Japanese Oak Wilt Spred analyzed with GIS and Multi-spatial-scale Data

Study on Land–use/Land-cover Change and Terrestrial Carbon Cycle in China

Jiyuan Liu, Quanqin Shao*, Mingliang Liu

Institute of Geographical Sciences and Natural Resources Research, CAS,

Beijing, 100101 China

*Email: shaoqq@igsnrr.ac.cn

Abstract: This paper introduces the research progresses on the carbon cycle of terrestrial ecosystems in China. To address the scientific issues such as temporal and spatial pattern of terrestrial ecosystem carbon sink, and driving mechanism and scenarios of carbon cycle, a method of geo-information science for studying carbon cycle of terrestrial ecosystems is proposed, and the study on the relationships of land–use/land-cover change (LUCC) and terrestrial carbon cycle in China is emphasized. In the research works bottom-up approach and top-down approach are combined by means of scaling models. The bottom-up approach is based on observations of comprehensive network of carbon storage and carbon cycle process of terrestrial ecosystems, adaptive experiments of biological processes, and researches on carbon transportation processes of rivers. Top-down approach is based on detecting land cover change and retrieving ecological parameters by using satellite data. Retrieval models of carbon budget are developed by means of the capacity of satellite remote sensing that can frequently supply surface information of geographical processes and ecological processes. On the basis of analyzing data-at-points collected by stations of Chinese Ecosystem Research Network, stations of Chinese Forest Ecosystem Research Network, and observation stations of CHINA-FLUX, combining with the retrieval models, a numerical simulation model of terrestrial ecosystem carbon cycle is constructed by means of surface theorem, grid generation method and grid computing technique. Pattern and process of carbon cycle are to be simulated; natural and human (land use change) impacts on carbon cycle of terrestrial ecosystems are to be analyzed; and evolution trends of carbon cycle process of terrestrial ecosystems are to be discussed under the condition of global climate change.

Key words : Terrestrial ecosystem; carbon cycle; geo-information science; land–use/land-cover change; global climate change

1. Introduction

The emission of several greenhouse gases is bringing about climatic change: the Earth is becoming warmer, with the last decade being the warmest in more than 600 years. Carbon in the form of carbon dioxide (CO2), carbon monoxide (CO) and methane (CH4) is a significant contributor to greenhouse gases. Burning of fossil fuels by human provides a net contribution of new carbon dioxide to atmosphere. Recognition of man's role in changing the climate, and concern for adverse impacts, has spurred the negotiation and implementation of the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol. It has also spurred intensive research into the carbon cycle. The UNFCCC and its Kyoto Protocol have given emission scalar of industrial countries for reducing greenhouse gases emission, and also promised industrial countries to balance out greenhouse gases emission by increasing carbon sequestration due to agricultural abandonment or new agricultural management, forestry techniques and soil conservation. It represents the first attempt by mankind to manage a global biogeochemical cycle of any kind.

Carbon cycle links human, biological, geochemical and atmospheric process. The change of the magnitude and spatial distribution of net carbon fluxes between ecosystems and the atmosphere is controlled mainly by prior disturbance and land-use/land cover change. To address the scientific issues such as temporal and spatial pattern of terrestrial ecosystem carbon sink, and driving mechanism and scenarios of carbon cycle, etc., a method of geo-information science for studying carbon cycle of terrestrial ecosystems is proposed (Liu etc., 2003). Bottom-up approach and top-down approach are combined by means of scaling models. The bottom-up approach is based on observations of comprehensive network of carbon storage and carbon cycle process of terrestrial ecosystems, adaptive experiments of biological processes, and researches on carbon transportation processes of rivers. The top-down approach is based on detecting land cover change and retrieving ecological parameters by using satellite. Retrieval models of carbon budgets are developed by means of the capacity of satellite remote sensing that can frequently supply surface information of geological processes and ecological processes. On the basis of analyzing data-at-points collected by observation stations of Chinese Ecosystem Research Network, stations of Chinese Forest Ecosystem Research Network, and stations of ChinaFLUX, combined with the retrieval models, a numerical simulation model of terrestrial ecosystem carbon cycle is constructed by means of surface theorem, grid generation method and grid computing technique. Pattern and process of carbon cycle are to be simulated; natural and human impacts on carbon cycle of terrestrial ecosystems are to be analyzed; and evolution trends of carbon cycle process of terrestrial ecosystems are to be discussed under the condition of global climate change.

2. Geo-information Method of Studying Carbon Cycle and LUCC

2.1 Terrestrial Carbon Cycle and LUCC

The transport and transformation of substances in the environment, through living organisms, the atmosphere, oceans, land, and ice, are known collectively as biogeochemical cycles. The Earth system is composed of a number of biogeochemical cycles, including the circulation of certain elements, or nutrients, upon which life and the earth's climate depend. Carbon is one of the most significant elements in that cycle.

The major reservoirs of carbon that contribute to the carbon cycle are the intermediate and deep oceans (36,730 billion tons, or Gt), fossil fuels (4,130 Gt), soil (1,200 Gt), atmosphere (720 Gt), surface ocean (670 Gt), and plants and animals (biomass at 600-1,000 Gt) (Falkowski et al. 2000). The most significant fluxes occur between the biota/soil layer and the atmosphere, which are on the order of 120 Gt per year of uptake and release by the biota/soil layer, followed by the ocean surface and atmosphere, which are on the order of 100 Gt/year in both directions, with a net uptake by oceans of 2.5 Gt (Sherbinin, 2002).

