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Interactions between land use change, regional development, and climate change in the Poyang Lake district from 1985 to 2035

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ABSTRACT

Land use change and climate change are two major global modifications of our environment and are predicted to continue in the future. To assess how climate change affects land use and regional development in the Poyang Lake district in China, we use agent-based modeling and simulate the physical and socio-economic drivers within two interactive sub-models for urban expansion and rural development. The modeling outputs from 1985 to 2005 show good agreement with the observed land use change. Possible land use changes and regional development paths until 2035 are examined for three SRES scenarios including A1B (rapid growth), A2 (regional-diversified growth) and B1 (growth with clean technologies). The results show that climate change induced impacts on land use change and regional development are highly relevant and may even amplify the complex interactions. In particular, cropland, forest, water area, urban, and grassland are more sensitive to these changes than unused land. The more environmental friendly B1 scenario results in less concerning land use changes.

1. Introduction

Land use plays an important role in regional development and global environmental change, and it has attracted increasing interests among scientists since the last decades. It is a keystone for sustainable development and a major element of human responses to global change. Consequently, it is important for regional development and the management and mitigation of many environmental problems (Turner et al., 1995). Recognizing the importance of land use change (LUC), the land use and land cover change (LUCC) was launched in 1994 as a core project of the International Geosphere–Biosphere Programme (IGBP) and the International Human Dimensions Programme on Global Environmental Change (IHDP) to improve understanding of the dynamics of land-use and land-cover change and its relationship with global environmental change (Turner et al., 1995). Following the LUCC initiative, the Global Land Project (GLP) was established focusing on coupled socio-environmental systems. Climate change (CC) is a major theme in the GLP (GLP, 2005).

In its fourth assessment report in 2007, the Intergovernmental Panel on Climate Change (IPCC) emphasized human induced climate change as a major concern for societies and estimated environmental, social and economic consequences from different projections on global temperature, sea level, and snow cover over the next 100 years. According to the IPCC, the global surface temperature will rise between 1.1 and 2.9 °C (2 and 5.2 °F) during the 21st century under its lowest emissions scenario B1 and between 2.4 and 6.4 °C (4.3 and 11.5 °F) under its highest emissions scenario A1FI (IPCC, 2007).

Changes in land use and climate are two major global developments projected for the future. The majority of previous studies have examined causes and consequences of these two processes independently (Dale, 1997; Dilly and Hüttl, 2009; Turner et al., 1993). A large number of studies have confirmed the major role of land use and land cover change and variability in the climate system (Foley et al., 2005; Pielke, 2005; Zhao et al., 2001). To our knowledge, less information is available about how climate change affects land use change and regional development. Especially the

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actions of stakeholders to improve quality of life through changes in economy and society cannot be ignored, because regional development may amplify or reduce the climate change impacts (Abildtrup et al., 2006).

LUC, CC and regional development are complex processes. Particularly, LUC is the outcome of complex interactions between physical factors including geological, hydrological, and climate conditions and human activities (Cai, 2001; Deng, 2008; GLP, 2005; Liu, 1996; Turner et al., 1993; Zhen et al., 2009). The interactions between LUC, CC and regional development can be hardly investigated by using traditional methodologies such as statistical analysis, linear programming, geographical information system (GIS), and system dynamics separately under temporal and spatial constraints. Many current approaches dealing with the interactions frequently rely on economic models with exogenous environmental impacts (Abildtrup et al., 2006; Britz et al., 2011; Lobell et al., 2006; Moss et al., 2001) or on geographic explicit biophysical models with exogenous economic impacts (Rokityanskiy et al., 2007; van Meijl et al., 2006). Complexity theory including system dynamics, artificial neural networks, fuzzy theory, fractal theory, genetic algorithms, and complex adaptive system have been increasingly used in geography since the 1990s (Beltratti et al., 1996; Huang and MacMillan, 2004; Li and Yeh, 2002; Manson, 2005; Yang and Li, 2007). As an important component of complexity theory, complex adaptive system was promoted by Holland (1995) at the interdisciplinary Santa Fe Institute, and was regarded as the core theory for agent-based modeling (ABM). In the context of land use change and regional development, ABM is a means to explore, explain, and assess the complex interactions between environmental dynamics and human activities (Parker et al., 2003). As a bottom-up methodology, ABM applied to land use and land cover change as well as regional development can reflect the complex spatial changes through simulating individual and collective behavior. While rules and regulations reflect the behavior of individual agents, interaction mechanisms between different agents are defined to reproduce macro-level phenomena (Sullivan, 2000).

