Chapter 2
Perspectives on Space and Time in US and Chinese Science

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2.1 Introduction

In principle, scientific knowledge is universal, and the methods of science similarly pay no attention to national boundaries, languages, or cultures. In practice, of course, these assertions are far from true, and great differences exist in how science is conceived and practiced around the world. Nowhere is this more true than in comparing scientific practice in the US and in China. The emergence of China onto the international scientific stage is comparatively recent, following the years of the Cultural Revolution, the reopening of universities, and the very rapid growth of the Chinese economy of the past three decades.

These issues penetrate science at all levels and in all domains, and nowhere more than in geography. The very definition of geographic science demands international consistency and collaboration, because geography is at once global and transcending of boundaries. While human systems are to some extent defined by language, culture, and boundaries, environmental systems are not, and lack of free exchange of environmental data is clearly an impediment to our understanding of how the Earth's environmental systems work.

This chapter focuses on these issues as they affect research that is framed in space and time. The authors represent the US (Goodchild) and China (Gong),

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M.-P. Kwan et al. (eds.), *Space-Time Integration in Geography and GIScience*, DOI 10.1007/978-94-017-9205-9_2

and while their interests as geographers span both the social and the environmental, one has worked in recent years more on the social side (Goodchild), and one on the environmental side (Gong). Thus the chapter presents two distinct perspectives, and ranges in content from the abstract issues of scientific method to the practical issues of data collection and sharing.

The next two sections present the US and Chinese perspectives. These are then followed by a brief conclusion.

2.2 A US Perspective

2.2.1 Methodological Perspectives

Science has long given greatest importance to discoveries that apply everywhere, at all times. In mathematics, physics, and chemistry, for example, it would be absurd to announce a discovery that was only valid on certain days of the week, in certain countries or places. Newton's laws of motion, Einstein's principles of special and general relativity, and Mendeleev's periodic table are all believed to be entirely independent of space and time.

The social and environmental sciences also inherited this perspective, though there has been almost continuous debate about its merits throughout their history. In economics, for example, a strong predilection for theory emerged in a discipline that showed little interest in how the principles of economic behavior might vary through time, and between different areas of the Earth's surface. The expression of economic principles might vary, of course, because of varying conditions, but the principles themselves should remain constant. In biology, Darwin's observations of finches in the Galapagos Islands led to a unified and universal principle of natural selection, rather than to a science based on detailed description of spatial or temporal variations.

In the United States, the discipline of geography has long struggled with these issues. The *nomothetic* argument holds that geography should be concerned with discovering principles that apply everywhere and at all times in the domain of geography, that is, the surface and near-surface of the Earth (see, for example, Bunge 1966). In the late 1950s it appeared that such principles might indeed be found, and great interest was expressed in apparent empirical regularities such as Zipf's rank-size rule and Horton's laws of stream number. Arguments grounded in economics led to the regularities predicted by Christaller and Lösch for patterns of settlement, and by von Thünen for patterns of land use. The spatial interaction model predicted a regular decline of interaction with distance. But many of these regularities turned out to be no more than the most likely outcome of random processes (Goodchild 1992), and the regularities predicted by Christaller and others turned out to be far too occluded by noise to be observable in any but the weakest forms (Goodchild 1969).

Many US geographers were unconvinced by the nomothetic arguments, preferring a discipline that focused on documenting the unique properties of places, a perspective termed *idiographic*. The nomothetic perspective lost further ground when the promised empirical regularities failed to materialize, when many found its version of *explanation* to be fundamentally weak, and when others saw it as detached from the world, rather than engaged with improving the world. By the late 1970s the nomothetic perspective had lost almost all of the momentum it had gained in the previous decade.

Maps have always been an important tool for explicit display of space for research, both inside and outside the discipline of geography. Biologists have long made maps of habitat and the distribution of species; sociologists have used maps to record varying human conditions in urban environments; and political scientists have used maps to study the dynamics of elections. In the 1960s it became possible for the first time to store the contents of maps in computers, and to use them for various purposes: editing the contents of maps prior to printing, making accurate measurements of properties such as area and distance from maps, and performing the detailed mathematical calculations needed to project the curved Earth onto flat paper. By the 1970s these and other applications had coalesced into the concept of a geographic information system (GIS), an integrated computer application for capturing, editing, storing, manipulating, and analyzing the contents of maps. The first commercially viable applications appeared in the 1980s, and GIS was well on the way to becoming the multi-billion-dollar industry that it is today.

