |
| Whole China     | 4.0    | 8.7    | 4.8    | 2.8    | 3.3    |

FIG. 3. Distribution of characteristic vegetation patterns in China under the present climate (1951–80). Numbers 1–8 represent temperate desert, temperate steppe, Tibetan alpine vegetation, cold-temperate coniferous forest, temperate mixed coniferous broadleaved forest, warm-temperate deciduous broadleaved forest, subtropical evergreen broadleaved forest and tropical rain forest, respectively.

INVESTIGATION METHODS AND DATA

Design and data for climate change scenarios

In order to specify the future implications of climate change for China, reliable prediction of transient change in regional climate is required. A simple global socio-economic-climate-impact model (GECM)1), which is based on the IPCC (1992) scenarios (Hulme et al., 1992; Houghton et al., 1992), has been used to predict the global mean warming projections for the future. To estimate the regional climate change scenarios for China, seven GCMs (GFDL, Wetherald & Manabe, 1986; GISS, Hansen et al., 1984; LLNL, Gates, pers. comm.; MPI, Cubasch et al., 1991; OSU, Schlesinger & Zhao, 1989; UKMO-L, Wilson & Mitchell, 1987; UKMO-H, Mitchell et al., 1990) were averaged to produce a ‘composite’ GCM scenario, and have been combined with the GECM model. A detailed description of the GECM model and the evaluations of seven GCMs in East Asia and China have been presented in a WWF booklet (Hulme et al., 1992). Related scenarios of the population growth, energy emissions (greenhouse gases, sulphur aerosols and others) and land use made by IPCC (1992) have been also used in this investigation.

The region of East Asia and China has been chosen as an area extent of 15°–60°N and 70°–140°E with resolution of 0.5° × 1.0°. Thus the total grid points in this region are 6300.
Approaches and data for investigation of natural vegetation

To investigate possible impacts of climate change on vegetation in China we use a special Chinese vegetation-climate model developed from a set of climatic parameters that define the current distributions of natural vegetation (Table 1).

All distributions and changes of natural vegetation types under current and future changed climates were calculated and mapped using China's data base and data of some weather-climate stations from surrounding countries. These data have the same normal time period of 1951–80 and geographical data and have been interpolated to computational grids at 0.5° × 0.5° (latitude and longitude) resolution for the whole of China's area extending from 15°N to 60°N and from 70°E to 140°E (Leemans & Cramer, 1991). Then the simulations of current and the projected future climates derived from seven GCMs were used to construct vegetation change scenarios.

CLIMATE CHANGE SCENARIOS FOR CHINA IN THE FUTURE

Considering the global warming projection as simulated by the GSECIM model combined with seven GCMs, the regional future climate change for East Asia and China has been calculated. Table 2 shows the future climate change scenarios as simulated by the GSECIM model (IPCC, 1992: scenario IS92a) combined with composite GCM. It is found that the temperature in East Asia and China might increase by about 0.88°C in 2030, 1.40°C in 2050 and 2.95°C in 2100, respectively. The precipitation also might increase by about 2.6% in 2030, 4.2% in 2050 and 8.9% in 2100, respectively. This means that the change of
temperature due to human activity in future might be much more obvious than that of the precipitation in East Asia and China.

For a more detailed investigation, the year 2050 has been chosen as an example in this paper. Distribution of the annual and seasonal temperature and precipitation in East Asia and China for 2050 and the present climate (1951–80) have been calculated. Fig. 1a,b gives the distributions of the annual mean temperature and annual total precipitation in the year 2050 and the present time. It is seen in Fig. 1a that the temperature might increase clearly from the present time to the year 2050. The isopleths of the temperature might shift northwards by about 1–3 degrees of latitude, especially by about 2–4 degrees of latitude in north east China. The change of precipitation might be much less than that of temperature. The isopleths of the precipitation in Fig. 1b might shift a little; therefore, it is not shown in Fig. 1b. It indicates that the effect of temperature induced by human activity might be much larger than that of precipitation in China. Fig. 2 shows the results of changes expressed by percentage of temperature and precipitation in East Asia and China from January to December to compare with the present climate (1951–80). Changes of precipitation might be between 8–20%, but changes of temperature might be between 20–210%. The more warming, the more evaporation caused. The combined effects of both precipitation and evaporation might induce a drier climate in East Asia and China, especially in winter, spring and autumn seasons, and in north China.

Seasonal and annual changes of temperature and precipitation in the areas of China induced by human activity were also estimated, and shown in Tables 3 and 4. Here, three regions have been chosen. They are north east China (32.5–52.5°N, 122.5–132.5°E); east China (22.5–42.5°N, 92.5–117.5°E) and west China (32.5–47.5°N, 77.5–87.5°E), respectively. Temperature and precipitation might increase in north east and west China, especially in winter.

