Geomorphology and GIS: A Review with an Emphasis on Japanese Classic Morphometric Studies

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地形学とGIS－日本の古典的地形計測研究との関連で

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Abstract: GIS and DEMs have frequently been applied to geomorphological studies in Japan since the 1990s. Increasing availability of DEMs with various resolutions has facilitated this trend. Between the 1930s and 1960s, some Japanese geomorphologists conducted innovative morphometric studies based on manual analyses of topographic maps. These studies are relevant to the modern GIS/DEM-based studies, but this fact is often overlooked. This paper provides a brief historical review on geomorphology in Japan in general, the Japanese classical morphometric studies, and the recent GIS-related studies.

Keywords: Morphometry（地形計測）, DEM（デジタル標高モデル）, Japan（日本）

I. Introduction

Geomorphology is a core discipline within physical geography, and like other scientific disciplines, researchers in North America and Europe have played a leading role in developing research since the 19th century. In the early days, concepts and techniques developed in North America and Europe were often applied to landforms in other regions of the world; whereas, the exchange of ideas in the opposite direction was much more limited.

Recent years have seen a rapid globalization of science, linked to advances in electronic communication. As a result, geomorphologists outside North America and Europe have started to publish research papers in international scientific journals and books. For example, during the 1990s there was a large expansion in the number of English papers written by Japanese geomorphologists in international journals.

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As Walker and Grabau (1993) indicated, the history, characteristics and priorities of geomorphological research differ between nations. Physiographic and environmental settings may account for these differences; for example, countries located in cold climatic regimes or high mountains have often developed strong traditions in periglacial geomorphology. This type of explanation, however, cannot be applied to GIS-related research, which is not specific to particular environments.

This paper discusses the background of GIS applications in Japanese geomorphology, including the history of Japanese geomorphology in relation to western countries and Japanese classic morphometric studies based on manual analyses of topographic maps. Japanese studies using Digital Elevation Models (DEMs) are also reviewed. Although this paper focuses on examples from Japan, it might provide some clues for examining national development in geomorphological and geographical research at a global scale.

2. Brief history of geomorphology in Japan

The Meiji Restoration of Japan in 1868 established a new Japanese Government that encouraged exploration

of advanced science and technology from western countries. Many western professors were invited to Japan. In 1876, the German geologist, E. Naumann, was installed as the first professor of geology at the University of Tokyo. He undertook geomorphological studies including the classification of the large-scale topography of the Japanese Islands. The Japanese Government also sent young researchers to western universities. N. Yamazaki spent three years in Germany, studying geomorphology with A. Penck. On his return to Japan in 1902, Yamazaki identified glacial cirques in the Japanese Alps based on the knowledge he gained in Germany. The first department of physical geography in Japan was established in 1911, at the University of Tokyo. Yamazaki was promoted to be a professor there, and his student, T. Tsujimura, became a lecturer in 1920.

Tsujimura translated the technical terms of geomorphology from western publications into Japanese and applied them to landforms in Japan. Most Japanese studies before World War II were published in Japanese-language journals such as *Journal of Geography* (*Chigaku Zassi*, published by Tokyo Geographical Society since 1889) and *Geographical Review of Japan* (*Chirigaku Hyouron*, published by the Association of Japanese Geographers since 1925). A rare exception beforeWorldWar II is G. Imamura's paper on glacial landforms in the Japanese Alps, published in English in a German journal (Imamura, 1937). The paper was highly innovative in an international context, introducing a new means of classifying cirques, based on the percentage hypsometric curves. This work was published some fifteen years before A. N. Strahler received considerable recognition for applying the percentage hypsometric curves for topographic comparisons (Strahler, 1952). Another paper with high international impact in the mid 1950s was a paper on the longitudinal profiles of the gravel-bed rivers (Yatsu, 1955) has been evaluated as a 'benchmark paper' within the field (Schumm, 1972). Until the end of the 1980s, however, the dissemination of most Japanese geomorphological research continued to be restricted mainly to domestic journals and books written in the Japanese language. Although articles in Japanese journals often quoted foreign publications (especially those from North America and Europe), papers written by Japanese geomorphologists were rarely quoted in international publications, owing to their lack of accessibility to non-Japanese speakers. This resulted in a significant 'import surplus' in Japanese geomorphology and a widely held belief amongst Japanese geomorphologists that models from North America and Europe were 'set in stone' and were thus applied to Japanese landforms with little critical evaluation. This resulted in problems of misinterpretation, because landforms and their processes of formation are often very different in Japan, which is subject to rapid tectonic activity and heavy rainfall (Oguchi et al., 2001).

It was not until the late 1980s and the 1990s that researchers properly evaluated the specific characteristics of Japanese environments in geomorphological studies. The real globalization of Japanese geomorphology began in the 1990s when increasing numbers of papers on Japanese landforms appeared in international journals such as *Catena*, *Earth Surface Processes and Landforms*, *Geomorphology*, and *Zeitschrift für Geomorphologie*. In addition, Japanese journals such as *Geographical Review of Japan* and *Transactions Japanese Geomorphological Union* also started to carry more geomorphological papers written in English. There seem to be several reasons for the increased international contributions from Japan in the 1990s. First, as noted above, Japanese researchers became more aware of the dangers of simply applying models developed in very different physiographic and climatic regimes, and realized the importance of disseminating results and ideas from Japanese research experience. Second, the foundation of the International Association of Geomorphologists (IAG) in 1989 significantly enhanced the international exchange of information in geomorphology. Third, the Japanese Geomorphological Union (JGU), founded in 1980, has established a close link with IAG. Fourth, publishing in English has become more popular amongst Japanese researchers: English publications, especially those carried in international journals, have now become a requirement for obtaining senior research positions in major universities and research institutes in Japan. As a result of this rapid internationalization, Japanese geomorphology in general seems to have achieved significant international standing and has attained a level comparable to wider international standards.

