

TECHNICAL SUMMARY

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Integrated Environmental Monitoring



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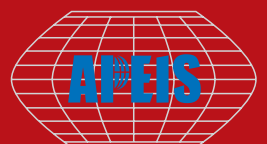
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June 2004

APEIS-IEM Technical Summary

1. What is APEIS-IEM?

Rapid population growth and economic development in the Asia-Pacific region has resulted in serious local, national, and regional environmental problems such as floods, droughts, forest fires, dust storms, air, water and soil pollution, desertification, salinization, water resource depletion, and soil loss. Such problems are serious constraints to sustainable development in the region. In order to cope with these problems, an integrated environmental monitoring system (IEM) is indispensable. The purpose of the APEIS-IEM project is to accurately describe the present conditions and trends of ecosystem services, as well as the pressures and impacts upon them, for policymaking to promote regional sustainability (Fig. 1).

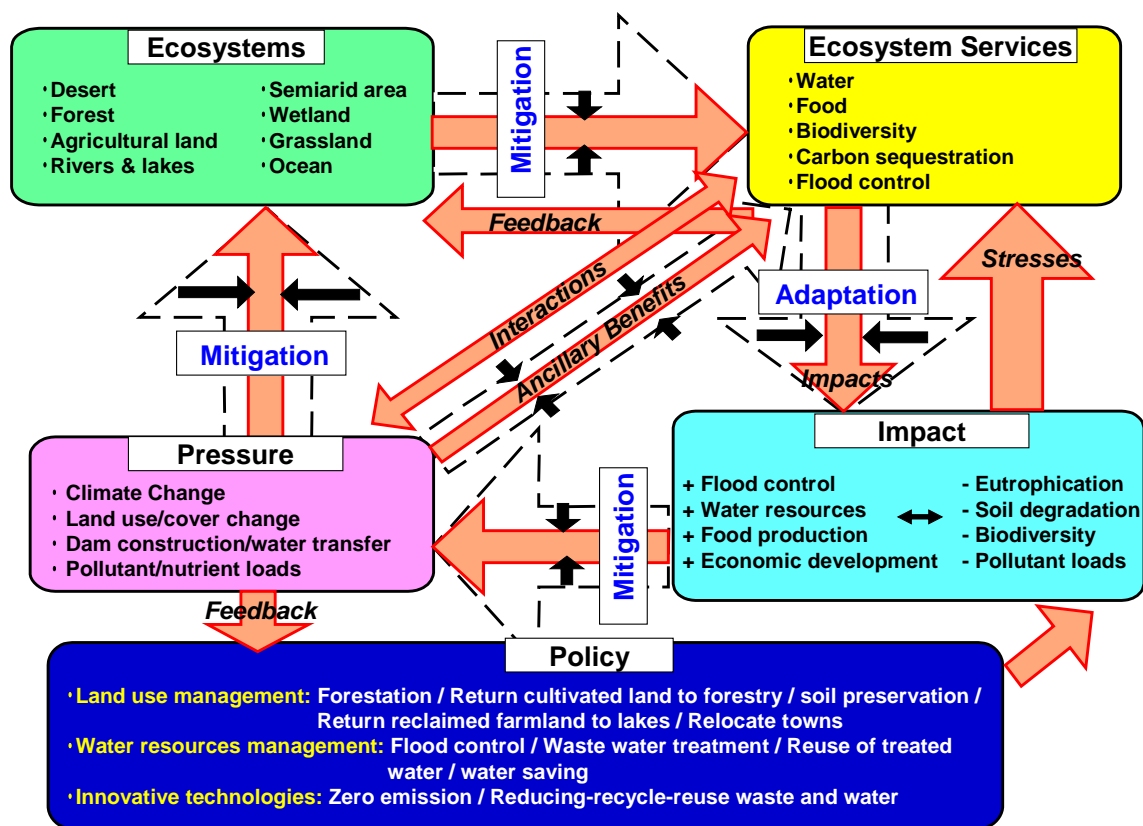


Figure 1. Interactive relationships among policies and ecosystem services

APEIS-IEM has developed an IEM system that can be used to detect, monitor, and assess environmental disasters and degradation, and their impacts in the Asia–Pacific region. The system provides validated remote sensing data and images from MODIS (Moderate Resolution Imaging Spectrometer), and derived ecological indices, such as water deficit index, dust storm index, land surface temperature (LST), and net primary productivity (NPP). APEIS-IEM has also developed an integrated model to assess the state of and changes in ecological goods and services, such as freshwater resources, carbon and nitrogen cycles, and food production. With this model, the trade-off between ecosystem services and effectiveness of policies for sustainability can be demonstrated (Fig. 2).

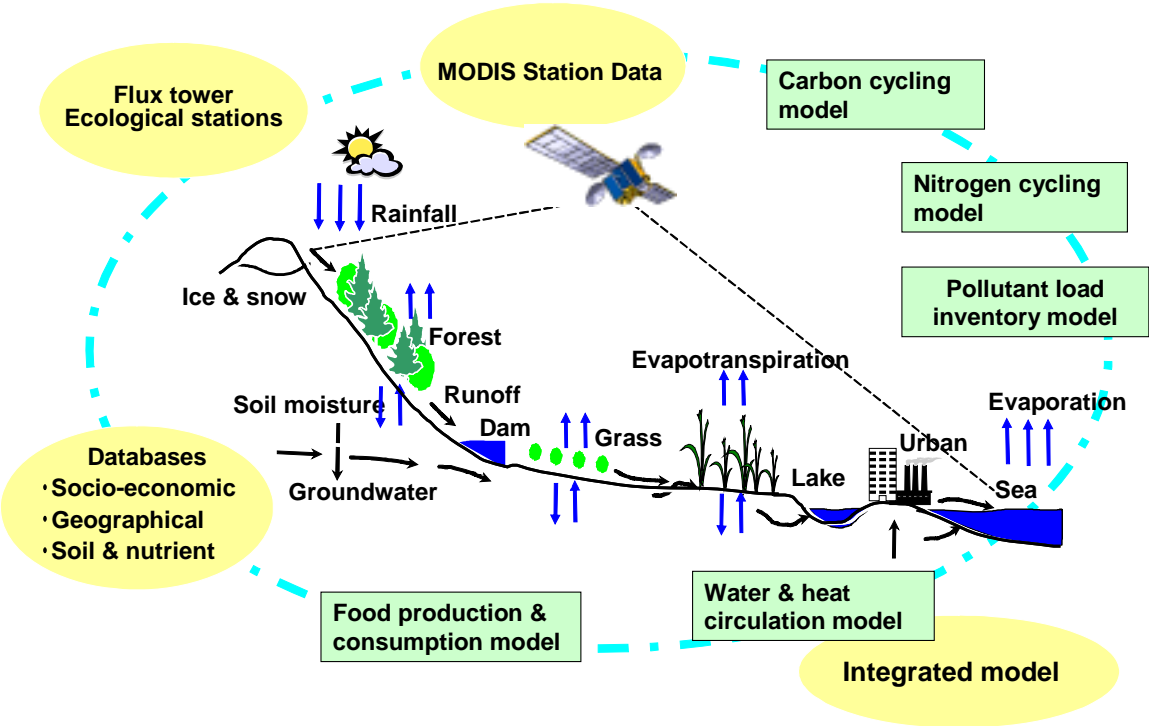


Figure 2. Integrated environmental monitoring system for the Asia–Pacific Region

The approaches of APEIS-IEM consist of the following components:

- To establish the APEIS-MODIS network, a network of satellite data receiving stations and analytical systems for MODIS data that covers the Asia–Pacific region
- To establish the APEIS-FLUX network, a ground-truth observation system to validate satellite remote sensing data for various ecosystem types
- To develop a data-processing software system to derive environmental indices that can be used to monitor environmental disasters and degradation
- To develop an integrated model to simulate territorial ecological processes, water resources, and agricultural production at a watershed scale in the Asia–Pacific region

