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Differences between physical and human process simulation in geography:

Empirical analysis of two cases

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Abstract: Physical geography and human geography are the principal branches of the geographical sciences. Physical process simulation and human process simulation in geography are both quantitative methods used to recover past events and even to forecast events based on precisely determined parameters. There are four differences between physical process simulation and human process simulation in geography, which we summarize with two specific cases, one of which is about a typhoon's development and its precipitation, and the other of which is regarding the evolution of three industrial structures in China. The differences focus on four aspects: the main factors of the research framework; the knowledge background of the systematic analysis framework; the simulation data sources and quantitative method; and the core of the study object and the method of forecast application. As the human-land relationship is the key ideology of the man-land system, the relationship between the physical and human factors is becoming increasingly close at present. Physical process simulation and human process simulation in geography will exhibit crossing and blending in the future to reflect the various geographical phenomena better.

Keywords: physical process simulation; human process simulation; geography; human-land system

1 Introduction

Geography is an essential part of the geosciences. Geography studies natural process changes and the interactions in human-land systems (Mackinder *et al*., 1887; Hartshorne, 1939; Kitchin *et al*., 2007; Gu, 2009). The development of geography was closely related to geology and meteorology in modern China. From the research point of view, geography studies the surface of the earth, including the lithosphere, hydrosphere, atmosphere, biosphere, the human geographical environment and their internal relationships. Traditional

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Western geography is mainly classified into general geography and special geography. The two branches of general geography are physical geography and human geography. Geography emphasizes time and space (Ackerman *et al*., 1965; Yang *et al*., 1997; Zhang, 2009). The branches of physical geography involve geomorphology, climatology and hydrology. These branches of physical geography study the geographic environment of natural elements. Physical geography focuses on the Earth's land surface, peripheral features and environmental, essential, contemporary spatial variation and temporal change. Physical geography aims to understand how the Earth's natural environment becomes the foundation of human activities and how the Earth's natural environment is affected by human activities (Gregory, 2000; Cai *et al*., 2009). In brief, human geography studies the geographical distribution, diffusion and variation of all types of human phenomena, and human geography studies the formation of the spatial structures caused by human activities. In a word, human phenomena include various social, political, economic and cultural phenomena (Gu, 2009). In recent years, new branches of geography have appeared, such as geocomputation, which is one of the core fields of geographic information science (Couclelis, 1998; Gahegan *et al*., 2002; Wang *et al*., 2007). However, physical geography and human geography are both essential branches of the geographic sciences, regardless of how the subject is classified. In addition, both physical and human geography have presented simulation theories and methods centering on physical and human processes, respectively, due to the related mathematical theoretical foundation and the rapid development of computer technology combined with the widespread application of GIS methods. Process simulation examines the recurrence of past events through quantitative methods. Process simulation compares analogue values calculated by analytical mathematical models with the actual values to improve accuracy and to recover past events to the greatest extent. This paper takes the process of typhoon development and its precipitation as a physical process simulation case and the process of Chinese industrial structure evolution as a human process simulation case. We make a concrete analysis of the differences of the process simulation through two specific cases, and we summarize the differences of physical process simulation and human process simulation in geography to provide a reference for the simulation of the human-land system, which is related to both physical and human process simulation. Both types of process simulations focus on dynamic and developmental processes.

