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Spatiotemporal characteristics, patterns, and causes of land-use changes in China since the late 1980s

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Abstract: Land-use/land-cover changes (LUCCs) have links to both human and nature interactions. China's Land-Use/cover Datasets (CLUDs) were updated regularly at 5-year intervals from the late 1980s to 2010, with standard procedures based on Landsat TM\ETM+ images. A land-use dynamic regionalization method was proposed to analyze major land-use conversions. The spatiotemporal characteristics, differences, and causes of land-use changes at a national scale were then examined. The main findings are summarized as follows.

Land-use changes (LUCs) across China indicated a significant variation in spatial and temporal characteristics in the last 20 years (1990–2010). The area of cropland change decreased in the south and increased in the north, but the total area remained almost unchanged. The reclaimed cropland was shifted from the northeast to the northwest. The built-up lands expanded rapidly, were mainly distributed in the east, and gradually spread out to central and western China. Woodland decreased first, and then increased, but desert area was the opposite. Grassland continued decreasing. Different spatial patterns of LUC in China were found between the late 20th century and the early 21st century. The original 13 LUC zones were replaced by 15 units with changes of boundaries in some zones. The main spatial characteristics of these changes included (1) an accelerated expansion of built-up land in the

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Huang-Huai-Hai region, the southeastern coastal areas, the midstream area of the Yangtze River, and the Sichuan Basin; (2) shifted land reclamation in the north from northeast China and eastern Inner Mongolia to the oasis agricultural areas in northwest China; (3) continuous transformation from rain-fed farmlands in northeast China to paddy fields; and (4) effectiveness of the “Grain for Green” project in the southern agricultural–pastoral ecotones of Inner Mongolia, the Loess Plateau, and southwestern mountainous areas. In the last two decades, although climate change in the north affected the change in cropland, policy regulation and economic driving forces were still the primary causes of LUC across China. During the first decade of the 21st century, the anthropogenic factors that drove variations in land-use patterns have shifted the emphasis from one-way land development to both development and conservation.

The “dynamic regionalization method” was used to analyze changes in the spatial patterns of zoning boundaries, the internal characteristics of zones, and the growth and decrease of units. The results revealed “the pattern of the change process,” namely the process of LUC and regional differences in characteristics at different stages. The growth and decrease of zones during this dynamic LUC zoning, variations in unit boundaries, and the characteristics of change intensities between the former and latter decades were examined. The patterns of alternative transformation between the “pattern” and “process” of land use and the causes for changes in different types and different regions of land use were explored.

Keywords: satellite remote sensing; land-use change; characteristics; spatial pattern; China

1 Introduction

Land-use/land-cover change (LUCC) is an important theme in the study field of global climate change and global environmental change (Mooney *et al*., 2013; Sterling *et al*., 2012). LUCC is the most direct manifestation of the effects of human activity on the natural ecosystem of the earth’s land surface, as well as a bond between human social and economic activities and natural ecological processes (Mooney *et al*., 2013). The LUCC process is closely related to material cycles and life processes on the land surface (Tian *et al*., 2012); thus, it has a direct impact on biosphere–atmosphere interactions, biodiversity, surface radioactive forcing, biogeochemical cycles, and the sustainable utilization of environmental resources (Meyfroidt *et al*., 2013; Mooney *et al*., 2013; Sterling *et al*., 2012; Tian *et al*., 2012). In 1993, two major international organizations, the International Geosphere and Biosphere Programme (IGBP) and the International Human Dimensions Programme (IHDP) on Global Change, launched a joint program, called the Land Use/Land Cover Change (LUCC) Research Program, as the core project regarding global-change research (Lambin *et al*., 1995; Turner *et al*., 1995). Furthermore, the Global Land Project (GLP) was launched in 2005 with emphasis on comprehensive integration and simulation studies of human–environment coupling in the terrestrial system. Thus, monitoring and simulation of the dynamic LUCC process, with the human–environment coupling system as the core, gradually became the research focus (GLP, 2005; Herrick *et al*., 2013; McMahon *et al*., 2005; Rindfuss *et al*., 2004).

To ensure the sustainable development of national resource environments, it is strategically important to perform high-precision remote-sensing monitoring of nationwide LUCC over a long period of time to identify spatial patterns of land-use changes (LUCs) across China (Herrick *et al*., 2013; Jin *et al*., 2013; Liu, 1996; Liu *et al*., 2003a; Liu *et al*., 2003b; Liu *et al*., 2010; Kuang *et al*., 2013). To reveal and understand the spatiotemporal characteristics of LUC in China, a national-scale LUC database was established in China in the early 1990s, using high-resolution satellite remote-sensing images. This nationwide land-use database has been updated every 5 years using the same (satellite remote-sensing) information sources and the same data-analysis methods (Liu, 1996; Liu *et al*., 2003a; Liu *et al*., 2003b; Liu *et al*., 2010). Up to the present time, a 1:100,000-scale national LUC vector database and a 1-km gridded database of component classifiers have been completed for five stages: the late 1980s, 1995, 2000, 2005, and 2010 (Liu *et al*., 2003a; Liu *et al*., 2003b; Liu *et al*., 2010). Based on these databases, the basic spatiotemporal characteristics of LUC in China were analyzed for the two decades following the early 1990s. The similarities and differences in China's LUC patterns between the last decade of the 20th century (1990–2000) and the first decade of the 21st century (2000–2010) were compared to reveal the dominant features of LUC across China over the past two decades and their main driving forces, thereby providing valuable scientific information for LUCC studies and related fields.

