

Integrated studies of physical geography in China: Review and prospects

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Abstract: Modern physical geography in China grew from Chinese traditional geography and has been profoundly influenced by the geographical disciplines of Euro-America and Russia. Since the 1950s, integrated studies of physical geography in China have made remarkable progress in the fields of comprehensive physical geographical regionalization, land studies, landscape ecology, and land surface geographical processes. During the past few decades, under the background of global change and rapid socio-economic transformation, a series of environmental and resources problems have boomed in China. To solve these problems and promote the development of integrated studies of physical geography, the following issues were proposed as research priorities: (1) coupling of land surface patterns and processes; (2) integrated research on regional responses and adaptation to global change; (3) analysis of human dimensions of the earth system; (4) ecosystem service research from a geographical perspective; (5) integration of multi-source data and model development; (6) integrated studies on unique geographical units; and (7) important global issues and relevant international programs.

Keywords: China; physical geography; integrated study; progress; prospect

1 Introduction

Modern physical geographical research in China is deeply affected by the thoughts and theories of Euro-American and Russian geography and Chinese traditional geography. Geographical research has a long history in China, and the earliest geographical writings can be traced back to over two thousand years ago (Sun, 1990). Numerous ancient chorographies, monographs and maps recorded abundant geographical information, most of which was filled with empirical descriptions. Traditional thoughts such as the ‘unity between the heavens and man’ and ‘practical statecraft’ were also embodied in those literatures (Yu, 1993; Cai, 2010). In the late 19th century, people began to translate foreign geography literature

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into Chinese (Ai, 1995, 1996). The western tradition of splitting geography into physical and human geography profoundly affected the development of this discipline in China. Henceforth, the theories, methodologies and techniques of modern physical geography were gradually learned and accepted by domestic scholars. In the 1930s, domestic integrated studies of physical geography began with physical regionalization and integrated studies on the environmental evolution during the historical periods (Xu *et al.*, 2009; Yue *et al.*, 2010). Intensive Sino-Soviet academic communications in the 1950s made significant contributions to the development of China’s physical geography. The zonality theory and the perspective of landscape science promoted the establishment of integrated physical geography as a new specialty (Cai, 2010), which greatly facilitated the advancement of integrated studies of physical geography (Chen, 1993). The framework (Figure 1) shows the fields, objects and approaches of integrated studies of physical geography. The major fields of integrated studies of physical geography include comprehensive physical geographical regionalizations, land studies, landscape ecology and land surface geographical processes. In recent years, studying ecosystem services from geographical perspectives has received increasing attention, which extended the research scope of physical geography (Li *et al.*, 2014). Multiple approaches have been adopted by scholars to understand the patterns and processes of the comprehensive geographical entities that were shaped by the interactions of various physical and human factors.