Physical process simulation mainly includes the developmental trends of atmospheric process simulation and hydrological process simulation. Taking atmospheric process simulation as an example, the multi-scale atmospheric numerical prediction model GRAPES created by China reduces the distinction between traditional atmospheric and mesoscale numerical models (Peng *et al*., 2010). In hydrological process simulation, for example, early Horton water infiltration equations and Penman evaporation formulas were developed into the Stanford model of Crawford and Linsley in the 1960s. Several artificial intelligence models have been developed in recent years (Shen *et al*., 2004). The nested and coupled techniques of these mathematical models have provided further development and improvement. Interdisciplinary characteristics are also continuously reflected in these process simulations. For example, meteorology, hydrology, oceanography and ecology have been combined and have even been applied to economics and management. Regarding the developmental trend of human process simulation in geography, the beginning of quantitative geography and theoretical geography in the 1950s and 1960s (Schaefer, 1953; Bunge, 1966) indicated the rise of quantification research on geographical phenomena and laid a solid foundation for human process simulation in geography. With the application of the Cellular Automation model, the Agent model (Han *et al*., 2003; Wu *et al*., 2008) and the Core-Edge model (Krugman *et al*., 2007), human process simulation in geography is being perfected. Numerous natural factors are involved in human process simulation by GIS. Human geography has also become increasingly closely related to ecology and climatology. These two types of process simulation express interdisciplinary characteristics. However, it is necessary for us to analyze and summarize the differences through two specific cases concerning these two types of process simulation in geography.

2 Two specific cases regarding physical process simulation and human process simulation in geography

On the one hand, the surface of the geographical environment is a major research field of geography. The study of human social activities on the surface of the geographical environment is also a major research field of geography (Mao, 1995; Jin *et al*., 1990). In the geographical environments, such as the lithosphere, hydrosphere, atmosphere and biosphere, weather processes caused by atmospheric flow and change are the most active and have the greatest direct impact on humans (Zhang *et al*., 1989). Because the weather process includes heat and water exchange, this process is closely related to the natural conditions of the geographical environment. In addition, weather is affected by the differences of the terrain, such as the differences between sea and land and regional geomorphological differences. Thus, the weather process is the main component of physical processes in geography. On the other hand, industrial development is closely related to human social activities. Industrial structure evolution reflects the change of human social economic relationships. The classical location theories in geography include agricultural location theory, industrial location theory and business and services location theory (Li *et al*., 2008). The development of location theory implies the evolution of industrial structure during the historical period. The changes of industrial structure reflect the changes of human social activities on the surface of the geographical environment in the historical process. In this study, we set a weather process and the Chinese industrial structure evolution process as the physical and human processes in geography, respectively, and we study the two types of process simulation in geography.

2.1 A case of physical process simulation: the landfall of typhoon Saomei (2006) and its precipitation

The typhoon is among the most severe weather systems, and accurate forecasts of typhoon tracks could be helpful to emergency management and disaster recovery. Numerical weather prediction and simulation is an effective approach to forecasting and researching a typhoon’s track and its precipitation. As an example of a physical process in geography, we present the simulation results of the landfall process of typhoon Saomei (2006) on August 10th, 2006 using the Weather Research and Forecasting (WRF) model system.

The WRF equations are formulated using a terrain-following hydrostatic-pressure vertical coordinate, which is defined as

$$\eta = (p_h - p_{ht})/\mu, \quad \text{where} \quad \mu = p_{hs} - p_h$$

p_h is the hydrostatic component of the pressure, and p_{hs} and p_{ht} refer to values along the surface and top boundaries, respectively. Because $\mu(x, y)$ represents the mass per unit area within the column in the model domain at (x, y), the appropriate flux form variables are

$$\vec{V} = \mu\vec{v} = (U, V, W), \Omega = \mu\dot{\eta}, \Theta = \mu\theta,$$

and $\vec{v} = (u, v, w)$ are the covariant velocities in the two horizontal and vertical directions, respectively, while $\omega = \dot{\eta}$ is the contravariant 'vertical' velocity. θ is the potential temperature. Using the variables defined above, the flux-form Euler equations can be written as

$$\frac{\partial U}{\partial t} + \nabla \bullet (\vec{v}U)_\eta + \mu\alpha\frac{\partial p}{\partial x} + \frac{\partial p}{\partial \eta}\frac{\partial \phi}{\partial x} = F_U$$

$$\frac{\partial V}{\partial t} + \nabla \bullet (\vec{v}V)_\eta + \mu\alpha\frac{\partial p}{\partial y} + \frac{\partial p}{\partial \eta}\frac{\partial \phi}{\partial y} = F_V$$