2 Datasets and methods

2.1 Data description

China's Land-Use/cover Datasets (CLUDs) were developed in the late 1980s, 1995, 2000, 2005, and 2010 (Liu *et al*., 2003a; Liu *et al*., 2003b; Liu *et al*., 2010). We continued to use the human–computer interactive interpretation method of remotely sensed LUC information to interpret the 2010 Landsat TM digital images covering China, based on the 2005 database of national land use, and to construct the 1:100,000-scale national land-use database for 2010. For areas not covered by Landsat TM data or covered with poor quality data, supplemental data from the CCD multispectral data from the Huanjing-1 satellite (HJ-1) were used. Comparison of the remote-sensing images in 2005 and 2010 revealed and delineated changing areas within the land-use data of 2005. The changes were labeled with attribute codes, which can simultaneously reflect the land-use type of the dynamic plots during the two stages of 2005 and 2010. We have carried out uniform quality control and integration checking for each dataset to ensure high-quality and consistent interpretation (Zhang *et al*., 2012). Before developing each dataset, nationwide field surveys were conducted, mostly in the fall for northern China and in the spring for southern China. Land-use situations in all provinces, except for Taiwan, were surveyed to obtain a large number of field-investigation records and photographs. The field survey materials and field records were randomly chosen at a 10% ratio to the number of counties to assess the accuracy of the database. The accuracy of the six classes of land use was above 94.3%, and the overall accuracy of the 25 subclasses was above 91.2%, which can meet the requirement of the user mapping accuracy on the 1:100,000 scale (Liu *et al*., 2003a; Liu *et al*., 2003b; Liu *et al*., 2010).

After updating the national land-use map of 2010, provincial classified areas were aggregated, and the areas of six classes and 25 subclasses of land use were calculated, including provincial and national cropland, woodland, grassland, water body, built-up land, and unused land, through graphics division and adjusted-area calculations (Liu *et al*., 2010) (Figure 1).

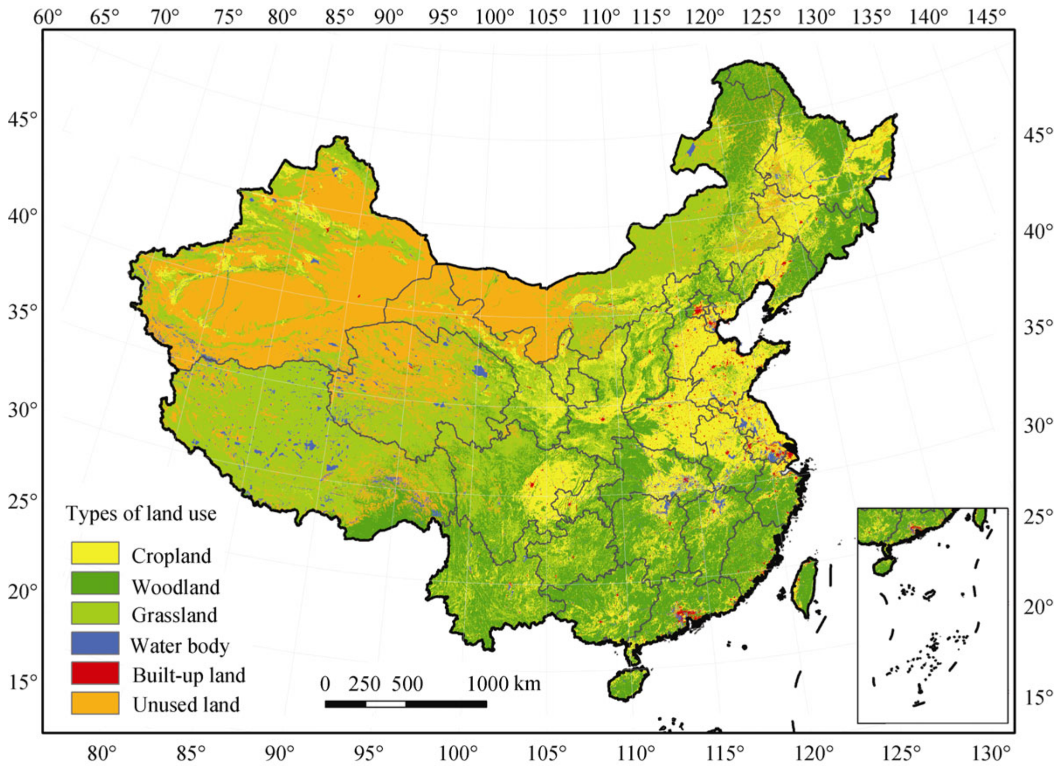

Figure 1 Acquired land-use map across China in 2010

A spatiotemporal information platform was constructed to reflect the LUC in China at the turn of the 21st century based on the five land-use databases of the late 1980s, 1995, 2000, 2005, and 2010 (Liu *et al.*, 2003a; Liu *et al.*, 2003b; Liu *et al.*, 2010). Using this platform, we analyzed areas and regional differences, and causes of changes in various land-use types for 5- or 10-year intervals between 1980 and 2010, and we reached some conclusions regarding the spatiotemporal characteristics and changing patterns of LUC at both national and regional scales.

2.2 Dynamic degree, mapping, and regionalization of land-use changes

The 1-km gridded land use and its dynamic data were used as the inputs for dynamic land-use zoning, which can eliminate the scale effect of spatial data while ensuring spatial and area accuracy. The map was divided into a vector net with 1-km cells. The land use and land-use conversions in each cell were counted. Each 1-km gridded cell includes such information as the percentage of the area of various land-use types and different land-use conversions (Figure 2).