In terrestrial ecological systems, carbon is retained in live biomass, decomposing organic matter, and soil. Changes in land use and cover are associated with large biogeochemical changes, and particular in the aboveground and soil carbon content. The changes, although largely associated with carbon emissions due to deforestation, are also associated with increasing carbon sequestration due to agricultural abandonment or new agricultural management practises (e.g., no tilling approach) and forestry techniques (Canadell, 2001).

To distinguish the human activities and natural factors that result in the change of terrestrial carbon cycle is a key issue for identifying spatial-temporal patterns and evolvement of terrestrial carbon cycle. LUCC is the most important human activity of affecting sink/source intensity of terrestrial carbon.

2.2 The Current Status and Issues of Terrestrial Carbon Cycle Research

The aim of terrestrial carbon cycle study is to provide an accurate knowledge for making policy of ecology system management at present. Thus three key scientific issues in terrestrial carbon cycle research were presented by IGBP and WCRP, which are:

(1) The spatial and temporal patterns of carbon sink/source;

(2) The control factors of C cycle processes, and their interaction mechanisms;

(3) Dynamic processes and trends of C cycle processes in future.

There exists about 1.4-1.7GtC missing sink in global carbon budgets (Schindler, 1999), The missing sink might happen in terrestrial biosphere and costal continental shelf. However, This guess is lack of support from scientific observation data and research methods. Based on national inventories of forest and soil, a lot of assessments about fluxes/storage and sink/source of global terrestrial carbon has been made scientists, but there are larger difference between evaluating values, which is mainly resulted by lacking data and uncertainty of complicate terrestrial carbon cycle. Thus Earth Observing System and Global Terrestrial Observing System have been implementing by many countries. The international FLUXNet has been built, and there are 41 observing stations by EuroFLUX, 69 observing stations by AmeriFLUX, 26 observing stations by AsiaFLUX.

Because the biological process of terrestrial ecological system has adaptability to increasing concentration of greenhouse gases and climatic warming. Scientists have designed various experimental scheme of artificial control for simulating and forecasting response of terrestrial biological process, finding adaptive mechanism of terrestrial biological process to environmental changes. The famous models for simulating carbon cycle are TEM, CENTURY, FOREST-BAG, MAPSS, Biome, CASA and SiB2, etc. in the word.

In resent 20 years, a big progress has made in studying land use/cover change and modeling of biophysical information retrieval of land surface by remote sensing (Myneni, et al., 1997). By remote sensing reverse, physical parameters of earth surface for modeling carbon cycle of terrestrial ecosystem can be got, for example, reflecting rate of earth surface, leaf area index, soil humidity, etc., which can be used as driving variables or parameters of carbon cycle models of terrestrial ecosystem, and also can be used to assess carbon reservoirs of plant, carbon dioxide exchange between plant and atmosphere, the seasonal variation of carbon fluxes of terrestrial, etc.

The challenge is how to produce the spatial distribution of carbon sources and sinks with high spatial and temporal resolutions by combining satellite data and in situ data with multiple scales.

2.3 Technique Scheme of Geo-information for Studying LUCC-CC

China has the third largest land area and diverse climate and biomes in the world. The terrestrial carbon cycle research in China has great significant to understand global carbon dynamics.

In order to resolve above scientific issues of carbon cycle of terrestrial ecosystem in

China, an integrated method is proposed (fig.1), which combines bottom-up method and top-down method by scaling up and down. The bottom-up method is based on integrated network observation of carbon fluxes and storage of terrestrial ecosystem, acclimatization experiments of biological processes of carbon cycle, carbon transportation processes study in river. The top-down method is based on remote sensing inverse to research land use and land cover change and retrieval other ecosystem parameters. This method has characters as follows:

(1) Based on carbon fluxes data of ChinaFLUX observation net, combining with sample zone investigation, and enriched CO2 experiments with ecosystems (FACE), to obtain integrated data of typical terrestrial carbon cycle by making contrast observation and study, to reveal mechanism of carbon cycle of terrestrial ecosystem, and its response and adaptability to carbon dioxide concentration increasing and climate warming, to answer questions of carbon source/sink.

(2) Using remote sensing data of multi-spectrum/super-spectrum, multi-time, multi-bands or multi-sensors, to retrieval parameters of carbon balance (absorb/sink and release/source) models and build carbon balance models which are modified by carbon fluxes of terrestrial ecosystem, to make out spatial-temporal patterns of carbon balance in local levels and national level.