$$\frac{\partial W}{\partial t} + \nabla \bullet (\vec{v}W)_\eta - \left(\frac{\partial p}{\partial \eta} - \mu\right) = F_W$$

$$\frac{\partial \Theta}{\partial t} + \nabla \bullet (\vec{v}\Theta)_\eta = F_\Theta$$

$$\frac{\partial \mu}{\partial t} + (\nabla \bullet \vec{V})_\eta = 0$$

$$\frac{\partial \phi}{\partial t} + (\nabla \bullet \phi)_\eta = gw$$

along with the diagnostic relation for the inverse density

$$\frac{\partial \phi}{\partial \eta} = -\mu\alpha$$

and the equation of state

$$p = \left(\frac{R\Theta}{p_0\mu\alpha}\right)^\gamma,$$

where ϕ=gz is the geopotential, p is pressure, and α=1/ρ is the inverse density. F_U, F_V, F_W and F_Θ represent forcing terms arising from model physics, turbulent mixing, spherical projections, and the Earth's rotation. p_0=10^5 Pa is standard air pressure, R is dry air constant, g is gravity acceleration, and γ=c_p/c_v=1.4 is the heat capacity ratio of dry air.

We simulated the landfall process of typhoon Saomei (2006) from 00 (UTC) August 8th to 00 (UTC) August 11th, 2006 using the WRF model with a horizontal resolution of 15 km. The model's initial field and lateral boundary conditions are interpolated from the analysis field of the global numerical weather prediction system at the National Meteorological Center (NMC) of the China Meteorological Administration (CMA). Figures 1 and 2 represent the actual observation and the model simulation, respectively, of the landfall process of typhoon Saomai (2006). Figure 3 represents the actual observation and the simulation of typhoon Saomai's (2006) precipitation.

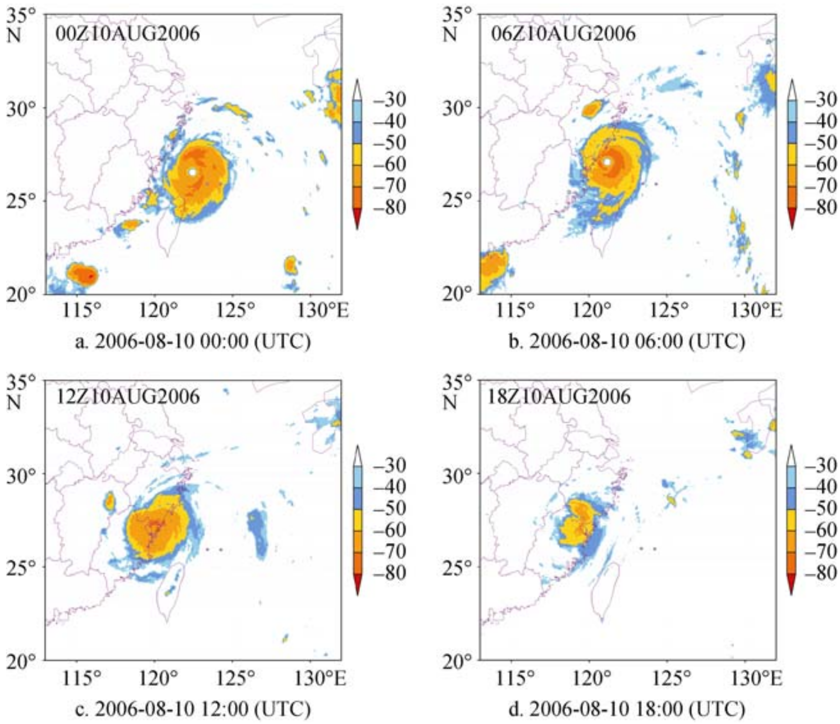


Figure 1 The observation of typhoon Saomei's (2006) landfall (infrared brightness temperature)