In the four decades since the initial development of GIS, its widespread adoption has led to a profound reassessment of the nomothetic/idiographic debate, of the nature of geography as a discipline, and of the significance of space and time in US science. Much of the work in this area has occurred within the field of geographic information science (GIScience), which can be defined as the scientific study of the issues surrounding geographic information and its associated technologies.

First, there are two concepts that are now recognized as universal properties of geographic information – spatial dependence and spatial heterogeneity – and several additional candidates (Anselin 1989; Goodchild 2004). Spatial dependence is the foundation principle of the disciplines of spatial statistics and geostatistics, and in its most conceptual form amounts to the observation that nearby things are more similar than distant things, a statement often attributed to Tobler (Sui 2004). Spatial heterogeneity implies that the Earth's surface exhibits uncontrolled variation, and that no place can therefore be representative of the whole. It has led to recent interest in *place-based* techniques such as geographically weighted regression (Fotheringham et al. 2002) that propose general principles, but allow the specific parameters of those principles to vary spatially and temporally over the geographic domain.

In a GIS the database captures and represents the properties of locations and thus expresses the idiographic perspective, or Varenius's concept of *special geography* (Warntz 1989). The software performs functions on the data, including analysis and modeling, applying the same functions uniformly, and thus can be seen as expressing the nomothetic perspective, or Varenius's concept of *general geography*. In this sense GIS straddles the nomothetic/idiographic debate, unifying them in a single structure.

Some of the earliest US applications of GIS were in resources management, especially in the forestry industry, where it is used to manage and plan the growth and exploitation of timber. GIS is now extensively used in planning, landscape architecture, and other disciplines that adopt an *interventionist* stance, applying science to the design, modification, and hopefully improvement of the geographic domain. Recently the term *geodesign* has come to be associated with this perspective (Steinitz 2012), which is exclusively neither idiographic nor nomothetic, but closer to the activist ideals of the 1970s critics of scientific geography.

GIS has also done much to increase the scientific community's interest in space and time, by making it much easier to study phenomena within a spatiotemporal framework (Liang et al. 2010). In epidemiology, for example, it is now much easier to make maps of rates of disease, to identify places where rates are anomalous, and to access other information about those places and their surroundings. Maps have been used to link rates of certain cancers to exposure to certain carcinogens, for example. A map (and a GIS) is now much more likely to be seen as an essential tool in any of the disciplines dealing with phenomena distributed over the surface of the Earth. Yet substantial skepticism remains. Some years ago one of the authors was engaged in conversation by a well-known US economist, who argued that the explanatory power of location, in the form of latitude and longitude, was no greater than that provided by *any* pair of socially significant variables, such as income and level of education. But this argument misses an essential point – that it is not latitude and longitude per se that explain (although causal arguments can sometimes be made, especially for latitude). Instead properties derived from latitude and longitude, such as distance, are more explanatory, and latitude and longitude provide the essential links needed to establish context, and to show how phenomena can be explained by what is near in space and time. Clearly similar explanatory arguments cannot be made for what is near *in income and education*.

2.2.2 New Data Sources and New Questions

The original motivation for GIS was the map, and the need to perform various functions on its contents. But the contents of a map are often highly synthesized and compressed versions of original observations. A topographic map, for example, is a synthesis of perhaps millions of observations of ground elevation and the positions of identified features. A printed map is also very selective in its contents, focusing on the more stable and persistent phenomena of the Earth's surface and avoiding the transitory, in order to be valid for as long as possible after printing (Goodchild et al. 2007).

Technical developments over the past few decades, many of them in the US, have brought profound changes to the nature of maps and the availability of geographic information. Instead of being exclusively the preserve of experts, maps can now be made by anyone using readily available data and software, at very little cost. Maps can be made of real-time traffic conditions, the locations of aircraft, or the ground-based view from the current location of a smart-phone user. Time has new importance, and is now increasingly integrated into GIS and geographic information generally. Yet it has proven difficult to escape the power of the map metaphor (Goodchild 1988) and its constraining influence on research and development. In the case of the automobile it took many years before the metaphor of the horse and carriage (the *horseless carriage*) could be dropped and the full potential of the new technology realized, and this same pattern has clearly influenced the integration of time into GIS.