The land-use dynamic degree map can reflect regional differences in LUC rates. The land-use dynamic degree is calculated as follows:

$$S = \left\{ \sum_{ij}^{n} (\Delta S_{i-j} / S_i) \right\} \times (1/t) \times 100\%$$

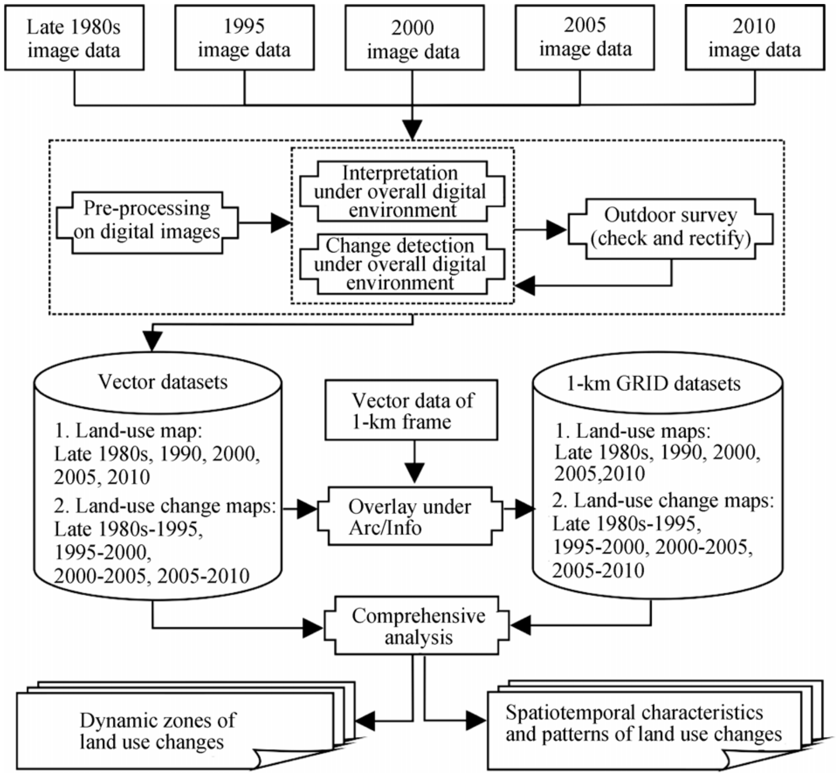

Figure 2 The flowchart of generated grid datasets on dominated land-use change types

where S_i is the area of land type i in the beginning of the period, ΔS_{i-j} is the total area of land type i converted into other types, t is the study period, and S is the land-use dynamic degree in the period of t. The model is mainly used for land-use change measurement of a single type of land.

Nationwide dynamic zoning of land use was carried out with a spatial grid of 10 km×10 km, based on the spatial differentiation pattern of land-use dynamic degree and transitions between various land-use types in 1-km gridded plots. Taking comprehensive physical regionalization and agricultural zoning of China as a reference (Huang, 1959; Zhou, 1993), we divided land-use dynamic zones in which the land-use conversion types are homogeneous. The main principles of dynamic zoning were as follows: (1) land-use conversions are consistent in the same regionalization; (2) the succession of land-use change for neighboring regions should be considered, including topographical and macroeconomic differences; (3) land-use change and natural/socioeconomic conditions should be consistent in a certain region (Liu *et al*., 2003a; Liu *et al*., 2010). Finally, zones of land-use dynamics that reflect the LUC features were formed for the two decades before and after the turn of the 21st century. For the two periods from the late 1980s to 2000 and from 2000 to 2010, there are 13 and 15 dynamic zones of land use, respectively (see Figures 3 and 4).

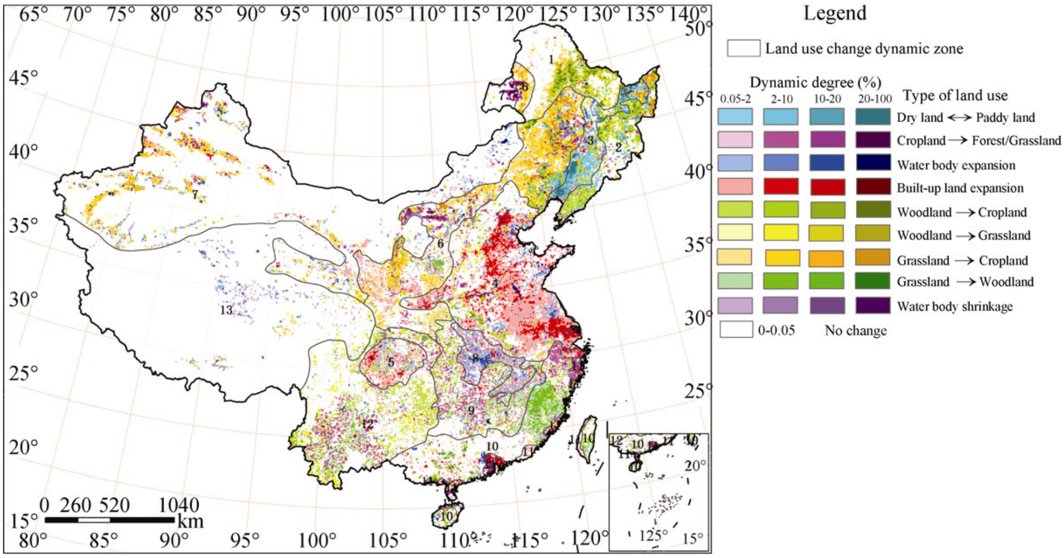

Figure 3 Spatial regionalization and distribution of national land-use change from the late 1980s to 2000