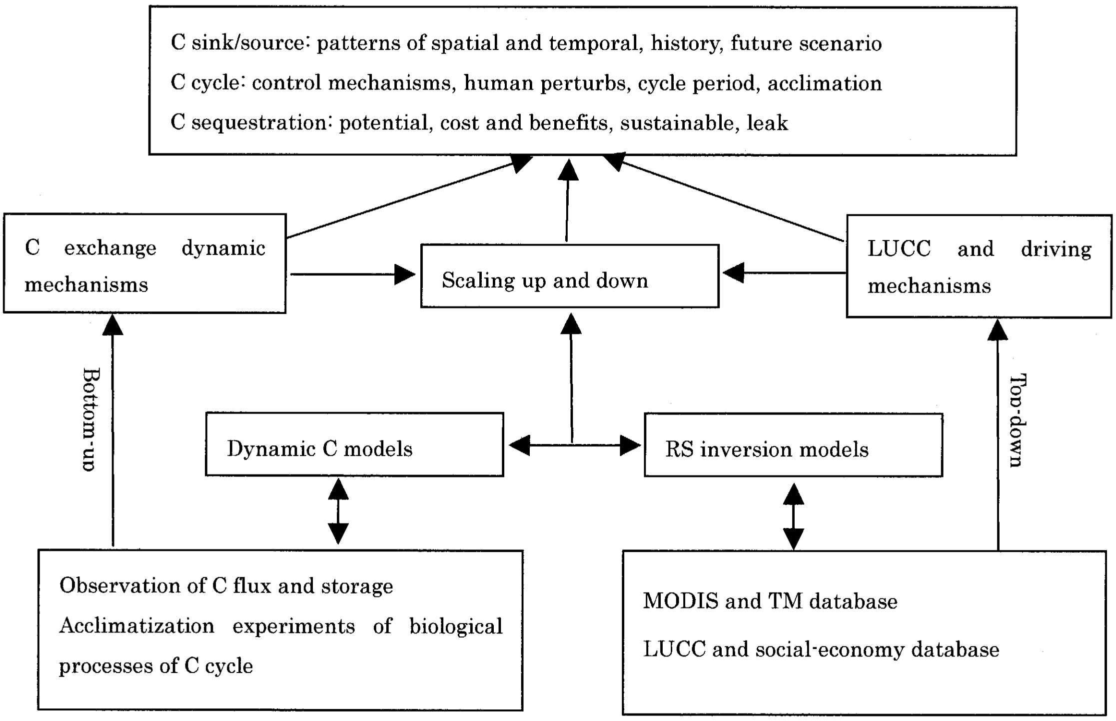


Fig.1 Framework of studying carbon cycle of terrestrial ecosystem in China (after Liu et. al, 2003)

(3) Based on carbon storage data of observation stations of Chinese Ecosystem Research Network (CERN), Chinese Forest Ecosystem Research Network (CFERN), and ChinaFLUX, combining with geographical and ecological process data with high spatial-temporal resolution by remote sensing, using surface method and grid point generating method, to build numerical simulating models of carbon cycle of terrestrial ecosystem.

(4) By coupling remote sensing reverse models, kinetic models of carbon cycle, economic models, climate models, and numerical simulating modes of carbon cycle, to assess synthetically patterns and evolvement of spatial and temporal of carbon source/sink of terrestrial ecosystem, to evaluate fixed carbon domino effect of momentous ecological and environmental projects.

(5) Based on compositive database and laws of regional difference of physical geography in China, combining spatial-temporal data analysis method of GIS technique with spatial factor analysis and partial correlation, etc., to analyze characters of variation and patterns of carbon storage and fluxes in China, and accordingly to distinguish quantificationally natural factors and human factors which effect carbon cycle of terrestrial ecosystem.

(6) By scaling up and down models, to integrate top-down method and bottom-up method.

3. Research Process of LUCC-CC in China

3.1 Capability construction for Studying LUCC-CC

3.1.1 Long Term Fluxes Observation Network

Carbon flux observation net of Chinese terrestrial ecosystem (ChinaFLUX) has been built, which has eight observation stations, supported by momentous project of Chinese Academic Sciences (CAS). These flux observation sites are located on different typical ecological zones in China (fig.2), which are:

Inner Mongolia Grassland

Changbaishan Temperate Deciduous Broad-leaved and Coniferous Mixed Forest

Haibei Hiland Frigid Meadow

Yucheng Warmer Temperate Dry Farming Cropland

Dangxiong Alpine Meadow

Qianyanzhou Man-planted Forest on Red Soil Hill Region

Xishuangbanna Tropic Seasonal Rainforest

Dinghushan Sub-tropic Typical Tropical Evergreen Broad-leaved Forest

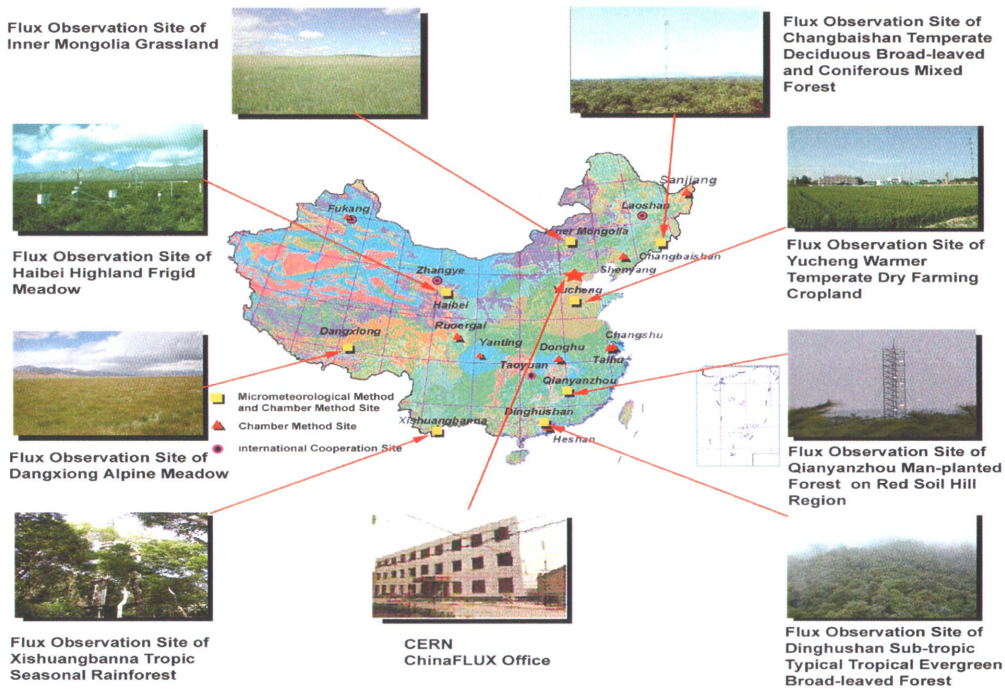


Fig.2 Distribution of flux observation stations of ChinaFlux

Forests are among the most carbon-dense ecosystems, comprising approximately 75% of live organic matter. When soils are included, forests hold almost half of the carbon of the world's terrestrial ecosystems (Houghton & Skole 1993). Fig.3 shows the diurnal cycles of CO2 flux in man-planted forest ecosystem by Qianyanzhou observation station during Sept.2002 to Jy.2003. The carbon flux ranged from -0.8 ($mgCm^{-2}s^{-1}$) in the daytime to 0.2 ($mgCm^{-2}s^{-1}$) during night. From 8am to 6pm forest ecosystem absorbs carbon from atmosphere, which absorb capability is strongest at noontime and dominated by the season. From 6pm to next day 8am forest ecosystem releases/absorb a little bit of carbon to /from atmosphere.