In the US, researchers now have access to a vast flood of geographic information, a significant part of what is variously referred to as the *exaflood* or *Big Data*. The locations of aircraft, buses, fleet vehicles, and ships are now continuously monitored and in many cases made available through the Internet. Mobile phones are continuously tracked when turned on, with positional uncertainties as small as a few meters. Credit and debit cards produce spatiotemporal records whenever they are used, though these will typically be available only to banks and law-enforcement agencies. Imaging sensors on satellites create terabytes of geographic information daily, as do sensors on aircraft and unmanned drones. Ground-based sensors monitor traffic conditions at points on road networks, and companies such as Google collect ground-based images from moving vehicles and even bicycles.

While these new data are abundant, major issues exist in linking and synthesizing them into the forms needed for research and applications. Traditional research sources, such as the US Census, are collected subject to rigid procedures and norms, compiled using replicable processes, and documented with detailed metadata. As a result it has been possible for vast amounts of research to be conducted on them over the years. But the new data sources often are incomplete, with no rigorous sampling design, and little in the way of metadata or quality assurance. Elwood et al. (2013) have argued that this new world of Big Data will be dominated by the need for synthesis and *post-hoc* quality control, and will require the development of a range of new techniques.

These arguments are especially apposite in the case of geographic information developed and contributed by citizens, as distinct from qualified experts. So-called *volunteered geographic information* (VGI; Goodchild 2007) or *crowd-sourced* geographic information is exemplified by projects such as Open Street Map and Wikimapia, and now constitutes a significant source of knowledge about the geographic world that is comparable in its value to that produced by the traditional mapping agencies. Many companies now rely on VGI to update their digital street maps, and mapping agencies such as the US Geological Survey make use of citizen input as well. Goodchild and Li (2012) have reviewed the available strategies for quality assurance, and the growing literature on VGI quality has often shown accuracies at least as good as those of traditional sources, especially with respect to timeliness.

It was argued earlier that maps traditionally emphasized stable phenomena such as buildings, streets, and topography over transitory phenomena such as traffic conditions. Map-making was expensive, requiring the fielding of crews of experts. But VGI has the potential to provide timely updates and observations of phenomena in near-real time because it takes advantage of a dense distribution of citizens rather than a sparse distribution of experts. As a result VGI has become increasingly important in the creation and distribution of time-critical information about disasters such as wildfires (Goodchild and Glennon 2010). Interesting results have been obtained from the monitoring of twitter traffic, either by relying on locations embedded in messages or by using the georeferences that are associated with a small fraction of tweets.

2.3 A Chinese Perspective

2.3.1 Traditional Chinese Science

Why did modern science, with its emphasis on experiment and logical positivism not originated in China? This has puzzled many. The early maturity of the Chinese culture with its orientation towards statesmanship is part of the reason (Gong 2012a). The development of traditional Chinese science valued practicality and relied heavily on the experiences of others. The knowledge acquired from traditional Chinese science was often spread through private and mostly oral imparting from a master to his limited number of apprentices. For example, knowledge in traditional Chinese medical practice was usually handed down secretly in the family from generation to generation. Compared to the widespread publication of knowledge in western societies, knowledge from traditional Chinese science could be easily lost. The pattern of knowledge loss and re-invention in the long Chinese history has been facilitated by a culture that promotes obedience in all aspects of daily life to rules made up by ancestors. Patenting knowledge through private impartment is an important characteristic in traditional Chinese science and has had a strong influence.