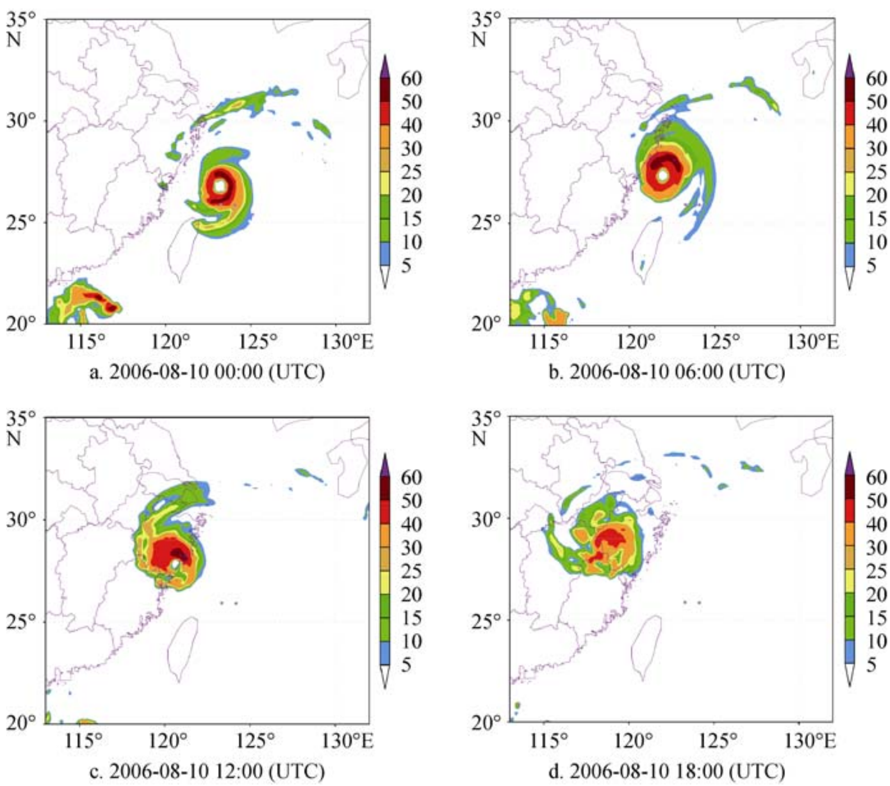
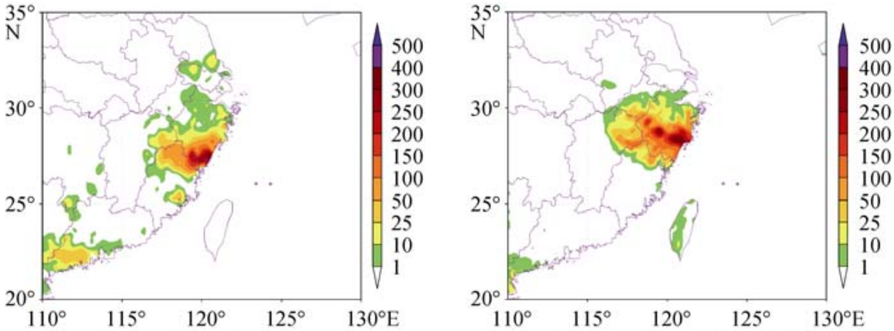


Figure 2 The simulation of typhoon Saomei's (2006) landfall process (composite radar reflectivity)



a. Precipitation of the actual observation b. Precipitation of the model calculation

Figure 3 The accumulated precipitation (mm) from 00 (UTC) August 10th to 00(UTC) August 11th, 2006

We have approximated the landfall of typhoon Saomei (2006) on the coastal area and its precipitation over China in terms of the expressed results in Figures 1–3 above by the WRF model. We also forecasted the precipitation and the flow field's changes over the next six hours by the WRF model. We now discuss a case of human process simulation in which the evolution of three Chinese industrial structures from 1991 to 2010 is examined.