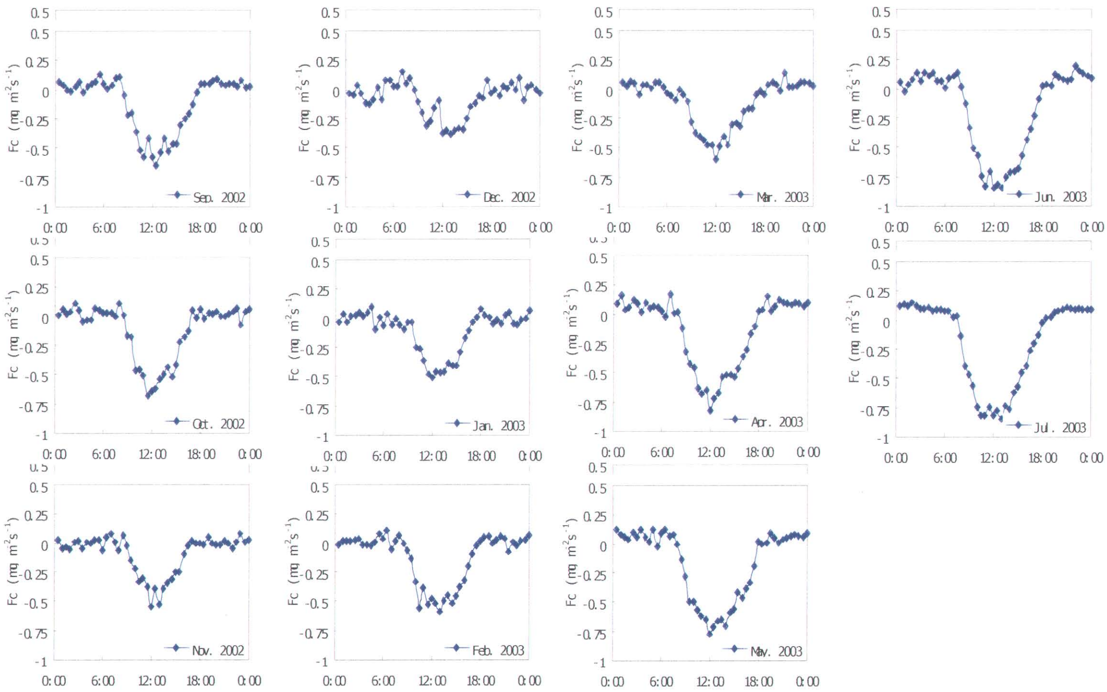


Fig.3 Diurnal Cycles of CO2 flux in forest ecosystem by Qianyanzhou observation station

3.1.2 Data Information System

In order to study LUCC-CC, a data information system has been built and updated continuously by Institute of geographical sciences and natural resources research (IGSNRR), CAS. In this data information system, there are mainly three kind data as follows:

Fig.4 The meteorological observation stations

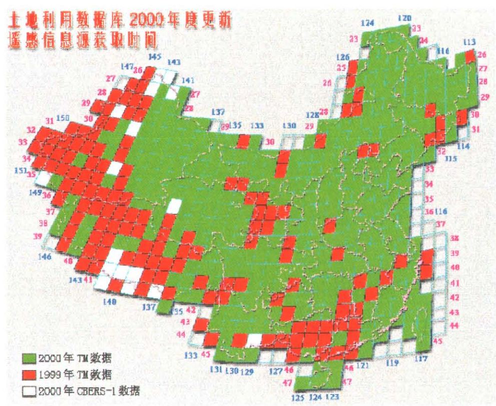


Fig.5 Coverage of landsat data in 2000/1999 period in China

(1) Observation data

Observation data include carbon flux data by Carbon flux observation net of Chinese terrestrial ecosystem (ChinaFLUX, fig.2), ecological data by Chinese Ecosystem Research Network (CERN) and Chinese Forest Ecosystem Research Network (CFERN), climate data by meteorological observation stations (fig.4). The climate data have a long time series for 40 years, including temperature, precipitation, cloudiness data. Based on climate data, annual and monthly mean temperature, precipitation, cloudiness with spatial resolution 1×1km have been analyzed as model parameters for numerical simulating of carbon cycle. Annual mean temperature increase 0.026℃ annually, which higher than global average in the same period. And 1990s is the warmest period. Precipitation increases 1.14 mm annually during last 40 years. But its dynamics is complicated and its spatial pattern is not consistent in large scale. Cloudiness has trend of increase during last 40 years in China, and the cloudiness increase about 0.1 percentage annually.

(2) Landsat image data and land use/cover data

In data information system, the Landsat digital image data cover whole main land of China with three time periods 1989/1990, 1995/1996, and 1999/2000. Fig.5 just shows the coverage of Landsat digital image data in 2000/1999 period. The main type of Landsat image is TM, and few of Landsat data are CBBRS-1 data (fig.5).