Some studies on climate change and ABM have addressed the concept of adaptive or sequential decision-making (Janssen and de Vries, 1998; Lempert et al., 1996). Janssen and de Vries (1998) employed a multi-agent model and implemented it in a dynamic model of a coupled economy–energy–climate system to demonstrate the possible relevance of adaptive learning. Ziervogel et al. (2005) applied an agent-based social simulation model to assess the impact of seasonal forecasts on farm management. This work shows little benefit for farmers when the forecast correctness is less than 60%.

Here, the objective is to identify the main driving forces of LUC and regional development in the Poyang Lake area of China using agent-based modeling and the regional impacts of the A1B, A2 and B1 CC projections. The effects of inertia, lake, urbanization, slope, neighborhood, climate change, and flood were taken into account. To compare site specific CC impacts on rice yields, the Environmental Policy Integrated Climate model (EPIC) is included in our research (Williams, 1995).

2. Study area and data resources

2.1. The physical geographic conditions

Poyang Lake district, located in the north of Jiangxi Province, China, between 115°21′E–117°04′E longitude and 28°09′N–29°51′N latitude, is the largest freshwater lake in China (Fig. 1). It is located at the south bank in the middle reach of the Yangtze River. Poyang Lake is fed by five rivers including the Ganjiang River, Fu River, Xinjiang River, Rao River, and Xiu River and connects the Yangtze River through a channel. The lake is one of the most important water retention reservoirs in the middle area of Yangtze River. It has a storage capacity of $191.9–208.5 \times 10^8$ m^3 (Wang and Dou, 1998). The water level of the Poyang Lake reflects seasonal changes and climate variability. Both droughts and floods have occurred frequently in this region in recent years.

The Poyang Lake district covers 20,220 km^2 or 0.21% of the Chinese land territory and contains 2 cities and 10 counties (Nanchang City, Jiujiang City, Nanchang County, Xinjian, Jinxian, Yongxiu, De'an, Xingzi, Duchang, Hukou, Yugan and Poyang) which belong to three prefecture-level cities (Nanchang, Jiujiang and Shangrao). The Poyang Lake district can be divided into four land types: mountains, hilly landscapes, lowlands, and plains. These types are distributed around the lake as rings (Zhu, 1983). Plains and lowlands dominate the area and together have a share of 61.9% (Zhu, 1980).

The Poyang Lake district is the most developed region of Jiangxi Province, and also a key national production base for rice, oil, cotton and fish. Between 1954 and 1998, the surface of Poyang Lake declined by 25% and the lake capacity by 22%, in part caused by wetland areas which were drained to meet the rising demands for both agricultural and industrial developments (Guo et al., 2008; Min, 1999; Zhen et al., 2011). The decline in lake capacity has increased the vulnerability of the lake basin to floods.

2.2. The economic conditions

The Poyang Lake district is the core of the Poyang Lake Ecological Economic Zone, and carries a function of accelerating the social and economic development in Jiangxi province. In 2010, the annual per-capita GDP of Jiangxi Province was 21,253 RMB Yuan (about 2400 Euro), 23% higher compared to 2009, but 29% lower than the national average of 29,992 RMB Yuan. The total GDP of the Poyang Lake district, which is the most developed area in Jiangxi province, was 301 billion RMB Yuan and contributed 32% to the entire GDP of Jiangxi Province. The annual per-capita net income of farmers was with 5789 Yuan below the national average of 5919 Yuan. Furthermore, the Poyang and Yugan counties were the key targets of China's *Rural Poverty Reduction and Development Program*. The per-capita net income of farmers in Poyang and Yugan were only 3015 and 3658 RMB Yuan.

2.3. The climate conditions

The Poyang Lake district is situated at the East Asia Monsoon zone and has a humid subtropical climate characterized by mild temperatures, hot, humid summers, and cool winters. The annual mean temperature ranges between 16 and 19 °C, the annual mean precipitation is 1472 mm. The highest mean annual precipitation and temperature were 2172 mm in 1998 and 19.2 °C in 2007. Large inter-annual variation of precipitation may result in severe floods and droughts (Fig. 2).

Future climate conditions are described by the IPCC AR4 projections of the fourth IPCC report. For this analysis, the SRES scenarios A1B, A2 and B1 for the years 2001–2035 are chosen (Fig. 2). The scenarios are described in the Special Report on Emissions Scenarios by IPCC. The A1B scenario is based on a world with rapid economic growth and fast development of new technologies at a global scale. The A2 scenario refers to a world with regionally oriented economic growth. Finally, the B1 scenario depicts a globalized, rapidly growing population with an ecologically friendly economy including the enforced introduction of clean and efficient technologies (IPCC, 2007). In each scenario, both mean temperature and annual precipitation sums increase from 2001 to 2035 in the Poyang Lake district. The mean temperature under the A1B scenario averaged over the years from 2031 to 2035 is about 0.8 °C higher than for the period 2001–2005. The years with