2.2 A case of human process simulation: the evolution of three Chinese industrial structures

The evolution of regional industrial structure shows the changes of the human social activities in the region. In this study, we choose three Chinese industrial structures. The development of the industry relies mainly on capital accumulation, labor increase and technological progress based on the theory of economic growth. Investment and employment are two key factors. We know that the social economic system is dynamic and complex. The structure of the interrelations among factors can be extremely complex, and any one small local change often causes other great changes that do not seem related through implicit links (Li, 2009). Thus, we need to consider the structured simulation of this type of question. First, we need to depict the feedback of related factors in this social economic system. In this case, we apply a system dynamics model. Two hypotheses in a system dynamics model should be satisfied, as follows:

Hypothesis 1: The operation of the model is limited to researching intraregional factors, ignoring the influence of other factors, such as trade and labor migration.

Hypothesis 2: The model is limited to researching fixed asset investment, ignoring the influence of current asset investment.

The variables involved in the system dynamics model are shown in Table 1.

Table 1 The main variables in the system dynamics model

Type of variables	The variables' names
Level	GDP1; GDP2; GDP3; Pop
Rate	detGDP1; detGDP2; detGDP3; Births; Deaths
Auxiliary	GDP; Tech1; detL1; detK1; Avergdp1; Tech2; detL2; detK2; Avergdp2; Tech3; detL3; detK3; Avergdp3; detLabour; detpop
Constant	Birth Rate; Death Rate

The meanings of the main variables in the system dynamics model are as follows.

Variable GDP1 means the value-added of the primary industry; variable GDP2 means the value-added of the secondary industry; variable GDP3 means the value-added of the tertiary industry; variable Pop means total population; variable detGDP1 means the increment of the value-added of the primary industry; variable detGDP2 means the increment of the value-added of the secondary industry; variable detGDP3 means the increment of the value-added of the tertiary industry; variable births means the increase of the total population; variable deaths means the decrease of the total population; variable GDP means the gross domestic product; variable Tech1 means the technology level of the primary industry; variable Tech2 means the technology level of the secondary industry; variable Tech3 means the technology level of the tertiary industry; variable detK1 means the increment of the fixed asset investment of the primary industry; variable detK2 means the increment of the fixed asset investment of the secondary industry; variable detK3 means the increment of the fixed asset investment of the tertiary industry; variable detL1 means the increment of the employment of the primary industry; variable detL2 means the increment of the employment of the secondary industry; variable detL3 means the increment of employment of the tertiary industry; variable Avergdp1 means the per capita value-added of the primary industry; variable Avergdp2 means the per capita value-added of the secondary industry; variable Avergdp3 means the per capita value-added of the tertiary industry; variable detLabour means the total employment increment; variable detpop means the total population increment; variable birth rate means the number of children born per 1000 people per year in China; variable death rate means the number of deaths per 1000 people per year in China. The flow chart in the system dynamics model is shown in Figure 4.