Based on Landsat images, through geometric correction, false color composition and mutual interpretation with PCI software and data processing with ArcGIS software, vector maps of land use in 1990, 1995, 2000 year have been generated. By overlay analyzing vector maps of land use in 1990, 1995, 2000 year with ArcGIS software, land use change maps during 1990-1995, 1995-2000, and 1990-2000 have been gained. By overlay analyzing land use maps and land use change maps with ArcGIS software, Land-use change maps of predominant types, Zoning maps of land-use net change, Conversion maps of land use during 1990-1995, 1995-2000 and 1990-2000 with spatial resolution 1×1km have been made.

(3) Inventories of soil and forest

In data information system, soil inventory data are provided by second national soil general survey in 1980s, there are 2473 soil profiles which spatial distribution is showed in fig.6. Forest cover data of China are from fourth inventory in 1990s (fig.7).

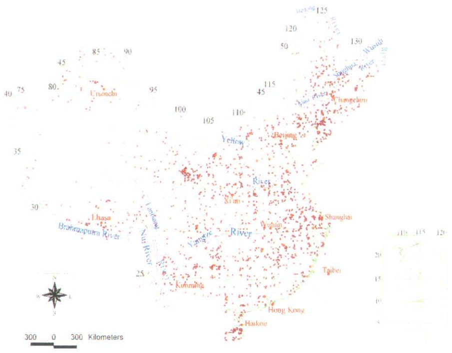


Fig.6 Distribution of soil profiles in China

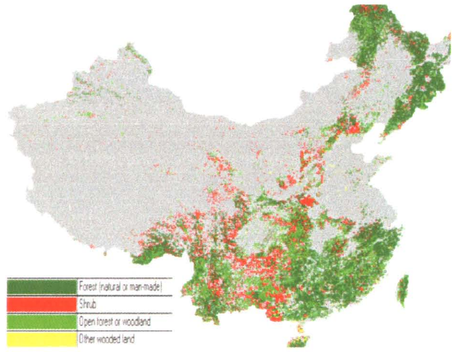


Fig.7 Forest cover from inventory in China

3.2 Assessment of carbon stock

According to the forth forest inventory data in 1990s, forest ecosystems in China which area is 108 Mha contain carbon *21.37 PgC* , where, carbon contained in live trees is *6.62 PgC* (31%), in understory is *0.26 PgC* (1.2%), in forest floor is *0.82 PgC* (3.8%), in forest soils is13.68 *PgC* (64%).

Based on 2473 soil profiles of second national soil general survey in 1980s, soil organic carbon stock has been assessed (fig.8). The soil organic carbon density is high in northeast area (about northern of 45°N), is middle in area of 90°E-122°E, 18°N -32°N) and area of 110°E -120°E, 40°N -45°N, and is low in other areas.

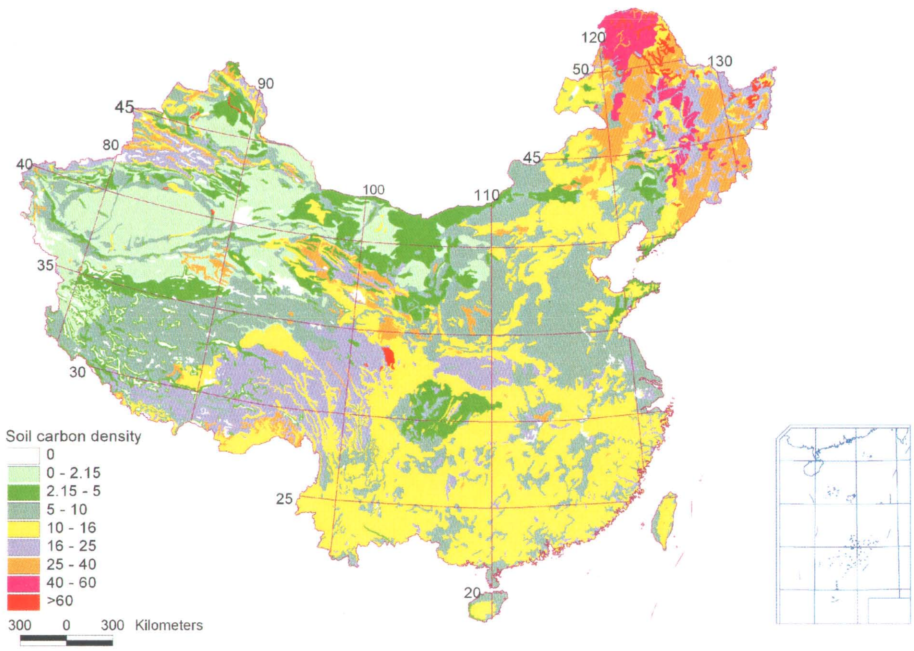


Fig.8 Spatial distribution of soil organic carbon in China

3.3 Study of Land Use /Cover Change by Remote Sensing

Based on Landsat images, land use maps in 1990, 1995, 2000 year have been made, and land use percentage of dominate types which are paddy land, dry farming land, wood land, grassland, residential area, water area, and total cropland with 1×1km resolution in 1990, 1995, 2000 year have been calculated. These data show paddy land is mainly distributed on south of China, dry farming land is mainly distributed on middle part and north of China, grassland is mainly distributed on west of China, woodland is mainly distributed on south and northeast of China. According to land use maps and land use percentage maps of dominate types in 1990, 1995, 2000 year, use change maps, Land-use change maps of predominant types (fig.9), Zoning maps of land-use net change, Conversion maps of land use during 1990-1995, 1995-2000 and 1990-2000 with spatial resolution 1×1km have been made. From net change maps of land use/cover types during 1990-2000 (fig.9), all cities have been expended and urban area is increased, especially in east of China, rural residential area and other built-up have been increased, especially in Jiangshu, Zhejiang, and Anhui provinces, the decreasing area of woodland is larger than increasing area, the grassland area in north of China is decreasing, and in south of China is increasing.