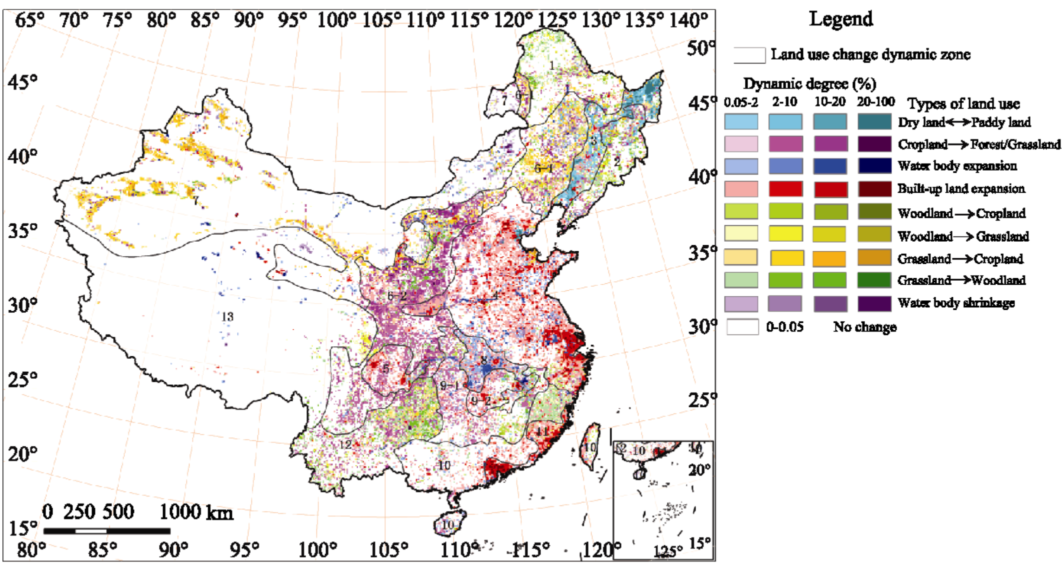

Figure 4 Spatial regionalization and distribution of national land-use change from 2000 to 2010

3 Results and analysis

3.1 Characteristics of land-use changes and regional differences

From the late 1980s to 2010, LUC in China indicated the significant characteristics of spatiotemporal differences:

(1) The basic characteristics of changes in cropland can be summarized as follows. Cropland area decreased in the south and increased in the north, and the total area remained basically unchanged. The focus of reclaimed cropland gradually shifted from the northeast to

the northwest. Within the two decades, cropland increased by 1.82×10^6 hm^2, of which dry cropland increased by 2.99×10^6 hm^2, while paddy fields decreased by 1.17×10^6 hm^2. Before 2000, the cropland increased by 2.83×10^6 hm^2, with reclaimed cropland concentrated mainly in the farming–forestry ecotones of northeast, north, and northwest China. The decreased cropland was mainly used for built-up land in southeastern coastal cities. After 2000, the cropland decreased by 1.02×10^6 hm^2. The reclaimed cropland was mainly in northwest China, and the expansion of built-up land and the "Grain for Green" project in ecologically fragile areas of central and western China exploited a large amount of cropland.

(2) The basic characteristics of the changes in built-up land can be summarized as follows. Accelerated expansion was found in the east, and this situation was spread to the central and western regions. Within the two decades, built-up land increased by 5.52×10^6 hm^2, which was mainly distributed in the flat-lying, rapidly developed and densely populated Huang-Huai-Hai Plain, the Yangtze River Delta, the Pearl River Delta, and the Sichuan Basin. Approximately 3.18×10^6 hm^2 of cropland were used for construction. In particular, the built-up land increased by 1.76×10^6 hm^2 before 2000. The built-up land expansion accelerated after 2000 and increased by 3.76×10^6 hm^2. Thus, the growth rate in the second decade was 2.14 times that of the first decade.

(3) The main characteristics of the other LUCs can be summarized as follows. Woodland first decreased and then increased; desert first increased and then decreased; grassland continued to decrease.

During the two decades, woodland decreased by 8.52×10^5 hm^2. Before 2000, decreased woodland (about 10.89×10^5 hm^2) was mainly concentrated in the major forests of northeast China due to the harvesting of closed forests and the expansion of cropland into woodland. After 2000, due to the implementation of the six key forestry projects and, in particular, the "Grain for Green" Project, the woodland increased by 2.37×10^5 hm^2, mainly in the Loess Plateau and the southern hilly areas.

Meanwhile, the grassland decreased by 5.32×10^6 hm^2. In particular, grassland was reduced by 3.44×10^6 hm^2 before 2000, mainly due to the reclamation of grassland for cropland in northeast, north, and northwest China, as well as the reforestation of grassland in the south. After 2000, grassland decreased by 1.89×10^6 hm^2, mainly due to the reclamation of grassland in northwest China and the regeneration of grassland in south China.

During the same period, unused lands decreased by 1.15×10^6 hm^2, a change concentrated in Xinjiang and Heilongjiang, mainly due to the reclamation of unused lands. Meanwhile, grassland degradation in Inner Mongolia resulted in an increase of unused land. In particular, unused lands decreased by 3.75×10^5 hm^2 before 2000 and decreased by 7.79×10^5 hm^2 after 2000.