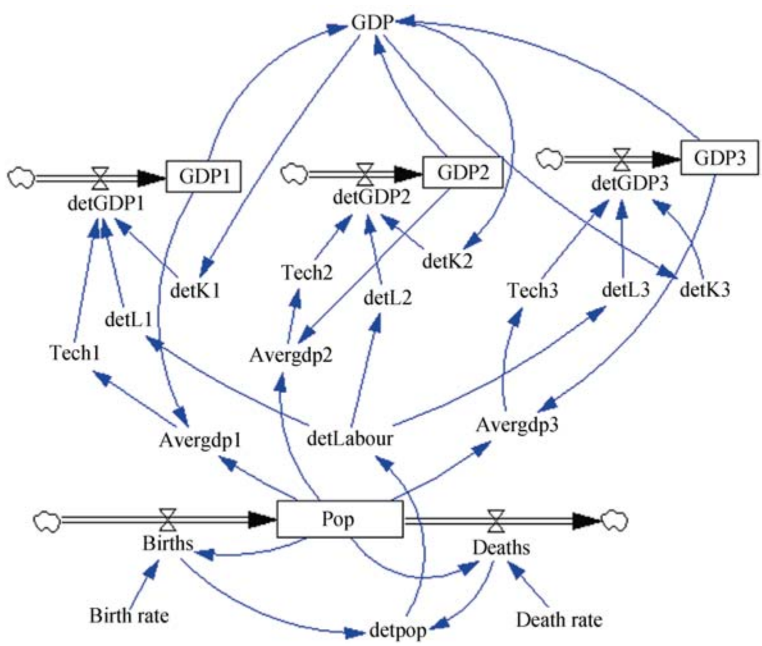


Figure 4 The flow chart in the model

The main equations (1)–(4) in the system dynamics model are as follows:

Economic growth of industry *i*

$$\det GDP_i = \rho_i Tech_i + \alpha_i^* \det K_i + \beta_i^* \det L_i + t_i \quad (1)$$

Employment increment of industry *i*

$$\det L_i = c_i \det Labour + d_i \quad (2)$$

Increment of the fixed asset investment of industry *i*

$$\det K_i = h_i GDP + f_i \quad (3)$$

The technology level of industry *i*

$$\det Tech_i = s_i Avergdp_i \quad (4)$$

In equations (1)–(4) listed above, when parameter i equals one, industry *i* is the primary industry; when parameter *i* equals two, industry *i* is the secondary industry; and when parameter *i* equals three, industry *i* is the tertiary industry. Some variables are known to us from Table 1; other variables are parameters that we need to give explicit values by the system dynamics model. In this study, we obtain the actual values and the simulation values of the three Chinese industrial structure percentages from 1991 to 2010 by the system dynamics model, which are shown in Figure 5. At the same time, we obtain the actual values and the simulation values of the Chinese gross domestic product (Figure 6).

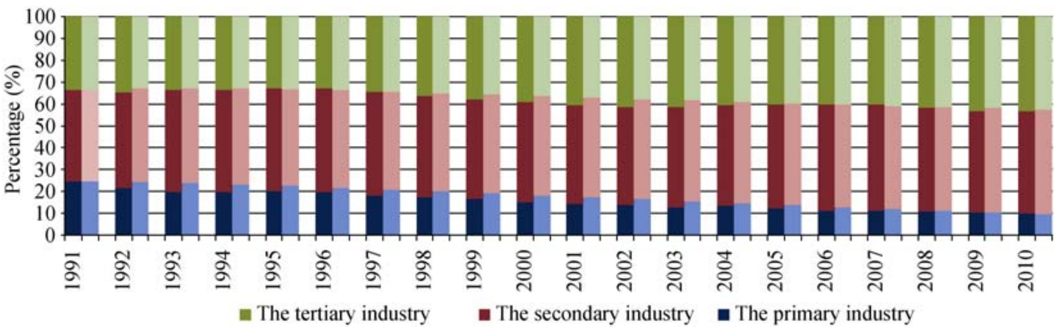


Figure 5 The percentage structural graph of Chinese three industries from 1991 to 2010
(The actual value on the left and the simulation value of the model on the right)