3. Morphometry, DEMs and GIS in Japanese geomorphology

Japan has a strong tradition in terrain analysis. Imamura's (1937) paper mentioned in the previous section is a classic example. Some other classic Japanese studies were also based on objectives and methods common to more recent work using DEMs (Digital Elevation Models) and GIS, although they depended on manual work using topographic maps (e.g., Tada, 1934; Yoshikawa, 1956). Some of them proposed unique methods of geomorphometry like Imamura

(1937); for example, Terada (1925) invented a method to estimate slope angle within a square cell on a topographic map using the number of contour lines crossing the edge lines of a cell. The most comprehensive work in this category was performed by Y. Sakaguchi in the 1960s. He created a DEM for all the Japanese Islands with a one arc-minute grid interval, manually from topographic maps, and summarized the data using mechanical desk calculators to provide an area–altitude curve for Japan (Sakaguchi, 1964). He applied the same method to various regions of the world such as the European Alps, the Jura Mountains, the Main Island of Taiwan, and the Sierra Nevada Mountains (Sakaguchi, 1966, 1968, 1969). He inferred relationships between general topography and past crustal movement based on these area–altitude curves. His studies depended on a large amount of manual labour. Meanwhile, in Canada in the 1960s, R. Tomlinson was also constructing the Canada Geographic Information System (CGIS), the first spatial analysis system bearing name 'GIS'. Experiments of digital mapping were also performed in the Laboratory for Computer Graphics and Spatial Analysis at Harvard University (Chrisman, 1998). In Japan, by contrast, computers were not widely used within geography and the geosciences during the 1960s, and consequently Sakaguchi's research relied on tedious manual methods. Manual data processing restricted the variety of his analysis; he did not perform analysis using any other geometric signature than height (Pike, 1988), because manual derivation of other parameters from DEMs was too time-consuming. DEMs created by Sakaguchi were also projected using the longitude/latitude co-ordinate system, and thus the area allocated to each grid point changed according to location. The lack of computers also restricted accurate consideration of this effect and, as a first approximation, Sakaguchi assumed that each point had the same areal weight.

A computer analysis of the 11.25"×7.5"DEM compiled by the Geographical Survey Institute of Japan in the mid 1990s has provided a revised area–altitude curve for the Japanese Islands (Oguchi, 1997). The change in metric grid interval according to location was taken into account. The resultant curve is more precise than Sakaguchi's curve, and the segmentations of the curve can be correlated with altitudinal zoning of erosion/deposition processes. Although this re-analysis confirms that Sakaguchi's work had some limitations, it does not in any way diminish the value of his pioneering work. One important aspect of Sakaguchi's work is the wide aerial extent of his studies: he dealt with the morphometric characteristics of whole countries and mountain ranges. In the 1960s, researchers of geomorphometry often concentrated on small watershed areas and hillslopes, under the influence of preceding studies such as Horton (1945) and Strahler (1952). Sakaguchi's interest in broad scale analysis may have been inspired by Gyle (1961) as well as classic publications by A. and W. Penck; however, the analyses he performed on his original data were unique and highly innovative.

Influential books on computer data analyses in geosciences were published in the 1970s (e.g., Chorley, 1972; Davis, 1973) and main-frame computers became more widely available for Japanese scientists in the 1970s. Consequently, the analysis of DEMs using computers began in Japan (e.g., Hirano and Yokota, 1976). In the 1980s, personal computers became a major platform for DEM-related studies (e.g., Nogami and Sugiura, 1985). By the 1990s, the propagation of GIS commercial software and the official release of DEMs from the Geographical Survey Institute facilitated more widespread DEM terrain analyses in Japan (e.g., Nogami, 1995; Katsube and Oguchi, 1999). However, studies related to DEMs and GIS have been a relatively minor component of Japanese geomorphology before the 1990s, despite the pioneering work on DEM analyses in Japan before the 1960s. During the 1970s and 1980s, other fields of geomorphology such as tectonic, fluvial, glacial, periglacial and hydro-geomorphology were much more popular.

In recent years, DEMs and their analyses using GIS have become increasingly popular not only in geomorphology. In February 2000, the NASA Space Shuttle Mission (STS-99) was launched to collect high-quality, high-resolution DEMs for the entire earth surface. The resultant SRTM DEM for the whole globe has frequently been used. Another global DEM dataset, ASTER G-DEM, became available recently. Moreover, very high-resolution DEMs (e.g., 1 m) collected by airborne LiDAR (Light Detection And Ranging) have also become a major data source for detailed geomorphological analysis. Following this trend, numerous Japanese scientists are conducting research using GIS and DEMs. However, many of them, particularly young ones, do not pay attention to classic Japanese geomorphometric studies although they are relevant to today's studies, and some of them were innovative even in an international sense.

4. Concluding remarks

Increased availability of DEMs of various resolutions and the propagation of GIS has facilitated quantitative

geomorphological studies. Indeed, many Japanese researchers have been conducting such studies since the 1990s. Between the 1930s and 1960s, geomorphometric studies using topographic maps and manually produced DEMs were also conducted and some of them were highly unique in an international sense, although many of them have been unknown to foreign researchers. Because of the decreased number of such studies during the 1970s and 1980s, the link or similarity between the recent DEM/GIS-related studies and the classic morphometric studies in Japan tend to be overlooked. However, the classic studies need to be revisited. Their international uniqueness at that time is particularly important from the historical point of view, because earth science in Japan in the mid 20th century tended to take ideas from western studies. It would be interesting to compare this research review for Japan with that of another country outside North America and Europe such as Korea.

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(J) in Japanese.
(JE) in Japanese with English abstract.