3.2 Spatial patterns and variations of land-use changes across China during the two decades before and after 2000

In the early 21st century, we analyzed the characteristics of the spatial and temporal patterns of LUC across China from the late 1980s to 2000 (Liu *et al*., 2003a; Liu *et al*., 2003b; Liu *et al*., 2010), and we thought that the characteristics of the 10-year LUC pattern were manifested by different characteristics of change for the 13 major LUC zones (Figure 3). The zones are as follows: 1) Da and Xiao Hinggan mountains in northeast China—woodland/grassland to cropland conversion zone; 2) the eastern part of northeast China—woodland/grassland to cropland conversion zone; 3) northeast China Plain—dry land and paddy field bidirectional conversion zone; 4) Huang-Huai-Hai Plain, Yangtze River Delta—cropland to built-up conversion zone; 5) Sichuan Basin—cropland to built-up area conversion zone; 6) northern China and the Loess Plateau—grassland to cropland bidirectional conversion zone; 7) northwest China—reclamation and abandonment of cropland coexisting zone; 8) central China Plain—water-body fluctuation and built-up areas expansion coexisting zone; 9) southeast hilly areas—woodland to cropland conversion zone; 10) coastal southeast China—grassland to planted forest bidirectional conversion zone; 11) coastal southeast China—cropland to built-up conversion zone; 12) southwest China—grassland to woodland, cropland to woodland/grassland conversion zone; and 13) Qinghai-Tibet Plateau—no change or little change zone (Liu *et al*., 2003a).

The new characteristics of LUC patterns in China between the two decades (before and after the turn of the 21st century) can be obtained by comparing the LUC data from 2000 to 2010 and from the late 1980s to 2000 (Figure 4). The predominant manifestations of these new characteristics are as follows: the accelerated expansion of built-up land in the Huang-Huai-Hai region, southeastern coastal areas, and the Sichuan Basin, mainly occupied high-quality cropland resources; cultivated reclamation in the north, which shifted from northeast China and the central and eastern parts of Inner Mongolia to the oasis agricultural area in northwest China; the continuous transition of dry cropland to paddy fields; the dominating "Grain for Green" project and significant grassland reforestation in southern agricultural–pastoral ecotones of Inner Mongolia, the Loess Plateau, and southwestern mountainous areas; and the small change in land use on the Tibetan Plateau, which is mainly manifested by the region's increased local water area.

Changes in zones and their boundaries mainly occurred in the following six areas: 1) northeast China Plain—dry land and paddy field bidirectional conversion zone, where the zoning boundary of the eastern Sanjiang Plain was significantly expanded; 2) northern China and the Loess Plateau—grassland to cropland bidirectional conversion zone, where zone 6 was divided into two subunits with different features in the latter decade and where the northern and central parts remained a grassland to cropland conversion zone, while the western part changed into a "Grain for Green" zone and the boundary of the zoning unit was significantly extended into Yunnan; 3) southeast hilly areas—woodland to cropland conversion zone, which was divided into two subunits with different features in the latter decade by separating the cropland–urban land conversion zone in central China from the original zoning unit; 4) coastal southeast China—grassland to planted forest bidirectional conversion zone, where the zoning boundary of coastal areas significantly shrunk due to the intrusion of urbanized areas; 5) coastal southeast China—cropland to built-up conversion zone, where the zoning boundary of coastal areas in Fujian and Guangdong expanded; and 6) southwest China—grassland to woodland, cropland to woodland/grassland conversion zone, where the northwestern part of the original zoning unit merged into the aforementioned "Grain for Green" zone.

The regional differences and characteristic zoning-type transitions of the changes in land-use patterns during the two decades are shown in Tables 1–3.

Table 1 Change area of dominated land-change types in the land-use dynamic zones across China from the late 1980s to 2000 (10^4 hm^2)

Dynamic zone	Ⅰ Dry land–paddy land	Ⅱ Cropland–forest/grassland	Ⅲ Other land–water body	Ⅳ Other land–built-up land	Ⅴ Woodland–cropland	Ⅵ Woodland–grassland	Ⅶ Grassland–cropland	Ⅷ Grassland–woodland	Ⅸ Water body–other land
1	0.82	1.65	1.24	0.63	66.39	11.18	24.29	1.62	0.17
2	14.56	4.30	1.44	2.21	39.95	2.44	27.52	7.56	2.14
3	110.90	2.40	2.13	3.47	14.61	1.02	8.85	1.16	7.14
4	6.16	6.12	22.79	110.40	6.33	6.83	13.01	6.67	14.21
5	1.11	0.73	0.23	8.26	1.09	0.37	0.13	0.21	0.17
6	34.82	46.44	6.93	6.43	21.04	12.52	203.31	25.93	18.52
7	1.03	27.12	19.68	8.55	1.57	3.21	62.82	4.11	6.49
8	0.00	0.97	7.75	4.84	0.50	0.36	0.03	0.74	4.48
9	0.00	3.73	3.53	3.39	3.24	2.28	0.30	4.15	0.66
10	0.53	6.81	4.82	6.17	7.74	7.85	0.90	34.54	1.02
11	0.35	4.49	5.78	18.58	0.95	0.27	0.11	0.77	2.57
12	1.06	11.01	1.93	4.38	11.04	31.28	3.70	15.82	0.28
13	0.00	0.03	2.57	0.30	0.28	1.52	0.79	1.44	4.54
All	171.35	115.80	80.81	177.63	174.73	81.14	345.76	104.73	62.40

Table 2 Change area of dominated land-change types in the land-use dynamic zones across China from 2000 to 2010 (10^4 hm^2)