The 1637 completion of the book *Tian Gong Kai Wu* (“making things like in the heaven with human technology”), written by Yingxing Song (1368–1644), was a highlight of traditional Chinese science, occurring in the late Ming Dynasty (Song 1637). It included detailed descriptions of traditional Chinese practical technologies of crop growing, silkworm growing, harvesting tools, weaving, ceramics, mining, and metallurgy. Some of the techniques and wooden instruments described in this book for wheat and rice growing and mining are still in use today. However, few abstract principles of physics and chemistry, that can be applied everywhere and at all times, have been put forward in traditional Chinese science. At around the same time, Guangqi Xu (1562–1633), mentored by foreign missionaries, became a pioneer modern scientist in China through his introduction of western geometry, arithmetic, surveying, and geography. His book entitled *Nong Zheng Quan Shu* (“comprehensive topics on agricultural affairs”), published in 1639, not only integrated historical agricultural achievements in China but also included his own contributions, obtained through his experiments in Shanghai and Tianjin (Xu 1639). Xu had hoped that a revolution in Chinese thinking would have occurred in the decades after he and Matteo Ricci translated part of Euclid's geometry into Chinese, in the early 1600s. Unfortunately, due to the downfall of the Ming Dynasty in 1644 and the succession of the Qing Dynasty (1636–1911), ruled by a minority nationality, widespread dissemination of western scientific thoughts did not happen for another 300 years.

Traditional Chinese science is primarily descriptive and less quantitative than western science. Despite the work of Guangqi Xu and Matteo Ricci in the early seventeenth century, it was unable to take advantage of western modern mathematics until recently. Traditional Chinese concepts of time are imprecise, being based on the division of the day into 12 time slots. Due to ignorance of western science and technology by the government and by humanities scholars, and the vulnerable approach to knowledge inheritance, many technologies developed in earlier Chinese history were lost and can only been seen through mentions in later writings.

Geographical knowledge is often recorded in local chronicles at the national, provincial and prefecture levels, impeding the search for nomothetic rules. Even idiographic approaches cannot be carried out thoroughly due to the lack of skills in quantitative analysis and lack of support from other disciplines such as mathematics, physics, chemistry, and biology. For example, a great expeditionary work entitled *Travel Notes of Xiake Xu* was completed in 1641, initially with 2.4 million words (only 0.4 million words remaining now). Self-supporting, Xiake Xu travelled over half of the provinces in China, primarily in southern China and mostly by himself. His travel diaries are primarily descriptive. Different from local chronicles, his diaries captured a bigger picture of China and its cross-provincial geographical conditions, including climate, landforms, living habits, products, mining, and hydrological properties (Xu 1641) at various locations. An important geographical work entitled *Du Shi Fang Yu Ji Yao* ("highlight of landmarks in historical works") was completed by Zuyu Gu in 1692, with 2.8 million words. In this book, Gu (1692) compiled from over 800 kinds of literature on geographical knowledge related to land resources, military fortresses, political evolution, and relative distances of every county in the late seventeenth century.

Modern earth science with a focus on location began in the late nineteenth century in China, when overseas Chinese scholars returned to China and began conducting field studies for mineral and coal exploration. Modern geological maps were being produced at the site and regional levels. For example, the first geological map made by a Chinese is the Geological Map of Zhili Province (now part of Hebei Province and Tianjin Municipality), developed by Rongguang Kuang in 1910. This map contains geological layers, drainage, cities, and railroad information. In the early 1900s, a handful of Chinese earth scientists returned from overseas established earth science programs in universities and research organizations. Modern geography and meteorology had been established by Dr. Kezheng Zhu in China in the 1920s. Station-based geographical data collection with instruments such as weather stations, runoff gauge stations, and water-level gauges also began in the early twentieth century. However, due to continuous national and international wars in the late 1800s and the first half of the 1900s, adding new geographical knowledge had been sporadic in space and time.

Large-scale field investigations of China's natural environment took place after 1949 in support of the rapid development of the agricultural and industrial sectors, and geographical science achieved significant progress in the 1950s and 1960s. As a result, a large number of maps at scales ranging from 1:4 million to 1:1 million were produced for the entirety of mainland China. These include maps of geological structure and mineralogy, soil, and physical geography. Large-scale topographic maps at 1:10,000–1:50,000 were being produced for the eastern part of China. In the meantime, relevant institutions developed rapidly in various levels of government. By the 1970s, in addition to agricultural bureaus established in the 1950s and 1960s, every county had a weather station, a hydrological bureau, and a forest bureau, part of whose responsibilities were collecting weather, hydrological, and timber data, respectively. Networks of weather observation, hydrological measurements, and timber inventory were rapidly developed in support of weather forecasting, flood and drought control, and planned timber production. In 1986, China began its second soil inventory which led to the production of soil maps at three scales: 1:50,000 at the county level, 1:500,000 scale at the provincial level and 1:1 million at the national level. However, due to poor archiving, many of the raw data of soil surveys were lost. In the same year, China began to monitor environmental quality in 113 selected cities under the administration of a newly established governmental agency: the State Environmental Protection Agency.