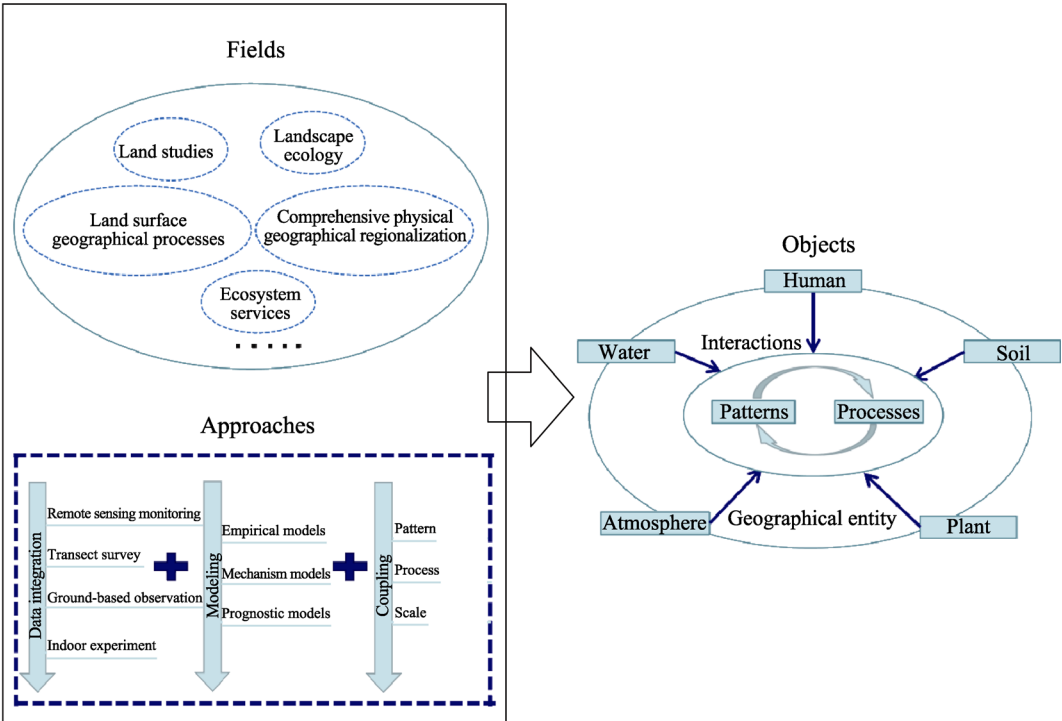


Figure 1 Framework of integrated studies of physical geography

Since the 1950s, Chinese scholars have made remarkable progress in integrated studies of physical geography. On the eve of the 33rd International Geographical Congress, there is a need to review the theoretical and methodological advances in these fields and look to their

future. The purpose of this paper is twofold: (1) to give geographers both at home and abroad a general idea of the development process of these studies and (2) to explore future trends and research needs.

2 Main theoretical and methodological progress

2.1 Comprehensive physical geographical regionalization

The earliest geographical regionalization scheme in China was recorded in ancient literature – *Yu Gong*, which was written more than 2500 years ago (Zheng *et al.*, 2005). However, it was only in the early 20th century that Chinese geographers began to carry out modern geographical regionalizations. Several domestic and foreign scholars such as Huang Bingwei, Li Xudan, Zhu Kezhen, G. B. Cressey and P. M. Roxby made certain explorations (Zhu, 1929; Lee, 1947; Zhao *et al.*, 1979). Although the schemes of that period may seem preliminary by today's standards, their contributions to the subsequent development of comprehensive physical geographical regionalization should not be neglected.

After the founding of the People's Republic of China in 1949, the new born nation had an urgent need for comprehensive knowledge of its physical environment and natural resources, which promoted systematic integrated surveys of natural resources (Sun *et al.*, 2010). These integrated surveys collected massive amounts of data about geographical entities, which laid a solid foundation for comprehensive physical regionalization research. Based on differences in climate, geomorphology, hydrology, vegetation, animal, and soil conditions, Luo (1954) proposed a three-level hierarchical regionalization scheme, which divided China into 2 parts, 7 basic regions, and 23 sub-regions. At almost the same time, another scheme arose (Lin *et al.*, 1954). That scheme partitioned China's territory into four parts according to landforms and geologic structures. The four parts were further divided into 10 divisions based on differences in climate, and those 10 divisions were in turn partitioned into 31 regions and 105 sub-regions according to disparities in landforms. The two schemes mentioned above set up a preliminary methodological framework for subsequent regionalization (Liu, 2004), although many of the concrete boundaries were different (Shi, 1954).

The establishment of the Natural Regionalization Work Commission in 1956 marked the beginning of systematic regionalization in China (Wu *et al.*, 2003). After that, the objective of regionalization changed from creating knowledge to meeting the demands of agricultural development. Based on several thematic regionalization formulations, a seven-level hierarchical regionalization scheme was proposed, dividing China into 3 natural realms, 6 heat zones, 18 natural divisions/sub-divisions, 28 natural zones/sub-zones, and 90 natural provinces (Huang, 1959). The regionalization hierarchy of this scheme was composed of zonal and azonal regionalization units. In the first five levels, bioclimatic conditions dominated the regionalization, and in the last two levels, azonal factors such as landforms, lithologies, and groundwater were taken into consideration. Holding the viewpoint that each regionalization unit was a comprehensive geographical entity controlled by both zonality and azonality, Ren and Yang (1961) put forward a novel scheme that did not use a unified regionalization index system. Under the 'top-down' methodological framework constructed by the four aforementioned schemes, two additional nationwide regionalization schemes were developed (Hou *et al.*, 1963; Xi *et al.*, 1984). Considering the drawbacks of the 'top-down' framework in the

classification of low-level regional units, Zhao (1983) proposed a ‘bottom-up’ approach that linked land use classification to regionalization.