Dynamic zone	Ⅰ Dry land–paddy land	Ⅱ Cropland–forest/grassland	Ⅲ Other land–water body	Ⅳ Other land–built-up land	Ⅴ Woodland–cropland	Ⅵ Woodland–grassland	Ⅶ Grassland–cropland	Ⅷ Grassland–woodland	Ⅸ Water body–other land
1	1.84	3.95	3.24	1.37	2.37	8.35	5.57	8.93	0.54
2	9.62	6.29	1.22	2.43	6.38	4.77	3.91	6.04	0.61
3	105.28	3.24	2.32	7.58	2.11	0.82	10.05	0.92	1.53
4	11.01	10.52	31.72	188.29	1.97	1.52	4.53	1.13	21.10
5	0.02	3.16	1.15	19.69	0.01	0.05	0.06	1.29	0.14
6-1	8.21	14.34	3.56	6.04	5.10	4.57	30.57	3.24	8.03
6-2	0.66	61.59	10.10	19.26	1.72	3.22	19.05	19.07	7.02
7	0.63	14.98	18.01	18.20	8.73	2.06	116.26	3.89	27.93
8	0.09	1.05	17.11	13.88	0.70	0.22	0.11	0.89	5.70
9-1	0.15	2.70	3.48	7.60	3.06	0.49	0.50	2.50	0.50
9-2	0.29	0.31	0.76	11.80	0.35	0.10	0.02	0.97	1.39
10	0.22	2.68	4.07	16.53	1.43	2.99	0.13	3.54	0.88
11	0.01	0.35	4.03	49.27	0.29	2.07	0.06	0.92	4.52
12	0.09	15.31	3.52	13.32	3.31	6.98	5.96	34.19	0.20
13	0.00	1.89	10.29	2.99	0.03	3.63	0.60	1.27	3.20
All	138.12	142.36	114.55	378.24	37.54	41.85	197.38	88.79	83.27

Table 3 Regional characteristics of land-use change across China in the two periods (late 1980s–2000 and 2000–2010)

Area code	Name	Land-use features from late 1980s to 2000 (Liu *et al*., 2003b)	Land-use features from 2000 to 2010	Variations in zones between the two periods
1	Da and Xiao Hinggan mountains. in northeast China—woodland/ grassland to cropland conversion zone.	The main features were land reclamation and forest harvesting, with the former as the main source of reclaimed cropland and the latter as the secondary source.	The main conversion type is woodland to grassland, followed by grassland to cropland. Grassland decreased by 5.92×10^4 hm^2, of which 8.93×10^4 hm^2 were converted to woodland and 5.57×10^4 hm^2 were converted to reclaimed cropland. Meanwhile, the forest harvesting-induced grassland was 8.35×10^4 hm^2.	No change.
2	The eastern part of northeast China—woodland/grassland to cropland conversion zone.	Woodland/grassland reclamation dominated.	Grassland decreased by 3.79×10^4 hm^2, cropland increased by 2.31×10^4 hm^2, the grassland-cropland transition area was 15.58×10^4 hm^2, and the woodland–grassland transition area was 10.81×10^4 hm^2.	No change.
3	Northeast China Plain—dry land and paddy field bidirectional conversion zone.	The main feature was the transition between dry lands and paddy fields, while dry land-to-paddy-field transition dominated.	The main feature was the transition between dry lands and paddy fields, over an area of 105.28×10^4 hm^2, and the dry land-to-paddy-field transition dominated. Cropland increased by 6.93×10^4 hm^2, of which 10.05×10^4 hm^2 were reclaimed from grassland.	Expansion of eastern Sanjiang Plain.
4	Huang-Huai-Hai Plain, Yangtze River Delta—cropland to built-up conversion zone.	The large expansion of built-up land into cropland dominated, accounting for 62% of the total built-up land expansion in China.	The large expansion of built-up land into cropland dominated. Built-up land increased by 187.46×10^4 hm^2, of which 84.60% was from converted cropland, accounting for 49.78% of the total built-up land expansion in China. Meanwhile, over 22.65×10^4 hm^2 of cropland was converted to water areas, leading to an increase of 14.76×10^4 hm^2 in water area.	No change.
5	Sichuan Basin— cropland to built-up area conversion zone.	The expansion of built-up land into cropland dominated.	The expansion of built-up land into cropland dominated. Built-up land increased by 19.69×10^4 hm^2, of which 94.61% was from converted cropland, resulting in a decrease of 23.91×10^4 hm^2 in cropland. The "Grain for Green" area was 3.16×10^4 hm^2.	Essentially no change.

(*To be continued*)

(*Continued*)

Area code	Name	Land-use features from late 1980s to 2000 (Liu *et al*., 2003b)	Land-use features from 2000 to 2010	Variations in zones between the two periods
6	Northern China and the Loess Plateau—grassland to cropland bidirectional conversion zone.	Grassland reclamation dominated, especially in the central and western parts of Inner Mongolia, followed by a cropland-to-forest/grassland transition.	*6-1 Central part of northeast China—grassland to cropland conversion zone: grassland reclamation dominated, cropland increased by 31.91×10^4 hm^2, of which 30.57×10^4 hm^2 was reclaimed grassland, accounting for 63.70% of the reclaimed cropland. "Grain for Green" lands followed, with an area of 14.34×10^4 hm^2. *6-2 Western China—cropland returned to woodland and grassland zone: "Grain for Green" dominated with an area of 61.59×10^4 hm^2, resulting in a decrease of 62.30×10^4 hm^2 in cropland and an increase of 19.02×10^4 hm^2, of which 57.11% was from converted cropland.	Zone 6 was divided into two zones with different features in the latter decade. In particular, 6-2 showed significant expansion into the Yunnan province.
7	Northwest China—reclamation and abandonment of cropland coexisting zone.	A large area of grassland was reclaimed, while a small amount of cropland constrained by the fragile ecological environment was abandoned.	The reclamation of a large area of grassland in Xinjiang dominated, with an area of 116.26×10^4 hm^2, resulting in an increase of 116.26×10^4 hm^2 in cropland and a decrease of 107.96×10^4 hm^2 in grassland. In addition, 14.98×10^4 hm^2 of abandoned cropland was converted to forest/grass lands.	No change, whereas more efforts were put into reclamation.
8	Central China Plain—water-body fluctuation and built-up areas expansion coexisting zone.	The area of water body increased significantly, and the built-up land area increased.	Expansion of the water area dominated, with an increase of 17.11×10^4 hm^2. The expansion of built-up land followed, with an increase of 13.83×10^4 hm^2, of which 74.40% was from converted cropland.	Essentially no change.
9	Southeast hilly areas — woodland to cropland conversion zone.	There was significant transition between cropland and forest/grasslands. Meanwhile, there was also transition between woodland and grassland.	*9-1 Southeast hilly areas—woodland to cropland conversion zone: there was significant transition between cropland and forest/grasslands; the forest/grassland–cropland transition area was 6.26×10^4 hm^2, and the woodland–cropland transition dominated; meanwhile, the built-up land increased by 7.50×10^4 hm^2. *9-2 Central China—cropland to built-up area zone: the expansion of built-up land into cropland dominated, with an increase of 11.80×10^4 hm^2, of which 58.9% was from converted cropland.	Zone 9 was divided into two zones with different features.