Mineral, hydrological, weather, soil, forest, environmental, and many more different types of data are collected directly under the coordination of governmental agencies at various levels. With multiple regional research institutes in geography and botany, the Chinese Academy of Sciences has completed several types of maps at the national level since the 1980s. These include China's 1:4 million vegetation map (Hou 1979) and the 1:1 million land use map in the 1980s (Wu 1990).

Geographic information systems gained popularity in the 1980s in the western world, and Chinese scholars quickly followed the trend. A state key lab was established in the Chinese Academy of Sciences on resources and environmental information systems by Shupeng Chen as early as 1989. GIS has been quickly included in university curricula. Now almost all geography programs in China offer GIS courses and many universities have established GIS departments. A large number of students specialized in GIS are employed in government agencies at various levels and in the industrial sector. This has effectively facilitated the digitizing of location-related data. Quick adoption of western concepts by Chinese scholars is also exemplified by the organization of the first International Symposium on Digital Earth in 1999 following the 1998 speech of Al Gore. In the following 9 years, the Chinese Academy of Sciences funded the International Society for Digital Earth in 2006 and the *International Journal of Digital Earth* in 2008 (Goodchild et al. 2012).

Since the 1990s, more detailed maps at the national scale have been made with digital remote sensing. Land-use and land-cover maps at 30 m resolution have been made every 5 years since 1995 (Liu et al. 2002). Wetland maps over the entirety of China have been made for 1978 (80 m resolution), 1990 (30 m), 2000 (30 m), and 2008 (20 m) (Gong et al. 2010; Niu et al. 2012). Urban expansion maps at 30 m resolution for all cities in China have been made for 1990, 2000, and 2010 (Wang et al. 2012). In addition, the 1:1 million vegetation map was compiled by Zhang (2007) and the 1:1 million landform map by Zhou (2009). In the meantime, most paper maps have been digitized and stored in various databases.

However, the temporal aspect of geographical data has lagged behind. This is reflected in a recent atlas that compiled population census data and environmental data in order to track changes from 1949 and 2009 (Gong and Liu 2010). Although China has conducted six population censuses since 1952, the finest mapping unit is at the county level, and population migration data can only be recovered at the provincial level. This has substantially restricted their use in city planning, not to mention location-based service analysis. Environmental data have a short history since 1986 and are limited to only 113 cities. This makes it impossible to have a comprehensive view of China's environmental change, not to mention forming widely applicable environmental policies. Recently atmospheric-quality analysis by third parties using satellite remote sensing has been demonstrated to be a viable solution (Zhang et al. 2012).

The situation with respect to temporal data is quickly improving thanks to the large number of satellites for environmental observation that are scheduled to be launched by the Chinese government (Kramer and Cracknell 2008), as well as to an intensification of ground-based observation networks. For example, in the 1990s the Chinese Academy of Sciences began to establish a network of ecological monitoring stations (the Chinese Ecosystem Research network) (Sun 2006; Yu et al. 2004). It has since grown to 46 stations in various ecosystems that provide data supporting research for thousands of researchers. Monitoring networks empowered by Internet and wireless sensor-network technologies serving different functions are being widely established by governmental agencies. For example, in order to prevent and control infectious diseases similar to the 2003 Severe Acute Respiratory Syndrome (SARS) from causing large-scale damage to public health, China developed in 2004 the Infectious Disease and Emergent Public Health Event Web-based Direct Reporting System linking all hospitals at township level and above. This system has been in operation for 9 years and has collected detailed information on 39 infectious diseases for the entirety of China on a daily basis. Also, many hydrological gauge stations are based on wireless sensor-network technology.