2. Current Progress and Contributions of APEIS-IEM

2.1 Enhancement of Monitoring System

The integrated monitoring network system established by APEIS-IEM now covers most of the Asia–Pacific region, and continuously provides real-time data of both remote-sensing and ground-based measurements in 2003 (Fig. 3). The MODIS images are publicly released from the APEIS-IEM website, and the original data are planned to be released on the Internet. (Web site: <http://www-basin.nies.go.jp/english/project/iem/index.html>)

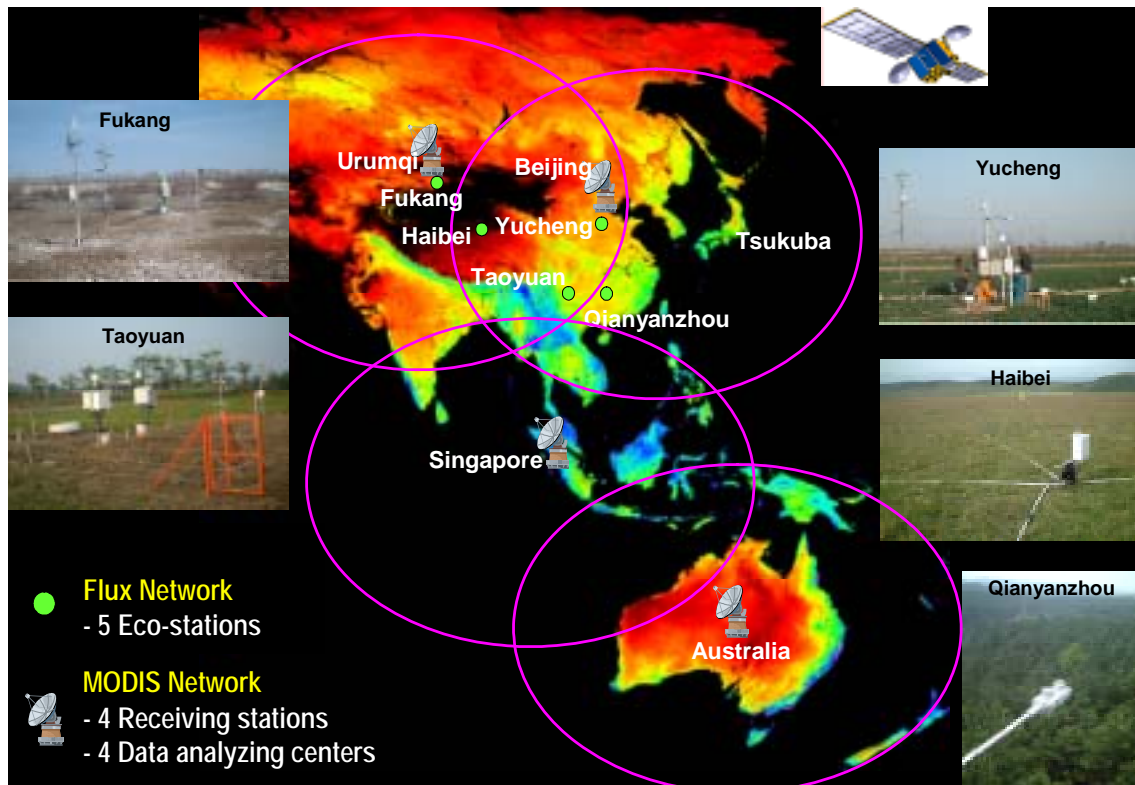


Figure 3. The APEIS integrated monitoring system was established in 2002 under the auspices of the National Institute for Environmental Studies (NIES) in Japan and the Institute for Geographical Sciences and Natural Resources Research (IGSNRR), the Chinese Academy of Science in China, and was expanded with additional participation by the National University of Singapore (NUS) and the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia

2.2 Establishment of APEIS-FLUX Network

The MODIS validation sites form a network that not only provides validation data for MODIS products, but also provides valuable data for research on fluxes of water, heat, and carbon in the Asia–Pacific region. APEIS-FLUX, as this network has been named, appears in academic journals, newsletters, and documents of the Millennium Ecosystem Assessment. APEIS-FLUX is a real-time monitoring system comprising five sites in different ecological systems in China: Haibei (grassland), Yucheng (crop land), Taoyuan (paddy field), Qianyanzhou (forest), and Fukang (saline desert). Data can be accessed through a mobile modem at any time and place, allowing analysis of observed data at any time. This design allows comparison of a given vegetation type across different locations, and of multiple

vegetation types within a given geographic area. The dataset contains eddy-correlation flux measurements of sensible heat, latent heat, and CO₂; micrometeorological measurements of air temperature, wind speed, and wind direction; measurements of total solar radiation, net radiation, and photosynthetically active radiation and soil water content, groundwater level, and salinity.

The major task of APEIS-FLUX is to measure the differences in fluxes of water, heat, and carbon in different ecosystems. By comparing five different ecosystems (forest, grassland, desert, crop land, and paddy field), an ecosystem model can be developed and calibrated to predict and evaluate the response of ecosystems to different forces (Fig. 4).