Debates remain on several regionalization issues, including the understanding of the zonality theory, regionalization principles, the selection of index systems and the determination of several critical boundaries (Yang *et al.*, 2002; Zheng *et al.*, 2005). A representative debate, which lasted several decades, dealt with the concepts and boundaries of the subtropical zone (Zhu, 1958; Zeng *et al.*, 1980; He *et al.*, 1988; Ren *et al.*, 1991; Huang, 1992; Qiu, 1993; Wu *et al.*, 2000). The majority of the physical geographers agreed that the northern boundary of the subtropical zone is situated at approximately 34°N; nevertheless, the locations of the southern boundary in different schemes differed significantly.

Since the 1990s, research on a comprehensive physical regionalization has entered a new stage, and more ecological and socio-economic considerations have been a trend in those studies. Promoted by the practical demands of environmental protection and ecological restoration, an increasing number of ecological theories and methods have been integrated into the regionalization process. Several influential schemes have been proposed (Hou, 1988; Yang *et al.*, 1999; Zheng, 1999; Fu *et al.*, 2001; 2004), which differ in terms of their objectives and concrete methods. However, ecosystem typological variability, environmental protection and management, ecological problems, and human pressure features have more or less been considered in all the schemes (Fu *et al.*, 2006a). The comprehensive physical geographical regionalization in China has conclusively shown a distinct ecological tendency (Gao *et al.*, 2010). As earth system science and sustainable development receive ever-increasing attention, the combination of physical and socio-economic factors has been a distinct characteristic of recent regionalization research (Wu *et al.*, 2010). Recently, the draft of major function oriented zoning plan for China has been developed (Fan, 2015), which provides a blueprint for the future development and protection pattern of China’s territory. The complex index system of the draft is composed of ten physical and socio-economic indicators: water resources, land resources, ecological importance, ecological fragility, environment capacity, disaster risk, economic development level, population concentration, transport superiority and strategic choice. In recent years, the methods used in comprehensive geographical regionalization have changed from being mainly qualitative to a combination of quantitative and qualitative approaches. Remote sensing, geographic information systems, and a variety of new methodologies such as self-organizing feature map neural networks, fuzzy clustering, cluster analyses of statistic tests, spatial wavelet transformation, and uncertainty reasoning have been applied to regionalization research (Ge *et al.*, 2002; Hu *et al.*, 2003; Cong *et al.*, 2007; Ye *et al.*, 2007; Li *et al.*, 2008a; Huang *et al.*, 2011; Wu *et al.*, 2015a).

2.2 Land studies

Modern land studies in China can be traced back to the late 1950s, when the main objective of those studies was to understand the comprehensive geographical entities. During the 1950s to 1970s, promoted by extensive natural resources surveys and studies of comprehensive physical geographical regionalization, research on systematic land classification and mapping experienced rapid development (Fu *et al.*, 2006a; Shen, 2010). Chinese geographers made great efforts in land type mapping across the country, the majority of which was

at regional scale. Land type research in that period provided abundant information about arable land, which laid a solid foundation for national agricultural exploitation (Yang *et al.*, 2005). To apply the achievement of land type research in production practices, scientists conducted a series of trials, including soil and water conservation planning, location selection for crops, and people's commune planning (Zhao *et al.*, 1979). In the 1980s, research on land classification and mapping entered a new stage. A serial mapping of land uses, land types, and land resources at various scales was produced at that time (Shi *et al.*, 1985; Chen *et al.*, 1994; Wang *et al.*, 2014). The compilation of the national 1:1,000,000 land type map made great contributions to the development of land studies in China. Subsequently, Chinese geographers shifted the emphasis from the national scale to the regional scale (Ni *et al.*, 1993). Several scholars applied the land type to bottom-up regionalizations at regional and local scales (Cai, 1986; Liu, 1994; Zhang *et al.*, 2013). On the basis of land type, applied research, which included land evaluations, land use and land planning, experienced rapid development. Promoted by those advancements, land type research blossomed into land science (Chen *et al.*, 1994).