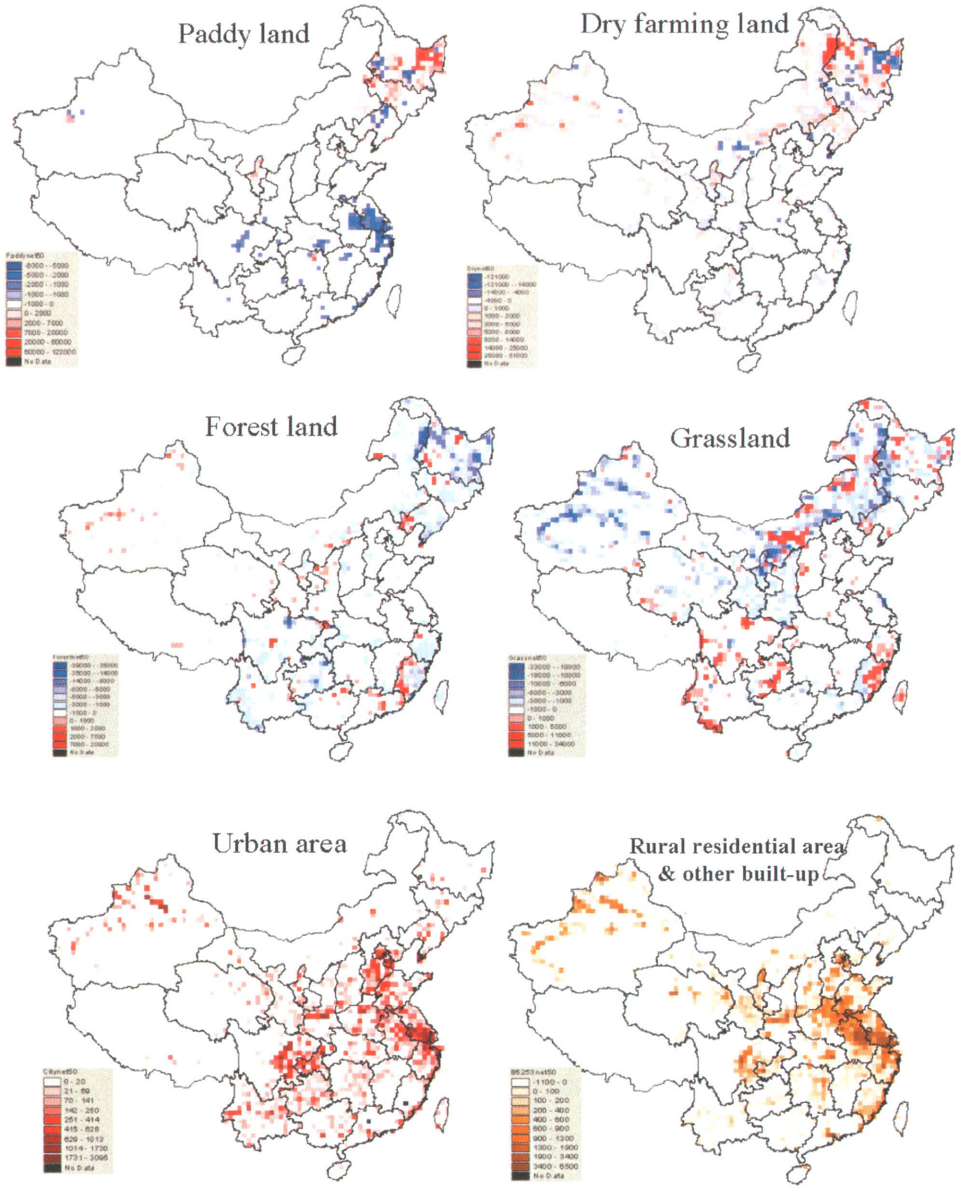


Fig.9 Net change of land use/cover types during 1990-2000

3.4 Simulation of Terrestrial Ecosystem Carbon Cycle by Numerical Models

3.4.1 Estimate NPP, HR, and NET with CEVSA and GLO-PEM

Cao M. et. al (2003) used a process-based biogeochemical model CEVSA (Carbon Exchange in the Vegetation-Soil-Atmosphere System), and a remote sensing- based production GLO-PEM (GLObal Production Efficiency Model) to estimate interannual variations in net primary productivity (NPP), soil heterotrophic respiration (HR), and net ecosystem productivity (NEP) caused by climate and atmospheric carbon dioxide increase from 1981 to 1998 in China.

CEVSA model (Cao & Woodward 1998a,b) includes 4 modules (fig.10): a biophysical module calculating canopy conductance, evapotranspiration and soil moisture; a plant growth module describing photosynthesis, respiration, carbon allocation among plant organs, and litter production; a biogeochemical module simulating the transformation and decomposition of organic materials and nitrogen inputs and outputs in soils; and a vegetation module determining vegetation distribution and composition.