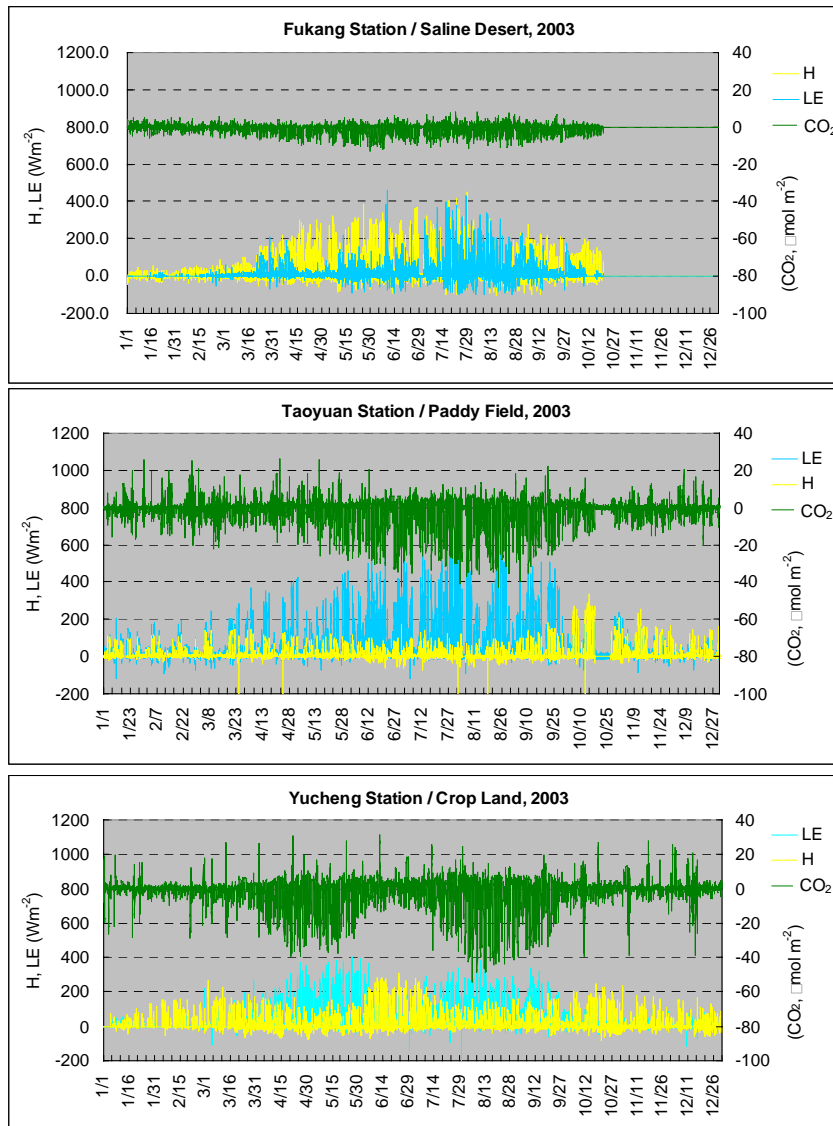


Figure 4. Observations of sensible heat flux (H), latent heat flux (LE), and CO₂ flux in 2003 at Fukang (desert), Yucheng (crop land), and Taoyuan (paddy field) at 30-min intervals in 2003. At the Fukang desert site, the sensible heat flux was larger than the latent heat flux, and CO₂ flux had a very small annual change. However, at the Taoyuan paddy field site, the latent heat flux was much bigger than the sensible flux, and the CO₂ flux was large during the whole year compared with other sites. At the Yucheng site, there was a high evaporation rate and high CO₂ fixation at

the beginning of June, and from the middle of July to the end of September, the major growing season of corn. It is clear that the dynamics of the water, heat, and carbon fluxes reflect the local plant growth patterns

The second task of APEIS-FLUX is to develop a methodology and models to estimate the spatial distributions of water, heat, and carbon fluxes from MODIS data. Data such as MOD09 for surface reflectance, MOD11 for land surface temperature and emissivity, MOD12 for land cover, MOD13 for NDVI (Normalized Difference Vegetation Index), MOD15 for LAI (Leaf Area Index) and FPAR (Fraction of Photosynthetically Active Radiation) and MOD17 for NPP, developed by the data-processing system, can be used to develop models to estimate the spatial variations in water, heat, and carbon fluxes in terrestrial ecosystems. With the help of Global Positioning System (GPS) and global information system (GIS) software, the temporal dynamics of MODIS-generated variables can be validated against APEIS-FLUX observations in different ecosystems.

The third challenge of APEIS-FLUX is to develop ecosystem models for understanding the mechanisms and processes of the water, heat, and carbon cycles in terrestrial ecosystems, both in natural ecosystems (e.g., forests, grasslands, and deserts) and in managed agricultural ecosystems (e.g., crop land and paddy fields). These models will rely mainly on MODIS data as input variables and are expected to accurately simulate the natural processes of water, heat, and carbon cycles in terrestrial ecosystems and the effects of human disturbance.

2.3 Improvement of the Data Processing System

A network of data-analyzing centers at NIES in Japan, IGSNRR in China, NUS in Singapore, and CSIRO in Australia was formed in 2003 under the umbrella of APEIS-IEM. These centers store both a wide variety of satellite data and various ground-based measurements. The data processing system for deriving the higher-order MODIS products was also improved (Fig. 5). Fig.6 shows an example of 16-day NDVI composite with a resolution of 500m in China.

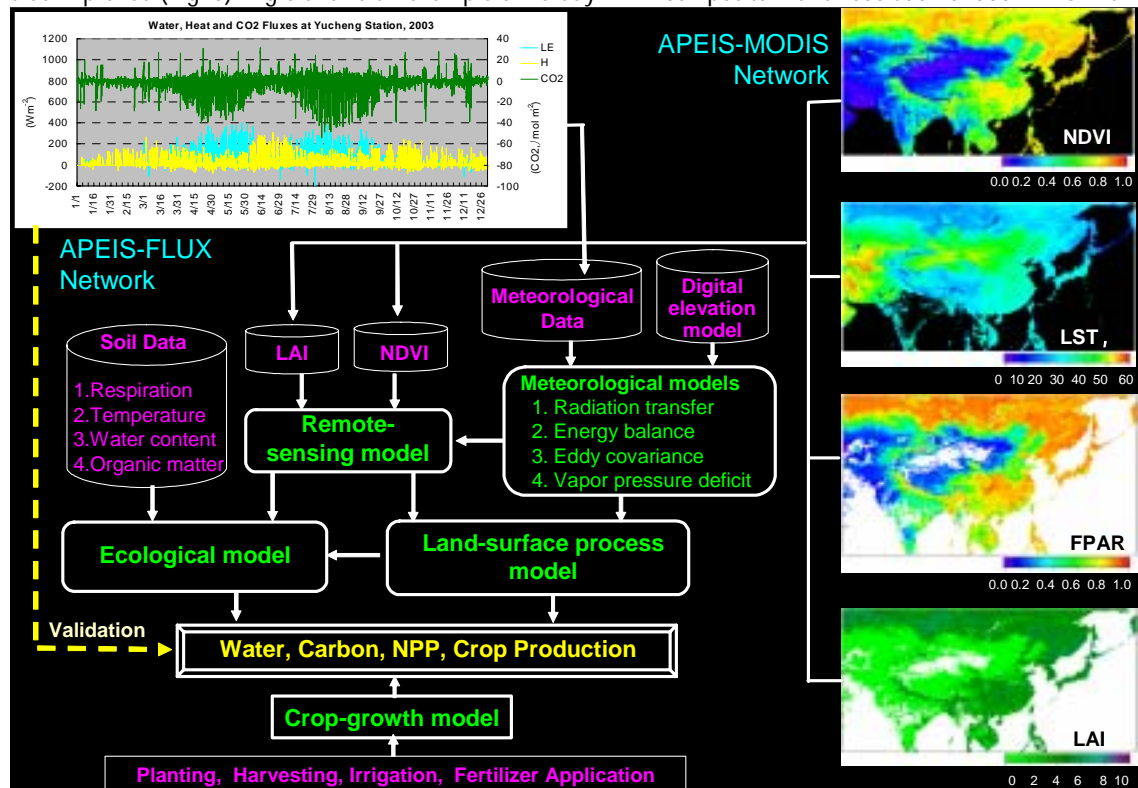


Figure 5. Flowchart of APEIS data processing

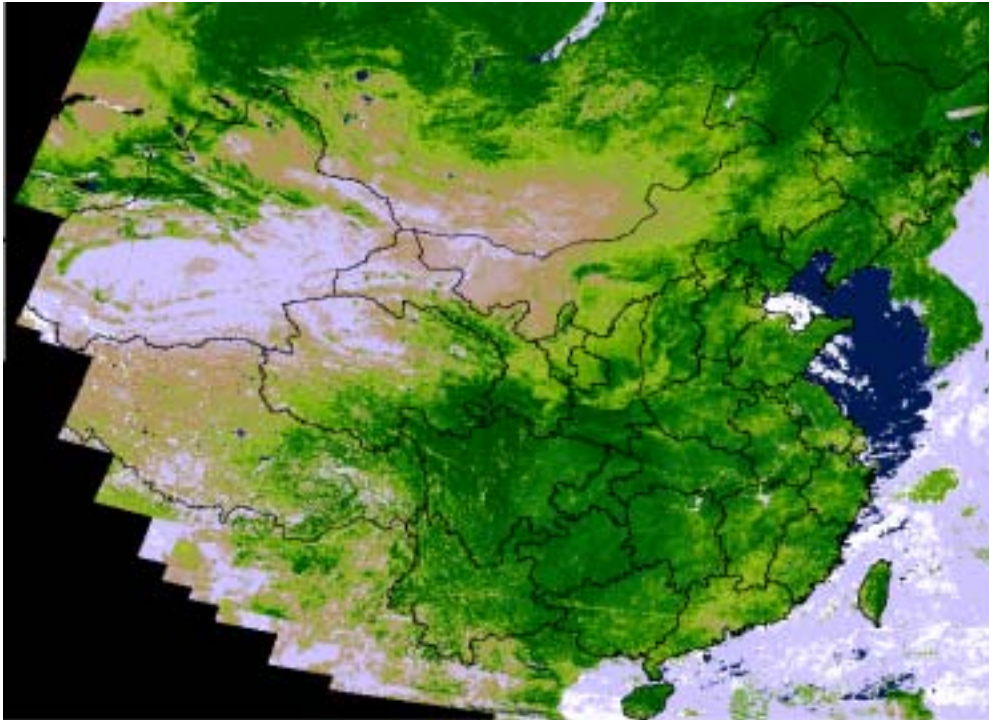


Figure 6. Map of 16-day NDVI composite with a resolution of 500m in China, 08-23, July-2002