Research on land science in China has witnessed noteworthy advances in many fields since the 1980s. Apart from the evaluation of agricultural land, the evaluation of tourism and urban land also received increasing attention and was carried out in numerous places with the rapid socio-economic development in China (Dong *et al.*, 1989; Mao *et al.*, 2005; Hu *et al.*, 2009). During the recent years, as sustainable development gaining increasing attention, sustainable use evaluation has become a hot research field, in which several theories have been proposed (Fu *et al.*, 1997; Chen, 2002; Xue *et al.*, 2010) and a variety of new methodologies such as the ecological footprint approach, artificial neural networks and grey relation analyses have been developed (Yang *et al.*, 2007; Su *et al.*, 2010; Yan *et al.*, 2012). Promoted by the development of GIS technology, land information management systems for diverse purposes were established (Ni, 2003). In addition, facilitated by advances in Geographic Information Science and applications of various quantitative approaches, research on land degradation and restoration evaluation, land suitability evaluation, land consolidation and carrying capacity also made remarkable advances (Liu *et al.*, 2003a; Shi *et al.*, 2007; Liu *et al.*, 2011a; Wang *et al.*, 2012).

Since the IGBP and IHDP initiated the joint project – Land Use and Land Cover Change (Turner II *et al.*, 1995), land use and land cover change (LUCC) has been among the core subjects in the field of global environmental change both at home and abroad. Domestic LUCC studies have made advances in data acquisition and information extraction, driving forces, environmental impacts, and modelling. Geographic information system and remote sensing have been widely used for data acquisition and analyses of LUCC and have provided substantial and reliable data for characterizing the spatio-temporal dynamics of LUCC (Yu *et al.*, 2002). The nationwide 1:100,000 spatio-temporal LUCC data platform has been established with the technologies of fully digital and human-computer interaction remote sensing information extraction and accuracy analysis (Liu *et al.*, 2010a; 2014a). The classification of remote sensing images has received increasing attention because it is the basis of land use information extraction. Numerous theories and methods have been developed to improve classification precisions (Shi *et al.*, 2012). In China, there is an abundant ancient literature that contains considerable information regarding land use in the historical period,

and several quantitative approaches have been proposed to extract the information and re-construct the ancient LUCC (Ge *et al.*, 2008; Liu *et al.*, 2010b; He *et al.*, 2013).

Studies on driving forces of LUCC are of great importance to realize regional sustainable development. Current studies on driving forces are focused on two types of regions: regions with active anthropogenic driving factors, like Beijing, Shenzhen and Yangtze River Delta, and regions where local ecosystems are fragile, such as the Loess Plateau and Hexi Corridor (Yu *et al.*, 2002; Zhang *et al.*, 2008a). The driving forces of LUCC are diverse and scale-dependent, among which a wide variety of socio-economic and physical factors have been identified. Socio-economic factors include economic development (Liu *et al.*, 2014a), population growth (Liu *et al.*, 2005), policy regulation (Xie *et al.*, 2005), urbanization (Wu *et al.*, 2011), land use management (Yu *et al.*, 2011), advances of science and technology (Hai *et al.*, 2005), road construction (Liang *et al.*, 2014), and enhancement of environmental awareness (Fan *et al.*, 2012). Physical factors include climatic change (Gao *et al.*, 2006; Song *et al.*, 2009), geomorphological processes (Wang *et al.*, 2005a), water availability (Zhang *et al.*, 2006), and land-ocean interactions (Wang *et al.*, 2007). When it comes to the driving mechanism analyses of LUCC, domestic scholars attach much importance to a comprehensive cognition of the driving mechanisms of varied factors. They emphasize the description, explanation, and prediction of the temporal and spatial processes of LUCC (Liu *et al.*, 2010a).