(*To be continued*)

(*Continued*)

Area code	Name	Land-use features from late 1980s to 2000 (Liu *et al*., 2003b)	Land-use features from 2000 to 2010	Variations in zones between the two periods
10	Coastal southeast China—grassland to planted forest bidirectional conversion zone.	Regeneration of grassland dominated, mainly occurring in the mountainous areas of Fujian.	The transition between closed woodland and other types of woodland dominated, with significant increases in non-wood forest and closed woodland. Built-up land increased by 16.42×10^4 hm^2.	Zoning boundaries of coastal areas decreased due to expanded urbanized areas.
11	Coastal southeast China—cropland to built-up conversion zone.	Built-up land increased, mainly due to cropland.	Built-up land increased by 49.27×10^4 hm^2, of which 61.48% was from converted cropland, resulting in a decrease of 34.84×10^4 hm^2 in cropland.	Zoning boundaries in the coastal areas of Fujian and Guangdong were extended.
12	Southwest China—grassland to woodland, cropland to woodland /grassland conversion zone.	The wood-land-to-grassland transition dominated, followed by the grass-land-to-woodland transition. Meanwhile, there was a large area of transition between cropland and forest/grassland.	The grassland-to-woodland transition dominated, with an area of 34.19×10^4 hm^2, followed by "Grain for Green" lands over an area of 15.31×10^4 hm^2. The grassland area decreased by 29.35×10^4 hm^2, the woodland area increased by 27.47×10^4 hm^2, and the cropland area decreased by 17.84×10^4 hm^2.	The northwestern part of the original zones merged into zone 6-2.
13	Qinghai-Tibet Plateau—no change or little change zone.	There was a small degree of change in land-use type, and the water-body area slightly decreased.	The water-body area increased by 8.31×10^4 hm^2, the grassland area decreased by 6.04×10^4 hm^2, and the built-up land increased by 2.94×10^4 hm^2.	Essentially no change.

* indicates new dynamic zones of land use in 2000–2010.

4 Causes of land-use changes across China

4.1 Changes in cropland

The expansion of built-up land was the main reason for cropland loss in traditional agricultural areas during the 20 years studied. From the late 1980s to 2000, 45.96% of decreased cropland was used for urban construction, while from 2000 to 2010, 55.4% of decreased cropland was used for urban construction. Our analysis shows that, with the acceleration of urbanization in China, the average annual area of cropland used for construction has increased drastically from about 1.3 million ha in 1990–2000 to more than 2 million ha in 2000–2010, further highlighting the conflict between urbanization and cropland conservation.

The use of cropland for ecological construction is the main reason for cropland loss in ecologically fragile areas. From 1990 to 2010, the forest/grass-based vegetation restoration project, especially the "Grain for Green" project since 2000, was one of the main reasons that cropland decreased. On average, the use of cropland for ecological construction accounted for 34.54% of cropland decrease, second only to the percentage used for urban construction.

Continued warming in northern China has led to increasing annual accumulated temperatures, providing relatively favorable climatic conditions for reclaiming large areas of forest and grassland in the arid areas of northern China. Since the 1990s, the population of China has continued to increase, and living standards have risen, raising consumer demand for food. Consequently, a conflict between food supply and demand has emerged due to limited cropland resources. Encouraged by local governments and driven by economic interest, large areas of grassland in northern China were reclaimed. However, due to arid climates and inadequate cropland infrastructures, the reclaimed cropland was more sensitive to climate changes and more unstable with regard to agricultural production, resulting in coexistent forest/grassland reclamation and cropland abandoned to agricultural–pastoral ecotones. In northeast China, driven by comparative advantages and facilitated by the introduction of cold-tolerant rice varieties and irrigation facilities, large areas of dry lands were converted to paddy rice lands. At the same time, the paddy fields in some areas were also converted to dry lands due to the adjustment of plantation structure(s). The increasing transition area between dry lands and paddy lands was also a significant regional feature of cropland change in northeast China over the past two decades.

4.2 Changes in built-up land

Since China's Reform and Opening up, with the implementation of policies of the socialistic market economy system, levels of coastal urban development have been increasing. In particular, the national implementation of a series of regional development strategies in the 21st century, including the Western Development, the Old Northeast Industrial Bases Revitalization, and the Rise of Central China Plan, has promoted rapid social and economic development and has substantially impacted dynamic changes in land use. Driven and encouraged by national macro policies, increasing investments in fixed assets and construction of large-scale urban development zones have promoted the growth of built-up land areas. According to the *China Statistical Yearbook*, the total population of China grew from 1.075 billion in 1986 to 1.341 billion in 2010; GDP increased from 1,030 to 40,120 billion RMB Yuan (adjusted for price changes), an increase of 9.16 times; the proportion of urban residents increased from 24.52% in 1986 to 49.90% in 2010, with a large rural population continuing to aggregate in urban areas, thus increasing the level of urbanization.