In summary, traditional Chinese science is empirical, descriptive, and handed down often privately through family inheritance or imparted from masters to apprentices. These characteristics are different from western science, which is experimental, quantitative, and analytic, and in which the spread of knowledge is rapid through publishing and open speech, that is later transformed into university lectures, seminars, and workshops. This restricted approach to the spread of knowledge made it hard for new ideas and new technologies to be quickly transmitted in ancient China. Geographical knowledge in space and time has been acquired only since the early twentieth century, particularly after 1949, following the widespread introduction of modern science. The collection of spatial and temporal data has been dramatically accelerated since the turn of the twenty-first century, supported by modern information technologies.

2.3.2 Challenges and Opportunities

Although significant progress has been made in spatiotemporal data collection and handling in China, some unique challenges exist. The most significant one is data sharing. From the above introduction it can be seen that with the exception of data created by the Chinese Academy of Sciences, most of the data products at the national level have been developed by governmental agencies. Access to small amounts of data at limited locations may be possible, but it is extremely difficult to obtain data for the entirety of China. For example, survey data such as topographic data at scales greater than 1:1 million are regarded as secret. Although hydrological data are not regarded as secret they are rarely accessible by the research community. Even among governmental agencies data are not sharable. For example, both the State Meteorology Administration (SMA) and the State Hydrology Bureau (SHB) collect precipitation and temperature data, and the number of weather stations operated by the latter is an order more than that operated by the former. But they do not share the data. Neither the SMA nor the research community has the opportunity to use the weather data from SHB to intensify the observational network and improve weather prediction. The second challenge is the lack of quality assurance to the data owned by the governmental agencies. For example, forest inventory data are collected through reports from provincial forest bureaus, who obtain their data from reports from the counties. Manipulation of data cannot be well tracked and quantified. Thus, the credibility of governmental data is uncertain. The third challenge, as discussed earlier, is the lack of creativity in making use of spatial and temporal data.

Chinese scientists currently face the best opportunities in history. They are now relatively well funded even compared with their colleagues in the western world. More creativity is naturally expected as the outcome. While sharing geographical data in China is a great bottleneck to the scientific community, additional efforts must be made to change the Chinese bureaucracy to improve data sharing among governmental agencies and the general public. The lack of quality assurance of the governmental data can be alleviated by using direct mapping methods, as in mapping wetlands and atmospheric quality using widely available remotely sensed data (Gong 2012b; Niu et al. 2012; Zhang et al. 2012). With the same group of people, the same set of tools, and the same sources of data, the whole China can be mapped more consistently under proper quality control. It is expected that through interdisciplinary collaboration and improved quantitative skills, Chinese scientists will bring more creativity in the analysis and effective use of spatial and temporal data (Xu et al. 2010). Lastly, China has a rich archive of local chronicles that contain geographic information through time. This unique source has been explored by some scholars of historical climate (Zhu 1972; Zhang 2004; Ge 2010). More coordinated extraction of spatiotemporal information from such data sources is necessary.

2.4 Conclusion

Tools for spatiotemporal analysis and modeling are currently in a state of flux, a result of rapid innovation in data collection and techniques of analysis, as well as in greater demand for real-time decisions and better planning. Yet as we have shown in this chapter, great differences still exist in the cultural and political context within which these tools must be used. While discussions aimed at improving data sharing and exchange are under way at several levels, the cultural and linguistic differences that have created the formidable impediments we see today will take much longer to address. We would be wise, also, to reflect on Chinese history and the political earthquakes that in the past have halted fragile progress. Nevertheless there are reasons to be optimistic, especially given the very rapid growth in scientific communication and exchange of personnel that has occurred between the US and China in the past decade. Organizations such as CPGIS (the International Association of Chinese Professionals in Geographic Information Sciences) are doing much to foster exchange, through cross-appointments, joint conferences, and publications. China's economic awakening of the past three decades is now reflected in a steady scientific awakening, and to creativity and innovation on a new and massive scale.

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Space-Time Integration in Geography and GIScience
Research Frontiers in the US and China
Kwan, M.-P.; Richardson, D.; Wang, D.; Zhou, C. (Eds.)
2015, XII, 412 p. 128 illus., 82 illus. in color., Hardcover
ISBN: 978-94-017-9204-2