2.4 Providing Validated Satellite-Derived Indices

Although numerous satellite-derived indices in the Asia–Pacific region have already been produced by other projects and organizations, most have yet to be calibrated or validated by ground-truth data and they might contain significant uncertainties. APEIS-IEM has established five validation sites in a variety of ecosystems in China (grassland, crop land, paddy field, forest, and semi-arid area) at which ground-truth data—including information related to radiation, meteorology, soil, and vegetation—is continuously measured. Using these consistent and quality-assured datasets, APEIS-IEM can produce accurate and reliable information specific to the region (Fig. 7).

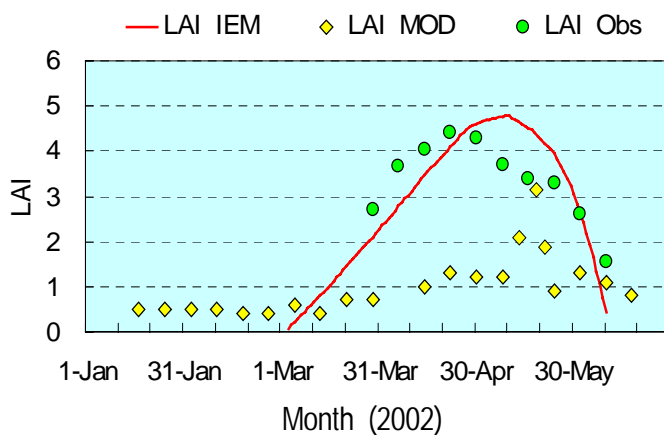


Figure 7. Comparison between APEIS-IEM product of MOD15 (LAI IEM) and that of NASA product of MOD15 (LAI MOD) in 2002, which shows LAI MOD has poor agreement with observations (LAI Obs). One of the reasons is that misclassification of land cover leads to errors in NASA product.

2.5 Contributions to Scientific and Technological Progress

Scientifically, APEIS-IEM contributes to mapping of land-cover types, identifying land-cover change, estimating the water level and volume of lakes, measuring land-surface attributes as inputs to ecosystem models, providing scenarios for realizing sustainable development through model simulations, and simulating the response of agricultural production to climate change.

(1) Mapping land cover types

During the 1980s, pioneering research was conducted to map vegetation at continental scales, primarily with data acquired by the U.S. National Oceanographic and Atmospheric Administration's (NOAA) meteorological satellite, the Advanced Very High Resolution Radiometer (AVHRR). In the 1990s, AVHRR data were used to map land cover globally at increasingly higher spatial resolutions: the first global land cover classification was at a resolution of $1^\circ \times 1^\circ$ (approximately 110×110 km); this was followed by classification at $8 \text{ km} \times 8 \text{ km}$ resolution and finally at $1 \text{ km} \times 1 \text{ km}$ resolution. A suite of recently launched sensors, including MODIS, SPOT Vegetation, and GLI, with their improved spectral, spatial, and radiometric resolutions, provide. An initial result of the APEIS-IEM project is the development of a set of maps of land-cover type in the Asia-Pacific region at $1 \text{ km} \times 1 \text{ km}$ resolution by using MODIS satellite datasets (Fig. 8).

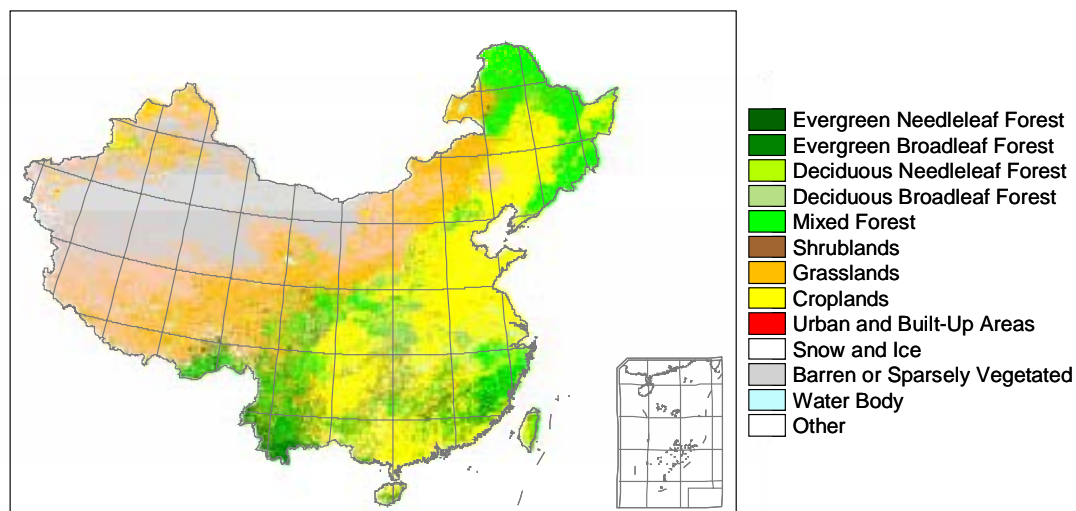


Figure 8. Land-cover types in 2002 derived from MODIS data

(2) Identifying land-cover change

One of the most significant contributions to be gained from satellite data is the identification and monitoring of land-cover change. Data acquired by Landsat and SPOT have been the primary sources for identifying land-cover change in particular locations. As one of the partners of IEM, the IGSNRR of the Chinese Academy of Science developed a series of maps of land-use change in China. In addition, they used the Land-Use Dynamic Degree model to calculate the degrees of land use change in China. The result shows that the change degree of the eastern part of China is larger than that of the western part. In the eastern part, the change degree is highest in the southeastern coastal area, the lower reaches of the Yangtze River plain, the northern part of the North China Plain, and the Northeastern China Plain, but the change degree is very low in the middle and southern parts of the North China Plain. In the western part of China, the degree of the middle and eastern parts of Inner Mongolia is very high, and that in the western part of Xinjiang, the Sichuan Basin, and the Yunnan Plateau is also relatively high. However, those of the

Tibetan Plateau and the western part of Inner Mongolia are very low. Furthermore, the IGSNRR studied the spatial-temporal dynamic change of land use in China from 1990 to 2000, based on analyses of the basic characteristics of change of major land-use types. They found that over the research period, areas of cropland, towns, rural residences, and water bodies increased in both eastern and western parts of China; the rate at which areas of cropland increased was higher in the western part. The areas of woodland and grassland decreased in both eastern and western parts of China over the past ten years; the rate of decrease was higher in the eastern part. The area of unused land in the eastern part of China decreased over the research period; however, the area of unused land in the western part of China increased over the same period (Fig. 9).