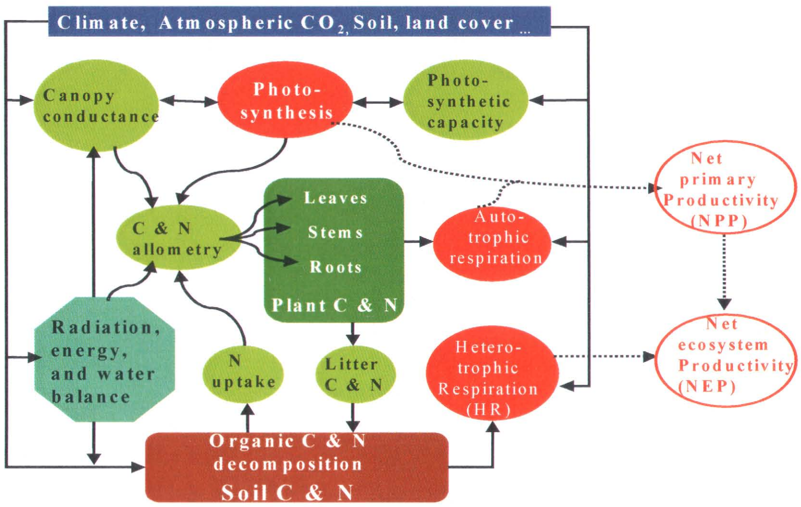


Fig.10 Carbon exchanges in the vegetation-soil-atmosphere systems (Cao & Woodward 1998)

CEVSA model was run with observation-based data of climate, atmosphere CO_2, soil properties, vegetation distribution at a spatial resolution of 0.5°and a time-step of one month, and to estimate NPP, HR, and NET.

GLO-PEM was also used to estimate NPP, which use data almost entirely from satellite observation, including both the normalized difference vegetation index (NDVI) and meteorological variables, therefore provides an independent estimate to evaluate the results of CEVSA (Cao et. al 2003). The remote sensing-based GLO-PEM (Prince, et. al. 1995, Goetz et. al, 2000, Cao et. al 2003) consists of linked components that describe processes of canopy radiation absorption, utilization, autotrophic respiration, and the regulation of these processes by environmental factors such as temperature, water vapor pressure deficit, and soil moisture.

The results of model simulation (Cao et. al 2003) show that China's terrestrial NPP varied between 2.86 and 3.37GtCyr^{-1} with a growth rate of 0.32%$year^{-1}$ and HR varied 2.89 and 3.21 GtCyr^{-1} with a growth rate of 0.40% $year^{-1}$ in the period 1981-1998. The increases in HR were related mainly to climate warming, the increases in NPP were attributed to increases in precipitation and atmospheric CO^2 concentration. NEP varied between -0.32 and 0.25GtCyr^{-1} with a mean value 0.07GtCyr^{-1}, leading to carbon accumulation of 0.79Gt in vegetation and 0.43Gt in soils during the period.

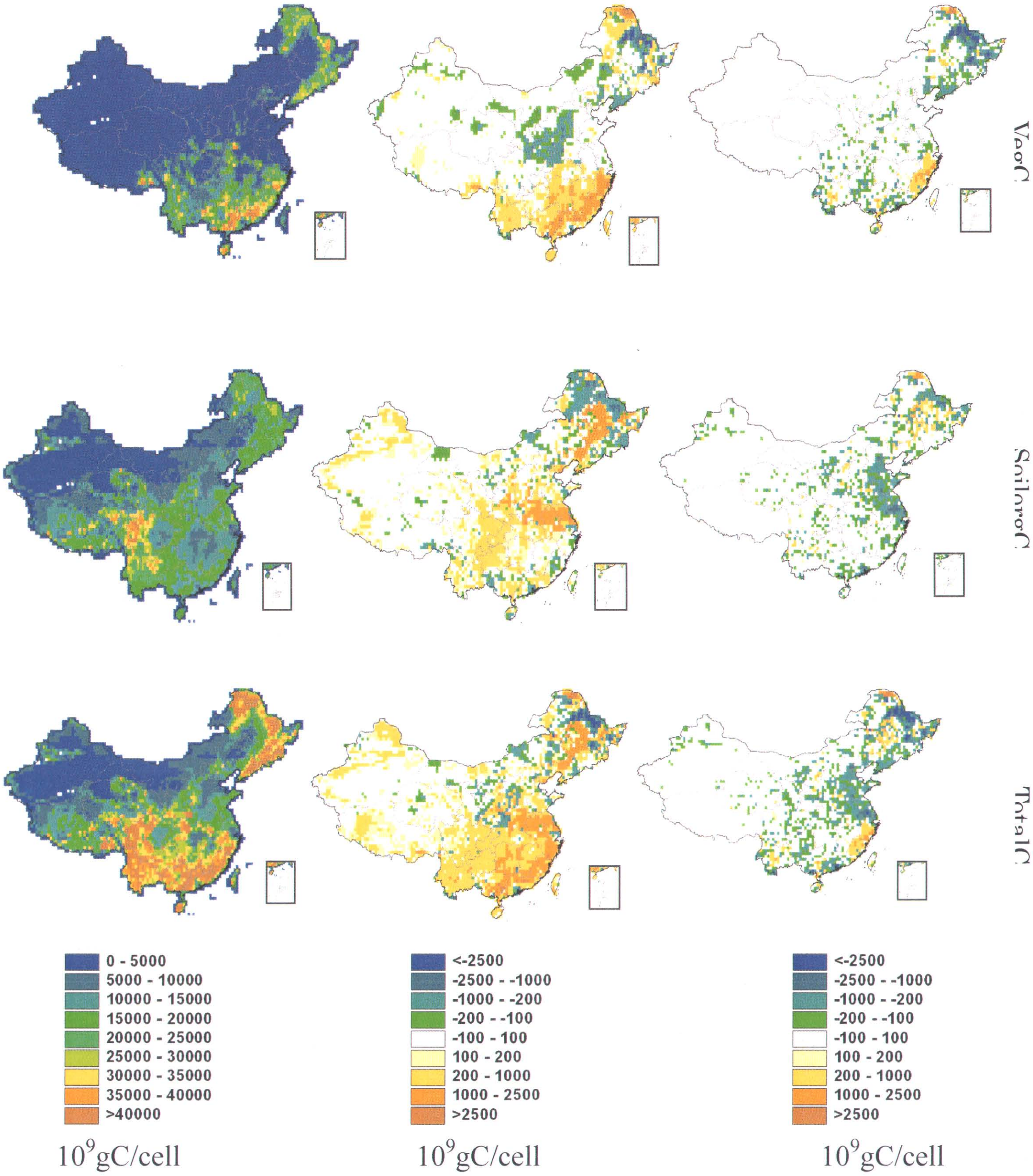
3.4.2 Estimate Carbon Storage and NPP by TEM