In the 1990s, foreign investment was introduced to coastal areas, and the real-estate market was booming with a rapid development of regional economy, which brought about rapid developments in rural areas surrounding cities. Residential lands in rural areas quickly expanded, and significant urban-area expansions appeared in the North China Plain, the Yangtze River Delta, and the Pearl River Delta. Since 2000, under development strategies, a large amount of capital and a large number of experts and technologies have been attracted to the western, central, and northeastern regions. Consequently, urban expansion in the central and western regions was more rapid than that in the eastern region. China entered a new round of rapid urbanization: the growth rate of built-up land was 2.14 times that in the first decade, and a large amount of the high-quality cropland that surrounded towns was occupied. This phenomenon is particularly prominent in high-quality cropland-concentrated areas in the more economically developed southern China, the main grain-producing area in the

Huang-Huai-Hai Plain, and the coastal area of southeast China.

4.3 Changes in woodland and grassland

The land-use intensity in China continued to increase during the two recent decades. Irrational land developments were mostly carried out at the expense of the environment. For example, the reclamation of forest/grassland in the north led to wind-sand disasters and exacerbated soil erosions, and the disastrous flood in 1998 further highlighted the adverse ecological effects of regional developments. To mitigate the continual deterioration of ecological conditions, the State Council of China approved a plan to implement six key forestry projects early in 2001. These projects are included in the 10th Five-Year Plan. The six projects are as follows: (1) natural forest protection, (2) the "Grain for Green" project, (3) construction of the shelter-belt system in the "Three Norths" and midstream and downstream of the Yangtze River, (4) control of sandstorm sources in Beijing and Tianjin, (5) wildlife protection and construction of nature reserves, and (6) construction of fast-growing timber bases in key areas. In 2003, the nation promulgated the Regulations on Restoring Cropland to Forest, and then reforestation entered a stage of full implementation enforced by laws. Because of ecological restoration, the croplands were converted in mostly sloping lands (with slopes greater than 25°) and dry lands, which were distributed in the agricultural–pastoral ecotones in northern China and the Loess Plateau.

Since the beginning of the 21st century, due to reforestation projects, the ecologically fragile area of western China has shown a significant increase in forest area, and the regional coverage situation has substantially improved. Large-scale ecological conservation and construction has inhibited the shrinking of natural forest areas, effectively expanding the plantation area, and inhibited part of the degradation of natural grassland. To some extent, the large-scale ecological conservation and construction plays a positive role in western ecological restoration (Lu *et al*., 2012; Feng *et al*., 2012).

5 Conclusions

LUCC is the most direct manifestation of interaction between human activity and the natural environment. Spatial patterns of LUC characterize the intensity and modes of human–earth system interactions in different areas. We regularly updated the CLUD from the late 1980s to 2010 using information sourced from high-resolution satellite remote-sensing images. Based on these datasets, we have proposed and developed a dynamic regionalization method for land use and studied the spatial patterns and spatiotemporal characteristics of LUC. The primary findings are summarized below.

(1) During the two decades between 1990 and 2010, LUC across China indicated significant temporal and spatial differences. Cropland decreased in the south and increased in the north, with the total area remaining essentially unchanged and the focus of reclaimed cropland shifting from the northeast to the northwest. The built-up land expanded at an accelerated rate; it was distributed particularly in the east and spread to central and western China. Woodland first decreased and then increased, deserts first increased and then decreased, and grassland continued to decrease.

(2) By comparing the two decades before and after 2000, we found some new characteris-

tics in the spatial patterns of LUC in China. The main characteristic of these changes was the significantly accelerated expansion of built-up land in the Huang-Huai-Hai region, the southeastern coastal area, the midstream area of the Yangtze River, and the Sichuan Basin. Meanwhile, cultivated reclamation in northern China shifted from northeast China and east of Inner Mongolia to oasis agricultural areas in northwest China. The dry farmlands in northeast China continued to change into paddy fields. The "Grain for Green" project began to take effect in the southern agricultural–pastoral ecotones of Inner Mongolia, the Loess Plateau, and southwestern mountainous areas.

(3) In the past two decades, although climate change in the north impacted the change in cropland, policy regulation and economic driving forces were still the primary causes of LUC across China. During the first decade after 2000, the human-related factors that drove variations in land-use patterns changed from emphasizing one-way land development to emphasizing both development and conservation.

In 2002, we proposed an integrated study regarding the characteristics of "spatial patterns" and "temporal processes" of research objects in geographic science by means of spatiotemporal information analysis, and we have revealed "the pattern of changing processes" and "the changing process of patterns." This is a basic scientific issue in LUCC research and is also an effective approach to studying LUCC dynamics (Liu, 1996; Liu *et al*., 2003a; Liu *et al*., 2003b; Liu *et al*., 2010). The study analyzes changes in the spatial patterns of LUCC across China during the past two decades using analysis by the "dynamic zoning method," which has effectively revealed "the changing process of patterns" of LUCC in China during the past two decades (i.e., the shift of dynamic zoning boundaries, changes in the internal characteristics of zones, and the growth and decline of units). Our analysis also reveals "the pattern of the change process," namely the process of LUC and regional differences in characteristics at different stages, and we clearly depict the growth and decline of zones during this dynamic LUC zoning, variations in unit boundaries, and the characteristics of change intensities during the former and latter decade. We also reveal the patterns of alternative transformation between the "pattern" and "process" of land use as well as the reasons for changes in different types and different regions of land use, in addition to proving the effectiveness of the analysis method.

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