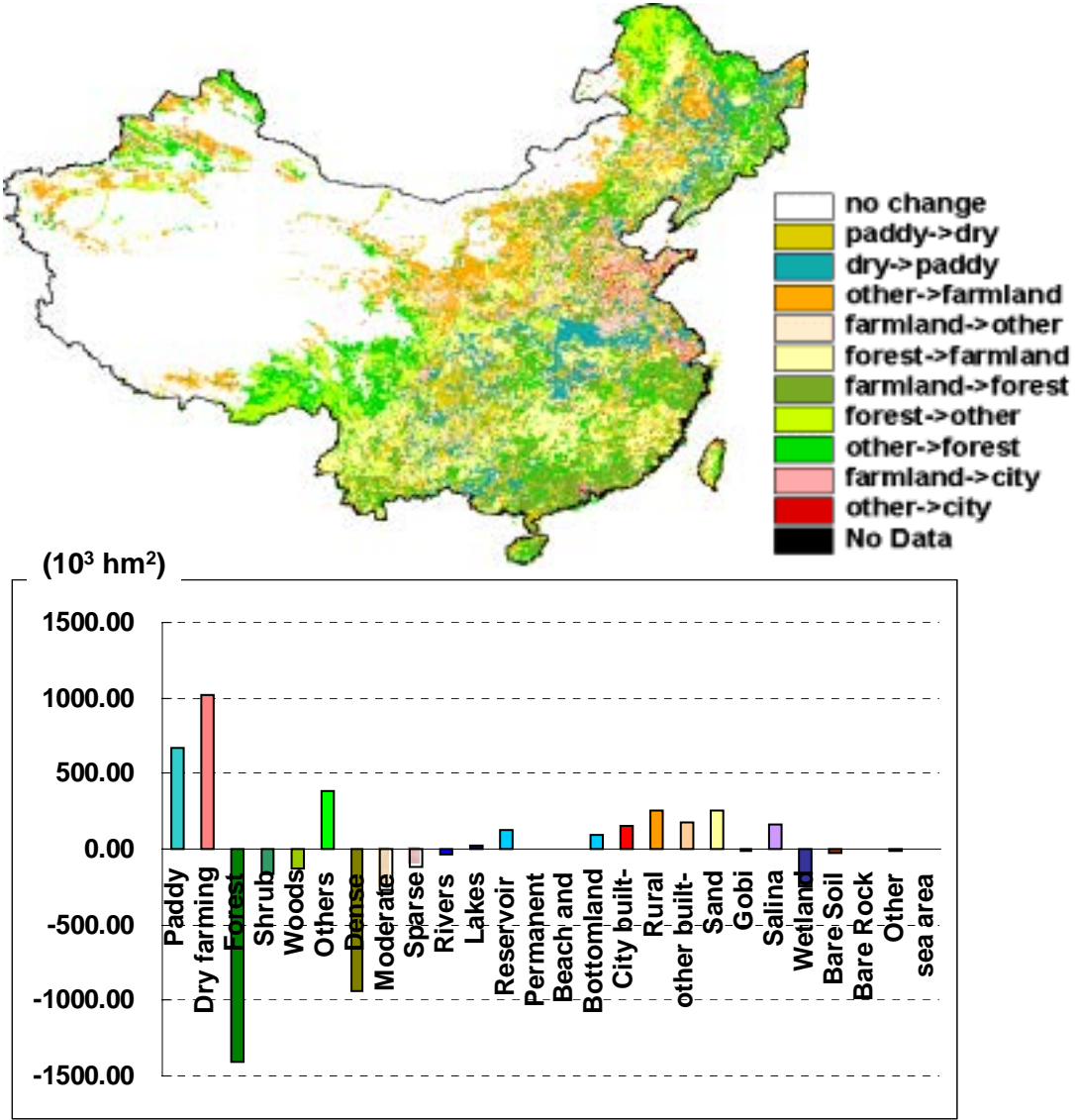


Figure 9. Land-use changes from 1990 to 2000 in China. Areas of cropland, towns, rural residences, and water bodies increased in both eastern and western parts; the area of cropland increased at a higher rate in the western part. Areas of woodland and grassland decreased in both eastern and western parts; the rate of decrease was higher in the eastern part. The area of unused land in the eastern part decreased; however, that in the western part increased.

To predict both quantitative and qualitative changes in the production and runoff of pollutant loads brought about by artificial changes in the environment, APEIS-IEM is developing a comprehensive method to estimate changes in pollutant load runoff due to land-use/land-cover change in the Changjiang basin (Fig. 10).

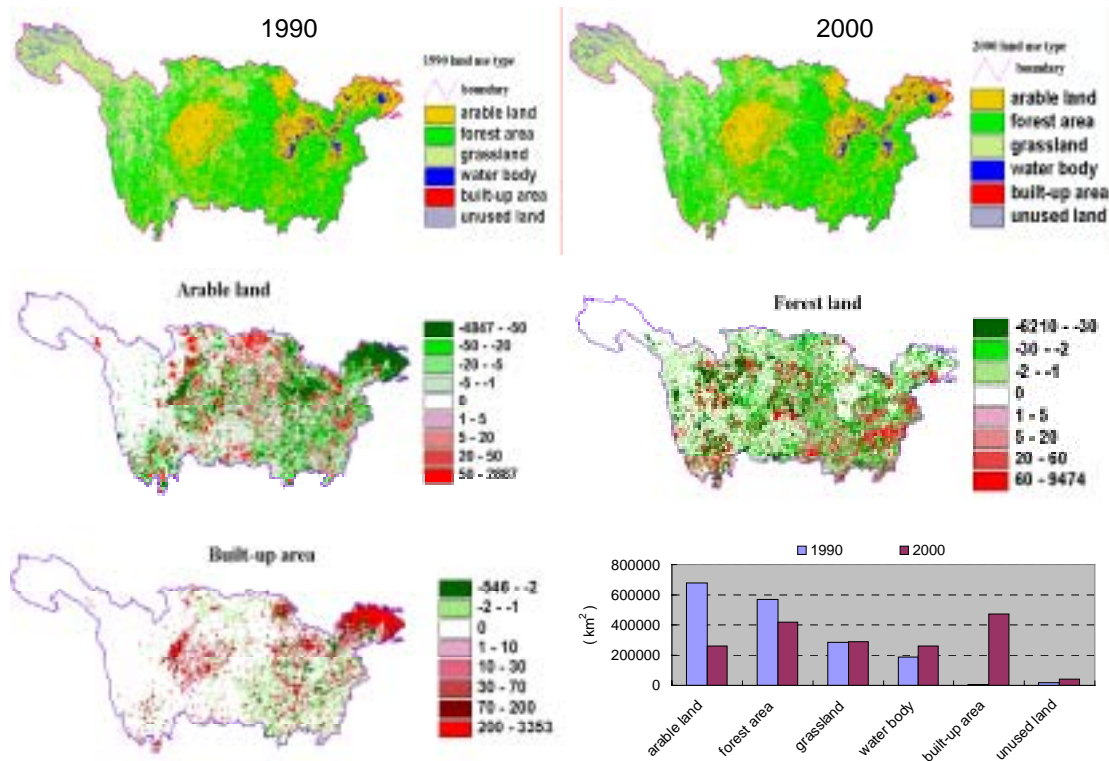


Figure 10. Land-use change from 1990 to 2000 in the Changjiang basin, China. (1) Areas of arable land and forest have decreased as shown in Figure 8. On the other hand, areas of grassland, water bodies, built-up areas, and unused land have increased. (2) The decrease in area of arable land is obvious, among which most has been converted to built-up areas, water bodies, or forests. (3) Areas of built-up regions greatly increased. Most were converted from arable land and forest. (4) Of the many kinds of land-use change, the main types in the Changjiang basin are conversion of arable land to built-up area, forest to grassland, grassland to forest, forest to arable land, arable land to water body, arable land to forest, and grassland to arable land.