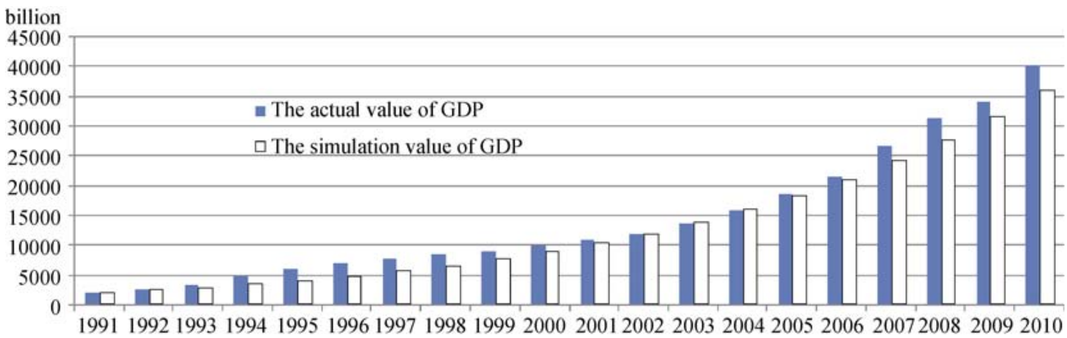


Figure 6 The actual value and the simulation value of the model for Chinese GDP from 1991 to 2010

We have approximately recovered the evolution of the three Chinese industrial structure percentages and the gross domestic product from 1991 to 2010 by the system dynamics, and the results are shown in Figures 5 and 6 above. We were also able to forecast the three Chinese industrial structures and gross domestic product in the next several years by the system dynamics model.

3 Study of the differences between physical and human process simulation in geography

The physical and human processes in geography both indicate the spatial distribution and time variation of geographical factors, and they share certain similarities. For instance, we can reconstruct how past events take place for both through mathematical models, such as differential equations, system dynamics, and linear regression. The two kinds of process simulation fit into the sequence of pressure, state and response, and both can predict future events based on the simulation's foundation to provide relevant suggestions for decision-making. When physical and human processes in geography are applied to mathematical simulation based on different theories in physical and human geography, the processes exhibit obvious differences in the recurrence of past events by mathematical simulation. These differences should be analyzed and summarized through the above two cases to provide scholarly thinking for process simulation in geography. We first compare the differences between physical process and human process simulation in geography. Next, we summarize the differences, which are listed as follows:

1) The main factors of the research framework. Regarding the physical process in geography, the geographical environment consists of numerous natural factors, and these interdependent and interacting factors invariably move and change together to form the physical process. For example, the main natural factors of weather processes include thermal factors, such as land surface, ice, sea surface, air, cloud water, and rainwater temperatures, as well as relative humidity. The main factors of the weather process also include dynamic factors, such as wind and air currents. The natural factors change continuously in various physical, chemical and biological processes under the influence of external conditions. When these factors meet certain conditions, different weather phenomena occur. Similarly, for human processes in geography, all kinds of human factors that are distributed on the Earth's surface are related and influence each other. For example, the various factors of one regional economic system can include fixed asset investment, employment, and technology, which promote the development of the GDP of the national economic system. In addition, the main factors of the national economic system include social factors, such as population, birth rate and death rate.

In short, the main factors of the research framework of physical process simulation consist mostly of natural factors, while the main factors of human process simulation consist mostly of economic and social factors. This difference is the first between physical and human process simulation.

2) The knowledge background of the systematic analysis framework. The past events of the physical process in geography that can be recovered are aimed at the natural factors on the Earth's surface. This physical process includes circulation of the atmosphere and hydrosphere and soil particle removal of the lithosphere. The flows and changes of the natural factors obey their own rules, mostly guided by physics, including fluid mechanics and thermodynamics. For example, the wind formed by airflow produced by the pressure gradient generally points from high pressure to low pressure, whether in low or high latitude regions. Human process simulation actually involves the recurrences of past human phenomena based on mathematical models. As man is a social animal, a person's activities and decisions

are affected by his or her own beliefs, values and social development, such as resource endowment and economic level, at that time. Therefore, the systematic analysis framework of human process simulation in geography complies with economic and sociological laws.

In brief, the knowledge background of the systematic analysis framework of physical process simulation mostly complies with the laws of physics, while the knowledge background of human process simulation mostly complies with economic and sociological laws. This property is the second difference between physical and human process simulation in geography.