LUCC results in variations of elements in the land surface system, and its environmental impacts have been studied mainly from six aspects: (1) carbon cycling in terrestrial ecosystems (Wang *et al.*, 2010; Feng *et al.*, 2013; Zhang *et al.*, 2015), (2) climate and atmospheric components (Jiang *et al.*, 2009; Deng *et al.*, 2014; Peng *et al.*, 2014; Zhang *et al.*, 2016), (3) soil properties and land degradation (Fu *et al.*, 1999; Zhang *et al.*, 2007a; Jiang *et al.*, 2015), (4) hydrological processes, water resources and quality (Li *et al.*, 2007; Feng *et al.*, 2012; Wu *et al.*, 2012a; Yan *et al.*, 2013), (5) biodiversity and ecosystem service value (Zhang *et al.*, 2008b; Fu *et al.*, 2015; Zhan, 2015; Wang *et al.*, 2015a) and (6) complex environmental impacts at the regional level (Shi *et al.*, 1999a; Cui *et al.*, 2012; Liu *et al.*, 2014b).

Modelling is a useful tool to give insights into the processes, mechanisms and environmental impacts of LUCC, and various types of LUCC models have been adopted, modified and developed by Chinese scholars for different purposes (Dai *et al.*, 2005; Huang *et al.*, 2005; Wu *et al.*, 2007; Luo *et al.*, 2010; Yu *et al.*, 2011; Xu *et al.*, 2015; Wu *et al.*, 2015b). Most of these models can be grouped into three categories: empirical-statistical models, concept mechanism models, and integrated models. In general, LUCC models in China are progressing from descriptive models to mechanism models. During the most recent two decades, LUCC models have greatly contributed to the understanding of the patterns, processes and mechanisms of LUCC and to the evaluation of the comprehensive impacts of LUCC. In addition, the models have provided support for governmental decision making (Tang *et al.*, 2009).

2.3 Landscape ecology

Landscape ecology is a newly emerging discipline in China. It was not until the early 1980s that landscape ecology was introduced into China by Lin Chao and others (Jing, 1990). The two papers that introduced landscape ecology research in Czechoslovakia (Liu, 1981) and

Federal Republic of Germany (Huang, 1981) marked the beginning of domestic landscape ecology research. Afterwards, the widespread introduction, evaluation and assimilation of landscape ecology as a new discipline occurred, primarily through the efforts of geographers (Fu, 1983; Huang *et al.*, 1984; Chen, 1986; Jing, 1986; Xiao *et al.*, 1988). The first national symposium on landscape ecology was held in 1989, which had an epochal significance in Chinese landscape ecology history (Cao *et al.*, 2001). Since then, domestic landscape ecology research has experienced rapid development, and the 8th IALE World Congress held in Beijing marked the recognition of domestic landscape ecology research by the international academia (Chen *et al.*, 2014). During the past 30 years, apart from tracking the international frontier, distinctive advancements have been made in domestic landscape ecology research. The main progress can be summarized as follows: (1) research on interactions between landscape pattern and process and their scale effects; (2) study of landscape pattern dynamics and their impacts on ecosystem services; (3) various landscape ecological applications; (4) the establishment of source-sink landscape theory.

The interactions between pattern and process and their scale effects are core issues of landscape ecology research. In recent years, there is an increasing concern over the coupling of pattern, process and scale (Fu *et al.*, 2011). One representative achievement was the study of interactions between landscape patterns and water-soil loss processes at different scales and their scale effects in the Loess Plateau (Zhao *et al.*, 2004; Fu *et al.*, 2009; Wang *et al.*, 2011a; 2011b). Specifically, researchers explored the mechanisms of how land use patterns affected soil water, nutrients and soil erosion processes (Fu *et al.*, 2000; Chen *et al.*, 2007; Feng *et al.*, 2010; Fu *et al.*, 2014). Moreover, soil loss evaluation indexes at different scales and methods for the coupling study of landscape patterns and water-soil losses were also proposed (Fu *et al.*, 2006b; Fu *et al.*, 2010). Different factors such as land use, soil properties, climate, vegetation characteristics, disturbance and landforms were found to play different roles in the process of water and soil loss at varied scales (Fu *et al.*, 2011; Gao *et al.*, 2013).