(3) Estimating the water level and volume of lakes

In 2002, APEIS-IEM used Terra/MODIS satellite data to estimate the dynamic variations in surface water area and water storage of Dongting Lake. Firstly, the whole of Dongting Lake was divided into three parts according to geographical characteristics (WDL: West Dongting Lake; SDL: South Dongting Lake; EDL: East Dongting Lake). Secondly, surface water area was determined from spectral differences between water and terrestrial areas by using satellite (Terra/MODIS) NDVI data. Thirdly, the surface water area was overlaid onto the lake bottom DEM data (grid size of 50 m × 50 m) to calculate water level. Finally, the water storage in each water column was obtained by multiplying water depth (difference between water surface elevation and lake-bottom elevation) by grid area. The total water storage of Dongting Lake was calculated by adding the values for all water columns for the whole lake. The estimated water level and storage corresponded well with actual measurements in the three parts of Dongting Lake (Fig. 11), which implies that the method is an effective approach to estimating water level and water storage of large lakes.

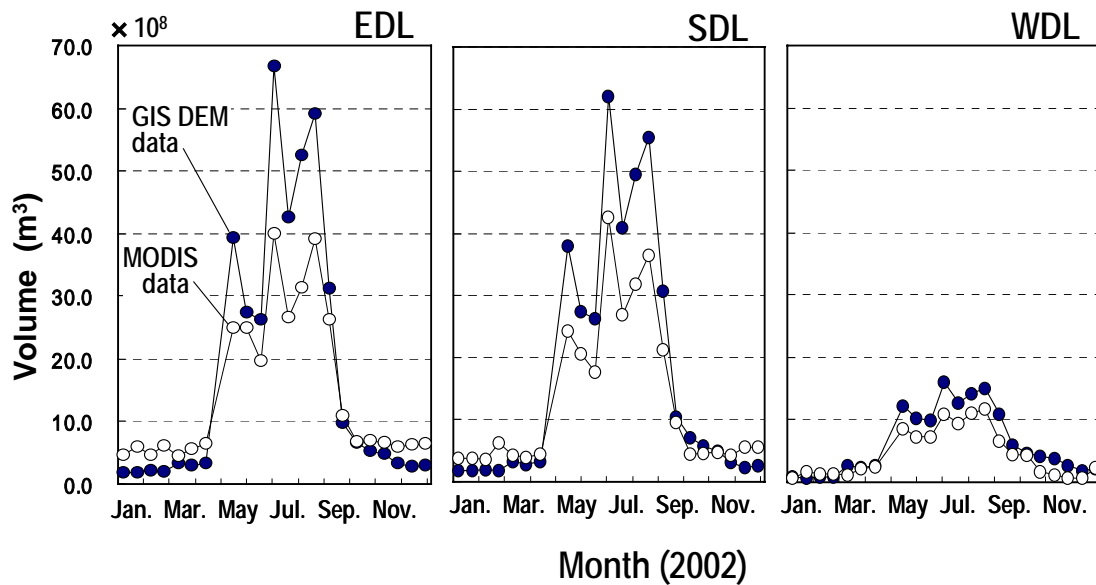


Figure 11. Comparison of water volumes in three lakes of Dongting Lake in 2002 calculated from measured data and from estimated data based on MODIS satellite images. ●: measured from data at each station; ○: estimation based on MODIS image analysis

(4) Measuring land-surface attributes as inputs to ecosystem models

Satellite data and ecosystem models provide spatially comprehensive estimates of parameters such as evapotranspiration, primary productivity, fraction of solar radiation absorbed by photosynthetic activity (FPAR), leaf area index (LAI), and percentage of solar radiation reflected by the surface (albedo) (Fig. 5). These parameters are related to several ecosystem services such as water resources, food, and carbon fixation. Satellite-derived parameters provide an important means for linking changes in ecosystem conditions with implications for their services. IEM's data-processing system has derived higher-order environmental indices from MODIS data that can be used as inputs to a range of models for assessing climate change, ecological conditions, and agricultural production.

(5) Creating scenarios for realizing sustainable development

APEIS-IEM data can help create scenarios for realizing sustainable development. As one of the most important drivers of both ecological change and economic development, changes in land use and land cover have been dynamically monitored by APEIS-IEM, as mentioned above. Furthermore, changes in NPP due to land-use/land-cover changes in China have been estimated by using ecological modeling. This modeling shows an increase in NPP from the 1980s to the 1990s in most parts of China, but a decrease in the Loess Plateau and western part of northeastern China (Fig. 12). Meanwhile, provisioning services, measured by food production, also increased.

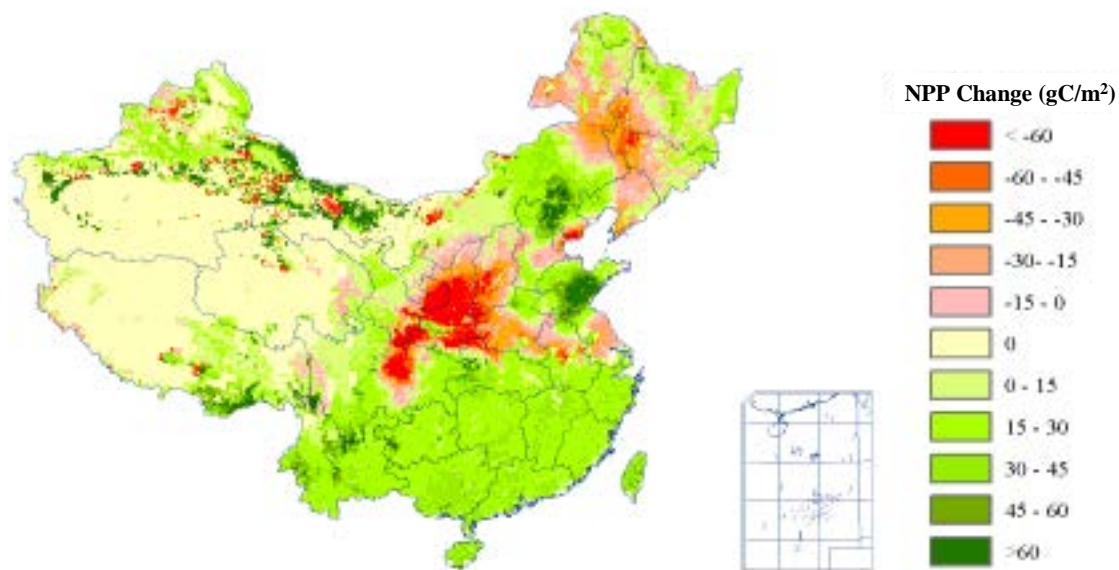


Figure 12. Changes in NPP due to land-use/land-cover changes from the 1980s to the 1990s in China

Water resource management is one of the most important issues that we are currently facing. APEIS-IEM developed an integrated watershed management model that simulates ecological functions, such as water, heat, carbon and nitrogen cycles, and sediment transport, as well as agricultural production. We used the model to simulate sediment loads under different land-use change scenarios over the whole of the Jialingjiang catchment (160 000 km², located in the upper reaches of the Changjiang basin), to evaluate how sediment loads from the catchment would be affected. One of the main flood-prevention policies adopted by the Chinese Government is conversion of farmland to forest on steeply sloped areas. Scenarios were given to conversing farmland on the sloped areas of 25 °, 20 °, 15 ° and 10 ° to forest, respectively (Fig.13). Simulations to these scenarios showed that the volume of sediment erosion in this catchment will obviously decrease according to the recovery of forest area on sloped areas (Fig.14).