3) Simulation data sources and quantitative method. From the first difference, the physical process simulation in geography consists mostly of natural factors. The data of these factors are obtained through direct observation from automatic weather stations, hydrological observatories, sounding balloons, remote sensing satellite and radar signals and other observational systems. Even data regarding soil-surface chemical composition or water samples needed for chemical analysis tests can be included. The data sources of the physical process in geography usually are obtained from instrumental observation data, but the accuracy of the data is often subject to the instrumental error and precision. Natural factors usually break through the boundaries of administrative areas with fluidity and continuity. Thus, the data of these factors are expressed in grid unit form in the mathematical model. The mathematical model often relies on the numerical solution of differential equations. The application of differential equations links three-dimensional space and one-dimensional time together within the framework of physical process simulation. The data of the human process show uncertainty with the temporal and spatial distribution because of the different research samples in different environments. The data are mostly from questionnaire surveys and interviews, which are first-hand information, or rely on published yearbooks and announcements, which are second-hand information. The accuracy of the data depends on the degree of representative samples.

In general, the data of physical process simulation often rely on discrete differential equation solutions to be resolved through instrumental observations, while the data of human process simulation often rely on the parameters of the statistical model through direct or indirect interviews and investigation. This property is the third difference between physical and human process simulation in geography.

4) The core of the study object and the method of forecast application. From the above three differences, we can deduce whether the research region of physical or human process simulation could be based on a global scale or a provincial scale. However, physical process simulation always focuses on various natural factors, and of course, nature becomes its core study object. As the establishment of the related physics framework, the physical process simulation in geography is a deterministic development mode relying on the observed parameters and parametric schemes; its prediction is based on the certain development track of the physical framework. Human process simulation focuses on the distribution and changes of the various human phenomena; its simulation form is not absolutely fixed or unified because of uncertain economic and social behaviors. The simulation accuracy is related not only to the observed parametric value but also to the explicit form of simulation. The prediction of the human process simulation in geography is inclined to be applied to scenario analysis because the prediction of scenario analysis complies with a person's rational

choices.

In summary, physical process simulation in geography takes nature as the core study object, and its prediction is mostly based on the certain physical framework, while human process simulation in geography takes humans as the core study object, and its prediction is mostly based on the scenario analysis. This property is the fourth difference between physical and human process simulation in geography.

4 Conclusion and discussion

This paper summarizes the abovementioned four differences between physical process simulation and human process simulation in geography by comparing two specific cases. As the two essential branches in geography, physical geography and human geography cannot be entirely isolated from each other, although their study emphasis is not identical. The distinction of physical geography and human geography is not clear to the essence of geography (James *et al.*, 1981). Mathematical simulation is a quantitative method to analyze and recover temporal and spatial geographical phenomena, and it can help us understand these phenomena precisely. Physical and human process simulation are both indispensable and have different theoretical expressions in geography. It is wrong to take the two kinds of process simulation in geography as being opposite each other or to simply determine what belongs to each.

In the history of mankind, there has always been an interaction between humans and land, and this relationship has formed the enormous system regarding this relationship, namely, the human-land system, of which the key ideology is the man-land relationship (Li, 1986; Lu, 2002). This paper summarizes the four differences that are shown through two cases concerning physical and human process simulation. The results of this study point out that the two kinds of process simulation are both essential in geography, and they often need to be applied together to reflect better the coordination of economic development and the ecological environment and to better promote the development of low the carbon economy, especially in the present situation of energy conservation and carbon emission reduction. As the tendency toward interdisciplinary research becomes increasingly important, physical and human factors maintain a close interaction in the geographical human-land system. With the development of the theory of the human-land system in geography, physical and human process simulation in geography will undergo crossing and blending. For example, the GAINS-Asia model, which was set up by Amann and Jiang *et al.*, has combined the PM2.5 distribution of physical process simulation with the energy utilization and health damage of human process simulation. Amann and Jiang *et al.* have calculated collaborative benefits under the conditions of air pollution and climate change, which are controlled. This model has achieved good results and has been applied by international research institutions, such as the IIASA, TERI, and JRC-IES (Amann *et al.*, 2008; The United Nations Development Programme, 2010).

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