Landscape patterns in many cities have changed significantly under the background of intensifying urbanization, which is embodied in the expansion of impervious land surfaces, declining green spaces and water landscape areas, and landscape fragmentation (Chen *et al.*, 2013). A large number of studies have analysed the spatio-temporal dynamics of urban landscape patterns with a series of landscape metrics and further explored the driving forces (Yu *et al.*, 2007; Qi *et al.*, 2013; Yang, 2015). Apart from urban landscape dynamics, several other research topics such as forest landscape dynamics and its simulation, wetland and agriculture landscape change, and the evolution of oases have also attracted substantial attention (Fu *et al.*, 2006c; Zhang *et al.*, 2007b; Chen *et al.*, 2014). In recent years, the study of the eco-environmental effects of landscape dynamics has become a hot research field (Liu *et al.*, 2003b; Chen *et al.*, 2013). Landscape patterns and dynamics alter ecosystem processes, which, in turn, influence ecosystem services. As a new trend, impacts of landscape pattern dynamics on ecosystem services have received increasing interest (Su *et al.*, 2012; Wu *et al.*, 2013; Fu *et al.*, 2015; Wang *et al.*, 2015b). Fu *et al.* (2013) proposed a conceptual framework linking landscape patterns, ecosystem processes, and ecosystem services, which provided the scientific basis for landscape planning and ecosystem management.

Landscape ecology is such a highly practical discipline (Xiao *et al.*, 2003) that many

concepts, theories, and methodologies in landscape ecology have been applied to the practice of regional ecological restoration and environmental protection. Landscape ecological applications are diverse but primarily include (1) urban landscape planning and landscape security pattern construction (Li *et al.*, 2005; Peng *et al.*, 2005; Yu *et al.*, 2009), (2) agricultural landscape design and management (Wang *et al.*, 2000; Xiao *et al.*, 2001; Yu *et al.*, 2012), (3) biodiversity conservation and nature reserve network optimization (Yu *et al.*, 1998; Chen *et al.*, 2000; Xu *et al.*, 2010) and (4) landscape ecological risk assessment (Liu *et al.*, 2008; Gong *et al.*, 2014; Peng *et al.*, 2015).

Landscape metrics have been widely used in landscape pattern analysis, which has greatly promoted quantitative studies in landscape ecology (Chen *et al.*, 2006). However, most of those studies were purely descriptive, and the landscape metrics used in them were lack of geographical and ecological meanings (Fu *et al.*, 2011). Hence, domestic ecologists have cast doubt on the uncritical use of existing landscape metrics (Li *et al.*, 2004; Chen *et al.*, 2008; Liu *et al.*, 2011b). Several new landscape metrics and theories have been proposed to establish quantitative relationships between landscape patterns and ecological processes (Chen *et al.*, 2003; You *et al.*, 2005; 2006; Fu *et al.*, 2006b; Wu *et al.*, 2012b). Among them, the source-sink landscape theory proposed by Chen (2003; 2006) is a representative sample. Implementing the common concepts of 'source' and 'sink' in air pollution research, landscapes were grouped into two types, 'source' landscapes and 'sink' landscapes, according to their effects on a certain ecological process. The 'source' landscapes result in positive effects, and the 'sink' landscapes result in negative effects. On that basis, a new landscape index, namely, the location-weighted landscape index, was developed to emphasize the role of landscape types in ecological processes (Chen *et al.*, 2009). This index has been preliminarily validated, and the source-sink landscape theory has been applied to the study of water-soil losses, non-point source pollution, and urban heat island effects (Chen *et al.*, 2014).

2.4 Land surface geographical processes

As early as the 1960s, Huang (1960) proposed that physical geographers should carry out research on the physical, chemical, and biological processes on land surfaces and integrate them in a unified system. In that proposal, a preliminary framework for the integrated research of modern geographical processes and their regional differentiation was constructed. Since the 1960s, field observations at fixed locations and indoor simulated experiments have been conducted for the in-depth study of various physical geographical processes and interactions between geographical factors (Yang *et al.*, 2005). These efforts have indicated that physical geographical studies in China were gradually changed from qualitative descriptions to quantitative research. Geographical process studies in that period usually focused on a single dominant physical factor such as landforms, vegetation or hydrological conditions. However, interactions between the dominant factor and other correlating factors were not fully considered (Leng *et al.*, 2005; Ding *et al.*, 2013). In addition to modern geographical processes, studies on historical geographical progresses also made prominent achievements. In those studies, a large number of archives were used to retrieve the environmental evolution, including ice cores (Yao *et al.*, 1997; Shi *et al.*, 1999b), loess (An *et al.*, 1990; Liu *et al.*, 1998), sporopollen (Song *et al.*, 1999), speleothems (Wang *et al.*, 2005b; Zhang *et al.*, 2008c), tree rings (Zhang *et al.*, 2003; Li *et al.*, 2006) and historical documentary data (Chu,