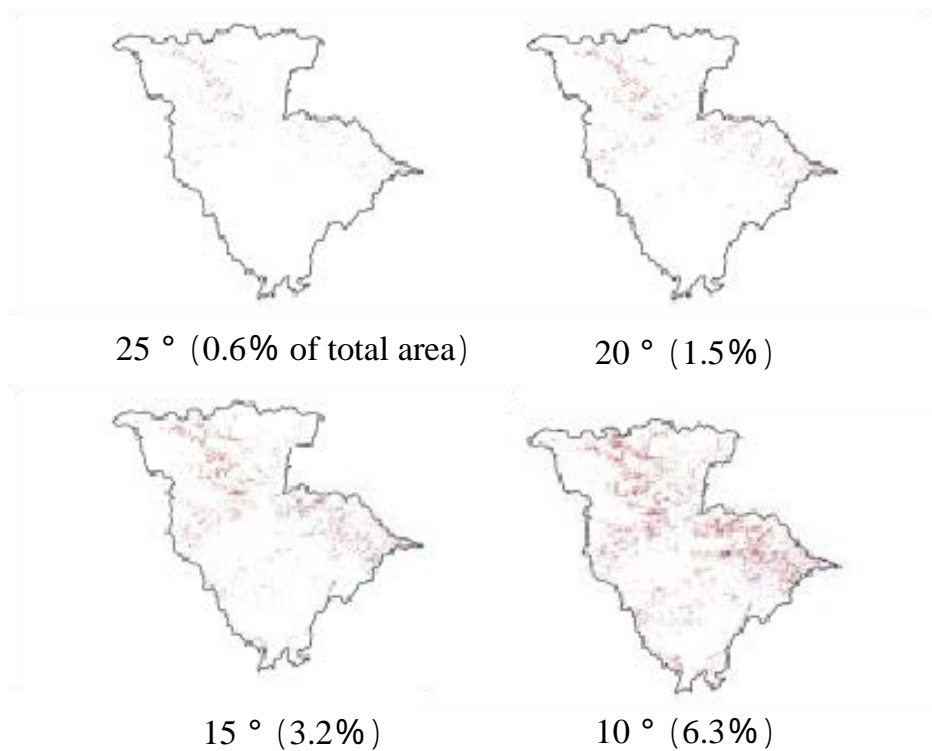


Figure 13. Distribution of the areas to convert farmlands to forest land on the slope of 25°, 20°, 15° and 10° respectively in the Jialingjiang Catchment, China.

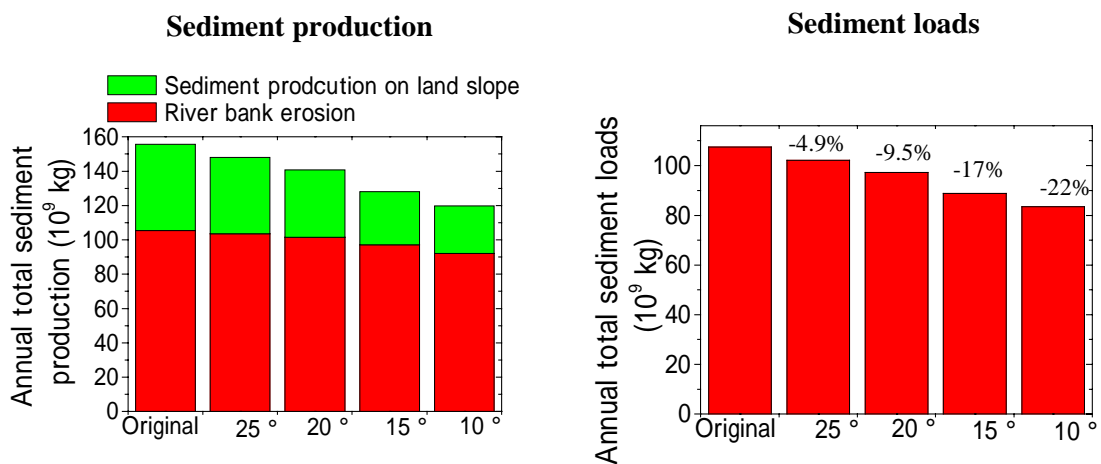


Figure 14. Effects of policy of returning farmland to forest on prevention of both sediment production and sediment loads

(6) Simulating the response of agricultural production to climate change

In order to test the response of wheat and corn (maize) growth under different climate conditions, we simulated the effect of climate change on growth under 3 climatic scenarios (using meteorological data from 1987 to 2001): 3 °C increase in mean daily temperature, double CO₂ concentration, and both combined. The basic simulation shows:

1. A 3 °C increase will shorten the growing periods of both crops: The 15-year simulation showed that if present cultivars are used, the average growth period might be 16 days shorter for winter wheat and 18 days shorter for corn averagely (Fig. 15). The decrease in growth period of both crops would be good for cultivation in North China Plain, which has an extremely limited growing season at present.

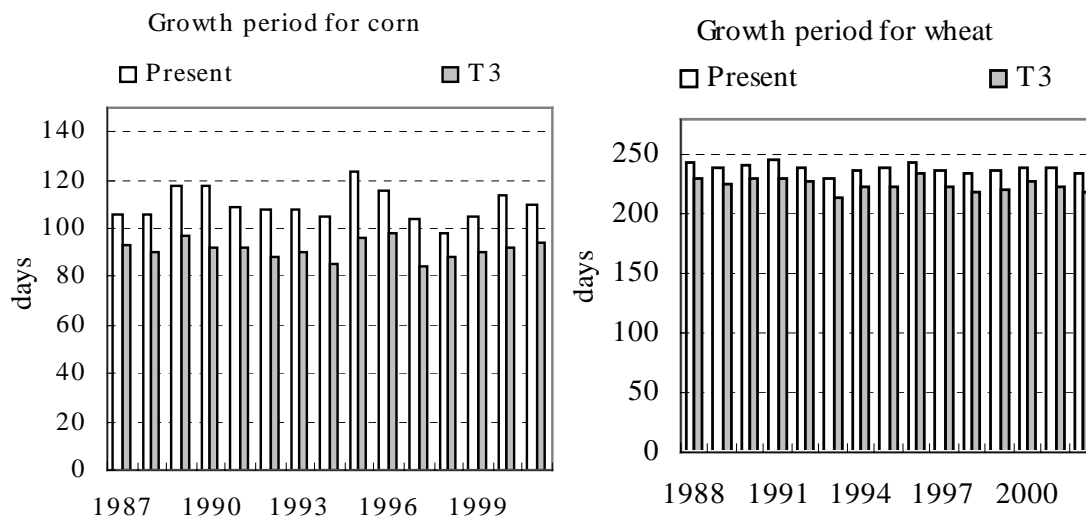


Figure 15. Effect of temperature rise on growth period of corn and winter wheat (T3: 3 °C increase in daily mean temperature)

2. Increased concentration of CO₂ will benefit the yield of both corn and wheat, while the effect of temperature is likely to be negative. Under the higher temperature and double CO₂ concentration, the yield of corn could decrease by 12%, influenced possibly by the shortened growing period at the higher temperature. However, the yield of winter wheat should benefit greatly from an increase in CO₂ concentration. Under the higher temperature and double CO₂ concentration, the yield of winter wheat could increase by 16% (Fig. 16).