**DISTRIBUTION AND CHANGES OF NATURAL VEGETATION IN CHINA**

**Present-day distribution of characteristic vegetation types**

The simulated distribution of characteristic vegetation types in China under present-day (1951–80) climate is shown in Fig. 3, there is good agreement between this map and the observed vegetation types (Wu, 1980; Ye, 1992). Here three points should be noted. First, the boundaries between forest, grassland steppe and desertified area are very clear. Secondly, from east to west, vegetation types reflect a moisture gradient, which means that the eastern regions are dominated by forests, gradually changing as one moves westwards into grassland steppes, such as those in Inner Mongolia, and then into temperate deserts such as those in Xinjiang region. Thirdly, from north to south it represents a temperature increase. The cold-temperate coniferous forests dominated in the northern region, southwards, gradually become more temperate deciduous broadleaved forests, succeeded further south by subtropical evergreen broadleaved forests, and finally into tropical rain forests in the most southerly region. Furthermore, the south western region, Qinghai-Xizang Plateau, is dominated by tundra vegetation, typical of such alpine environments.

**Impact on vegetation implied by composite GCM scenario**

Future changes in climate should have profound effects on the distribution of characteristic vegetation patterns in
China. The impacts on these vegetation patterns can initially be approximated by the above model. To simulate these effects, we here assume that as climate changes, vegetation will follow closely, maintaining its equilibrium correlation with climate. The model, however, describes only the current status for China and cannot identify future vegetation types that have no analogue under current conditions. We have therefore added the 'undefined vegetation' type. This category includes vegetation types which are not currently observed in China, such as savanna, grasslands and vegetation characteristic of warm and hot deserts.

Fig. 4 shows substantial changes in vegetation that would result by the year 2050, assuming a global mean warming of 1.2°C and composite-GCM scenario. There are significant shifts between the different vegetation types. The area of cold-temperate coniferous forest would be geographically restricted by the Siberian border and disappears almost completely from China in some scenarios, while an increase in the areas potentially suited to tropical
and monsoon rain forest would occur in southern China (see Table 5). The intermediate forested zones are relatively stable in area, but shift northwards by about 500 km. It should be pointed out that climate warming will reduce the south western Tibet alpine vegetation in extent and furthermore, the vegetation type in northwest China (Xingjiang area) would become a warm or hot desert, rather than the temperate desert or of steppe today, because of the relatively large increase in temperature without an adequate increase in precipitation to counterbalance the increased water loss through enhanced evapotranspiration. These vegetation shifts would, consequently, have large influences on land use patterns and sustainable agricultural development of this area would become much more difficult.

Implications of climate-vegetation changes for agriculture

China is a large agricultural country with a high population. During the historic development of several thousand years large areas of forest and grassland have been converted into arable lands. Fig. 5 shows clearly how much natural vegetation has been converted into arable land during the course of history.

Figs 6 and 7 demonstrate the potential changes in cropping patterns projected by composite GCM scenario in the year 2050. Large changes would occur almost everywhere in China. As a result, the current area of single-cropping would be reduced by about 23.1% and the triple-cropping area could be extended by roughly 22.4%, while the double-cropping area would almost remain the same as under the current climate (Wang & Zhao, 1995).

To some extent, such changes as described above show that climate warming would be favourable to Chinese agriculture due to a diversification of cropping patterns. In fact, however, the area suitable for rice and wheat cultivation, which are the major two crops in China, would increase but mean yield would decrease due to reduced water availability. This means that by 2050, the not balance between precipitation and evapotranspiration would be negative and moisture stress would be more severe than today, although precipitation by 2050 would increase somewhat (Tables 2, 3 and 4). Therefore, the probable impact of climate warming on agricultural production in some eastern regions of China would be unfavourable. Certainly, in some other regions such as north east China, currently one of the coldest agricultural regions where low temperature often prevents crop maturation or early frost occurrence results in harvest failure, climate warming by 2050 would certainly increase yield (Wang & Zhao, 1995).

On the other hand, the substantial impact of climate warming induced by the increase of greenhouse gases in the atmosphere on vegetation cover would occur almost everywhere. That is, tropical and monsoon rain forests would expand significantly while the Tibet alpine vegetation will probably reduce in extent, and some intermediate vegetation types will be replaced by other warmer and drier vegetation types. Also, cold-temperate coniferous forest in the north east would disappear completely from China. However, it is also very difficult to estimate and assess the impacts of climate warming on vegetation cover. There are several reasons for this. First, on a time-scale of centuries to millennia, the assumption that characteristic vegetation types are in balance with the climate is valid, but on the terms for which the current greenhouse-induced climate change is anticipated this simple assumption seems illogical. Vegetation types and ecosystems are assemblages of many different species. Each species responds differently to environmental change according to its own life history and adaptation strategies. Even though past vegetation changes appeared in near-equilibrium with prevailing and slowly changing climate, future greenhouse-related changes may be so rapid that equilibrium cannot be maintained. It means that the actual short term of vegetation response could be highly nonlinear and, depending on the species and through time, become less predictable. Secondly, changes in temperature and precipitation will alter the hydrological cycle, which influences runoff, moisture availability, sedimentation and erosion and, furthermore, the recycling of organic matter and nutrients. All these in turn will influence plant growth, competition between species, biodiversity and distribution and intensity of pest and diseases. Thirdly, a current major difficulty is to predict this greenhouse-related climate change with enough confidence due to the uncertainties mentioned above. This prediction, however, is simply a basic pre-condition of all other adapted strategies and programmes. Consequently, the analysis in this paper only gives some idea of the aspect, scale, direction and implications of potential future changes in climate and vegetation cover for China.

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