1973; Ge *et al.*, 2003). Some of the studies even reached an international advanced level.

In recent years, the rapid development of global change, sustainable development and earth system sciences has greatly promoted the integrated research of geographical processes (Ding *et al.*, 2014). Four international programs (IGBP, IHDP, DIVERSITAS, and WCRP) were launched for the systematic and integrated study of earth sciences (Leemans *et al.*, 2009). The focus of geographical process research in China is also shifting from single factor or progress to the coupling of multiple factors and multiple processes. Conspicuous achievements have been made in the following areas: (1) interactions between hydrological processes and vegetation at various scales (Wang *et al.*, 2009; Chen *et al.*, 2011), (2) mechanisms of soil erosion and its relationship with vegetation (Xu *et al.*, 2006; Li *et al.*, 2008b), (3) contaminant transportation and transformation in soil and water (Zhang *et al.*, 2005; Tang *et al.*, 2014), and (4) the environmental impacts of changes in the cryosphere and interactions between cryospheric and other geographical factors (Qin *et al.*, 2009; Leng *et al.*, 2010). A representative research example is the 'Integrated Study of Eco-hydrological Processes in the Heihe River Basin', which was intended to explore the complex interactions between the hydrological system and ecosystem in inland river systems and reveal the underlying mechanisms. Since the implementation of this program, a basin-wide eco-hydrological observation system that integrates remote sensing, monitoring and experimentation has been established, and important coupling mechanisms of eco-hydrological processes have been revealed (Cheng *et al.*, 2014a).

Growing evidence shows that human activities are dominating the global environmental change and have pushed us into a new geological epoch: the Anthropocene (Steffen *et al.*, 2011). Further human pressure may result in widespread and irreversible changes to the basic processes in earth system (Griggs *et al.*, 2013). The objectives of terrestrial system research have transformed from environmental changes driven by natural processes to those driven by both natural and human processes (Leng *et al.*, 2005). Having its origin in global environment change research, and in combination with social science research, the 'Future Earth' research programme (2013) noted the direction of geographical process research in the new period. In China, a similar concept and philosophy can be traced back to the 1980s, when Qian (1983; 1991) proposed the establishment of earth surface science. On that basis, Huang (1996) formulated the concept of 'land system science' to gain a comprehensive understanding of natural and human factors in the land surface system and to lay the foundation for regional sustainable development. Subsequently, however, no remarkable progress was made over a long period of time (Ding *et al.*, 2013). Only recently has the comprehensive study of interactions between man and nature again received due attention, which has been promoted by the demands of sustainable development. Ding (2014) analysed problems in land surface process research and forwarded a basic framework for studies in land surface system science. Fan (2014) discussed several key issues of regional sustainable development research under the framework built by the 'Future Earth' plan and noted difficulties in the study of the processes and patterns of the human-environment system. Integrated studies of the water-ecosystem-economy in the Heihe River Basin have made encouraging progress in the ecological economics of the changing relationships between human and natural factors. Moreover, strategies and plans seeking a win-win situation for local economy and environment have been proposed (Cheng *et al.*, 2014b).

3 Prospects

During the past few decades, the physical and the social humanistic environments in China have undergone remarkable changes under the background of global change and rapid socio-economic transformation. As a result, dozens of problems in ecological restoration, environmental protection, natural resource utilization, and territorial management have exploded (Li *et al.*, 2011). These environmental and resource problems urgently require the guidance of scientific theories and methods. This situation provides a good opportunity for integrated studies of geography that adopt a holistic prospective and engage in understanding the complex dynamics and interactions of the constituent elements in the land surface system. Despite the prior prominent achievements, domestic integrated studies of physical geography still can't fully meet the changing needs of society. To facilitate the development of integrated studies of physical geography and achieve a social service value, the following initiatives should be adopted.