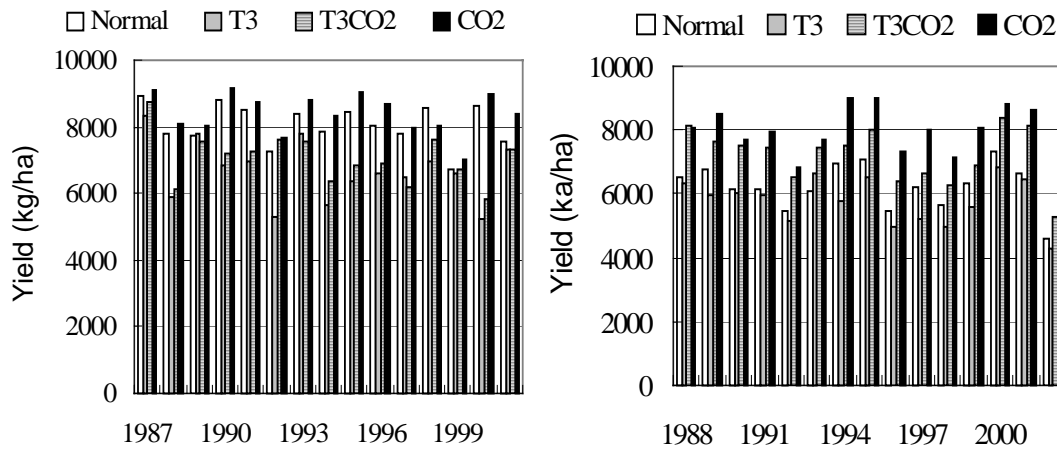


Figure 16. Effect of different climatic scenarios on yields of winter wheat (right) and corn (left) (T3: 3 °C increase in mean daily temperature; CO2: double CO₂ concentration; T3CO2: combination of 3 °C increase and double CO₂ concentration)

- Under conditions of double CO₂ concentration, water use by corn growth might greatly decrease. On the other hand, increased temperature will increase crop water use, in both corn and winter wheat. Under 3 °C higher temperature and double CO₂ concentration, water use by corn could decrease by over 14%, while water use by winter wheat could rise by 3%, showing the trade-off between the positive effect that increased CO₂ has in decreasing crop water use and the much stronger negative effect caused by increased temperature (Fig. 17).

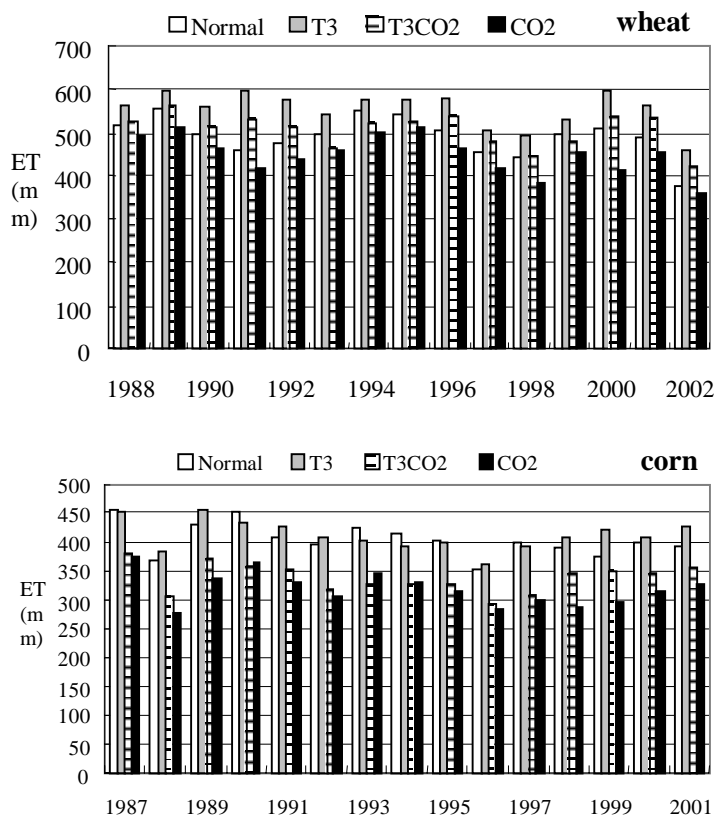


Figure 17. Effect of climatic change on crop water use (ET: evapotranspiration) by winter wheat and corn (Normal: crop water use under the present climatic conditions; T3: 3 °C increase in mean daily temperature; CO2: double CO₂ concentration; T3CO2: combination of 3 °C increase and double CO₂ concentration).

3. Capacity Building and Contributions to Policymaking

The Second APEIS Capacity Building Workshop on Integrated Environmental Monitoring of the Asia–Pacific Region was held in Sydney, Australia, on 27 and 28 November 2003 (Fig. 18). Participants from the Philippines, Malaysia, Australia, Pakistan, Nepal, Japan, Singapore, and China attended. The first day of the workshop presented the importance of capacity building in the APEIS-MODIS Network and the APEIS-FLUX network, as well as the regional integrative models and their applications to the Asia–Pacific region. In the first session, several advantages of the integrative model based on MODIS data were presented and discussed. The CSIRO Atmospheric Research Project, the Global Carbon Project, and the APEIS-IEM Project each reported the current situations and problems encountered with the model. In the second session, for the purpose of making most efficient use of the MODIS datasets, it was discussed how MODIS data could be validated and calibrated through APEIS-FLUX research activities. On the second day, presentations focused on land-use/land-cover change, the carbon cycle, and MODIS validation in different countries. In the afternoon sessions, topics concerning APEIS-IEM collaboration and integrated capacity building were discussed.

Participants pointed out that APEIS-IEM can help in developing and validating integrative models for sustainable development of the Asia–Pacific region. The models are constrained by multiple factors, which can be produced by the MODIS data processing system and by flux-tower measurements. Participants suggested that the integrated models need to include not only natural processes, such as atmospheric advection, but also the human dimension, such as population movement and material transportation. It was also suggested that APEIS-IEM should foster collaboration with NASA, particularly with the Boston group, to validate MODIS products. Finally, the workshop concluded that the participants:

- Need to share data processing code, MODIS direct broadcast code, and validation strategies
- Need to compare MODIS products developed by different groups
- Need to expand the MODIS network to other countries, such as Russia
- Need to foster data exchange between MODIS stations
- Need to process AVHRR data (e.g., as a record of past land-use change—especially for phenology, crop harvesting, burning history, etc.—and rapid land-cover change)
- To collaborate toward developing maps of the ecological conditions in the Asia–Pacific region, such as fire and land-use change. Other future developments could include maps of water resources, biomass, flood variation, and wetlands, and methods to detect environmental changes and disasters
- To exchange information on how to improve the performance of tower sites, especially those with marked topographic variation; and will promote inter-comparison among tower sites to gain insights into the ecological controls of energy, water, and carbon cycles
- To emphasize both flux measurements and the study of ecological processes with the APEIS-FLUX network; and will develop methodologies of scaling up and scaling down flux data to validate MODIS products
- To encourage collaboration among the regional flux tower networks (e.g., OZ-FLUX, CHINA-FLUX, APEIS-FLUX)
- To expand the application of the IEM network to south and central Asia and to Russia



Figure 18. Participants of the second APEIS-IEM capacity building workshop in Australia. Major suggestions: Strengthen the cooperation and data exchange among stations; Improve the quality of tower site data, especially in regard to the effects of topographic variation and horizontal advection; improve scaling methodologies that enable flux data to be used to validate MODIS products and integrated models

APEIS-IEM also published a special issue of the *Journal of Geographical Sciences* (Vol. 59, No. 1, 2004), and the APEIS-FLUX sites have become important training centers for the Chinese Ecological Research Network, and have been visited by many scientists, students and policy-makers (Fig. 19).



Figure 19. APEIS-FLUX sites have become important training centers for the Chinese Ecological Research Network; the sites are visited by many scientists, students, and policy-makers

Finally, the activity of APEIS-IEM is closely linked with the Millennium Ecosystem Assessment (MA) through the participation in the China MA, one of the sub-global assessment projects. The outcomes of APEIS-IEM are contributing to Chapter 7 in the sub-global assessment as a core scientific method for assessing conditions and trends of ecosystem services.

APEIS

APEIS-IEM Web sites :
**[http://www-basin.nies.go.jp/english/
project/iem/index.html](http://www-basin.nies.go.jp/english/project/iem/index.html)**