The Terrestrial Ecosystem Model (TEM) [1]is a process-based ecosystem model that describes carbon and nitrogen dynamics of plants and soils for terrestrial ecosystems of the globe. The TEM uses spatially referenced information on climate, elevation, soils, vegetation and water availability as well as soil- and vegetation-specific parameters to make monthly estimates of important carbon and nitrogen fluxes and pool sizes of terrestrial ecosystems. The TEM operates on a monthly time step and at a 0.5 degrees latitude/longitude spatial resolution.

Vegetation carbon storage/change, soil organic carbon storage/change, and total carbon storage/change of terrestrial ecosystem in China were simulated by TEM to assess the concurrent effects of increasing atmospheric CO2, climate variability, and land use change during 1980-2000 (Tian et al., 2003). Vegetation carbon storage/change, soil organic carbon storage/change, and total carbon storage/change of terrestrial ecosystem in China, which respectively due to increasing atmospheric CO2, climate variability, and land use change, were also simulated by TEM during 1980-2000 (Tian et al., 2003).

Fig.10 shows that vegetation carbon storage in southeast and northeast of China are higher than other areas, soil organic carbon storage in southwest of China is higher than other areas, and total carbon storage of terrestrial ecosystem in south and northeast of China are higher than other areas in 2000 year. LUCC alone has led to a loss of carbon, however increasing carbon dioxide concentration and climate variability have added carbon to terrestrial ecosystem to compensate for the losses due to land-use change during 1999-2000.

[1] The Terrestrial Ecosystem Model, http://www.mbl.edu/eco42



C storage in 2000 C storage change during 1990-2000 C storage change due to LUCC

Fig.10 Carbon storage simulated by TEM in China

4. Conclusion

The natural and human factors that influence terrestrial carbon cycle in China are complicated. In the terrestrial carbon cycle research, the important objectives include: to develop geo-informatics methodology, to build integrated database of terrestrial carbon cycle, to combine ground observation data and remote sensing reverse data by scaling up and scaling down, to understand the spatial-temporal patterns of carbon distribution at national level, to identify the impacts on terrestrial carbon cycle by both land use change and global climate change, to solve scientific questions involved in the implementation of the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, and to provide scientific evidences for relative environmental decision making in China. In order to achieve above objectives, it is necessary to apply geo-informatics methodology into carbon cycle research in China.

Although some progresses in LUCC and terrestrial carbon cycle research in China has been made in recent ten years, there still some scientific research works need to be done, including:

Model parameterization and calibration by Chinese terrestrial ecosystems, linking model results with field observation and remote sensing detection, combining more detail mechanisms of carbon processes due to land-use change in the model, and more long-term historical land-use data should be introduced into running model, etc.

Reference

Canadell J., 2001, Land Use Change and the Terrestrial Carbon Cycle in Asia, http://www.gcte.org

Cao M., Prince S., Li K., et. al, 2003, Response of terrestrial carbon uptake to climate interannual variability in China. Global Change Biology, 9:536-546.

Cao M., Woodward F. I., 1998a. Dynamic responses of terrestrial carbon cycling to global climate change. Nature, 393, 249-252.

Cao M., Woodward F. I., 1998b. Net primary and ecosystem production and carbon stocks to climatic change. Global Change Biology, 4, 184-198.

Goetz S. J., Prince S. D., Small J. et. al, 2000, Interannual variability of global terrestrial primary production: reduction of a model driven with satellite observations. Journal of Geographical Research, 105, 20077-20091.

Houghton, R.A., and D.L. Skole. 1993. "Carbon." In The Earth as Transformed by Human Action, B. L. Turner II, W. C. Clark, R. W. Kates, J. F. Richards, J. T. Mathews, and W. B. Meyer (eds). New York: Cambridge University Press, pp. 393-408.

Liu J., Yu G., Wang S., Yue T., Gao Z., 2003. A Method of Geo-Information Science for Studying Carbon Cycle and Its Mechanism of Terrestrial Ecosystems, Geographical Research (In Chinese), 22(4):397-405.

MYneni R.B., Keeling C. D., Tucker C. J., et al., 1997, Increased plant growth in the northern high latitudes from 1988-1991. Nature, 386:698-703.

Prince S. D. Goward S. N., 1995, Global primary production: a remote sensing approach, Journal of Biogeography, 22, 815-835.

Schinder D. W., 1999, The mysterious missing sink, Nature, 398:105-107.

Sherbinin A. D., 2002, A Guide to Land-Use and Land-Cover Change (LUCC), http://sedac.ciesin.columbia.edu/tg.

Tian H, Melillo JM, Kicklighter DW, Pan S, Liu J, McGuire AD, Moore III B.(*2003*) Regional carbon dynamics in monsoon Asia and its implications for the global carbon cycle. *Global and Planetary Change* ***37***, 201-217.