(1) The coupling of patterns and processes should be emphasized. As the foundation for the comprehensive understanding of complex geographical entities, pattern and process coupling has been an important approach for integrated studies of physical geography. There is a need to facilitate the coupling of patterns and processes at different spatio-temporal scales and seek for the establishment of relevant scaling mechanisms. In the study of pattern and process coupling, it is necessary to strengthen the integration of indoor experiments, fixed point monitoring, transect surveys, remote sensing observations, and model simulations.

(2) Integrated studies on regional responses and adaptation to global change need to be enhanced. The practical problems caused by global change and the corresponding adaptive measures are diverse in China because the effects of global change, physical environment, and socio-economic condition are unique in each region. Chinese physical geographers should shift the orientation of global change studies from basic studies designed to understand the fundamental rules regulating the land surface system to integrated studies on regional environmental and resource problems and the adaptation of both human societies and ecosystems. More importance should be attached to the integration of multiple disciplines and the development of regional land surface process models.

(3) More attention should be paid to the human dimensions of the Earth system. Anthropogenic activities are changing the Earth system with significant impacts on the environment at various scales (Future Earth, 2013), creating a higher degree of complexity through the interactions of processes that are within the domains of both physical and human geography. However, the human dimensions are often neglected in contemporary integrated studies of physical geography, impeding the further understanding of the anthropogenic impacts on the Earth system. Future integrated studies of physical geography in China need to take more human dimensions into consideration and incorporate pertinent methods from human geography, with the aim of providing new knowledge and solutions for national sustainability.

(4) There is a need to advance ecosystem service research from a geographical perspective. Research on ecosystem services attaches increasing importance to spatio-temporal heterogeneity, spatial flow ability and regional features. Meanwhile, geography can provide much help in understanding issues of space and region (Potschin *et al.*, 2011). Constructing

the geographical study paradigm of ecosystem services expands the scope of integrated physical geographical studies and improves the research capacity for ecosystem services. Researchers need to pay close attention to the theme of ecosystem structure and function-ecosystem services-human well-being.

(5) Facilitating the accumulation and integration of multi-source data and the development of models. Sufficient data accumulation by long-term network-based monitoring, field surveys, indoor experiments and remote sensing observations is the foundation of physical geographical research. As the research issues of physical geography are becoming increasingly comprehensive and diverse, researchers need to address data that are acquired via various approaches and have very different properties. Thus, the integration of multi-source geographical data becomes an urgent need for integrated studies of physical geography, and data assimilation is a possible solution. The complexity of the geographical factors and their interactions determine the importance of models for understanding the land surface system at various scales. The majority of the models used in physical geographical research in China belong to empirical models, whereas the proportion of mechanism models is relative low. The parallel development of the two types of models is a feasible approach, given a consideration of the effectiveness of those models in both interpretations of mechanisms and future prediction.

(6) Strengthening integrated studies on unique geographical units. Integrated physical geographical studies should be based on physical and socio-economic circumstances. China has a vast territory that features a large variety of both physical landscape types and cultural diversity. The natural conditions and man-land relationships in several regions are unique and of high research value. Integrated studies of those special geographical units ought to be facilitated, including land surface geographical processes on the Tibetan Plateau and their responses to global change, the evolution of the man-land system in arid regions, the ecological effects of water and soil conservation on the Loess Plateau, and evolutionary processes and sustainability of karst ecosystems.

(7) Chinese physical geographers should pay more attention to global issues and enhance international collaboration. The land surface system is composed of a large number of interactive geographical factors, and many physical geographical processes are of global significance. However, the concerns of most domestic geographical studies have been limited to issues at local or regional scales. Because little attention has been paid to global issues, the improvement of research capacity and findings of geographical laws of universal significance have been hindered. Enhancing research on global issues and taking a more active part in major international programs will certainly improve the level of internationalization of Chinese physical geography and enable contributions to the holistic development of integrated studies of physical geography.

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