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Geomorphology 76 (2006) 148–165

GEOMORPHOLOGY

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Geomorphological mapping of glacial landforms from remotely sensed data: An evaluation of the principal data sources and an assessment of their quality

M.J. Smith [a,b,*], J. Rose [b], S. Booth [b,c]

[a] *School of Earth Sciences and Geography, Kingston University, Kingston-upon-Thames, Surrey, KT1 2EE, UK*
[b] *Department of Geography, Royal Holloway, University of London, Egham, Surrey, TW20 0EX, UK*
[c] *British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK*

Received 27 July 2005; received in revised form 1 November 2005; accepted 2 November 2005
Available online 19 December 2005

Abstract

This paper presents the results of an experiment to compare glacial geomorphology mapped from remotely sensed imagery with 1 : 10,000-scale field mapping. The field mapping was validated against high resolution LiDAR imagery of an area glacierized during the Younger Dryas and found to provide an essentially reliable, if not complete, representation of the glacial geomorphology. The experiment consists of comparing the field mapping with digital elevation models (Shuttle Radar Topography Mission C-Band, Landmap, OS Panorama®, OS Profile®, NEXTMap) and satellite imagery (Landsat Thematic Mapper) of a 100-km^2 region of central Scotland, north of Glasgow, that was last glaciated during the Last Glacial Maximum and during the Younger Dryas, respectively c. 14.5 and 11.5 cal. ka BP. For the purposes of this exercise, we concentrated on glacial lineaments (flutes, drumlins, and crag and tail), but attention was also given to moraine ridges and eskers. Qualitative and quantitative comparisons are performed and the results show that of the remotely sensed data sets, only NEXTMap Great Britain™ provided results that showed any approximation to the field mapping. OS Panorama® and OS Profile® provided very poor approximations, and the other methods fail to provide any information of value. Attention is given to the issues of scale and the differences between a small-scale detailed study, such as this experiment, in which a high resolution glacial geomorphological reconstruction is required, and the small-scale studies where the remote sensing techniques used here provide important evidence of regional significance when glaciers formed the largest elements of the landscape. The paper concludes with a consideration of protocols for future geomorphological mapping exercises, and outlines some of the requirements that must be adopted as these protocols are developed.

Keywords: DEM; Glacial; Drumlin; Bedform; Geomorphological; Mapping; Satellite

1. Introduction

Glacial systems have a dynamic and pivotal role in the control of global climate (Ruddiman et al., 1989). Therefore, precise and accurate representation of landforms and sediments as proxies of past glacial and glaciofluvial processes is critical. Sediments have been

* Corresponding author. School of Earth Sciences and Geography, Kingston University, Kingston-upon-Thames, Surrey, KT1 2EE, UK. Tel.: +44 208 547 7500; fax: +44 208 547 7497.
E-mail address: michael.smith@kingston.ac.uk (M.J. Smith).

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doi:10.1016/j.geomorph.2005.11.001

the subject of extensive research (Brodzikowski and van Loon, 1991; Benn and Evans, 1998), but landforms have received far less attention, even though landform mapping dates back to early geological research (Close, 1867) and has been subject to a number of studies in the 1960s and 1970s (Rose and Letzer, 1975).

The reconstruction of the dynamics of glaciers and ice sheets from landform evidence requires the synthesis of regional data sets, integrated across multiple scales. Initially researchers used information such as contours and hill-shading to depict glacial landforms (Rose and Letzer, 1975), then used field mapping to record landforms upon topographic base maps (Close, 1867; Charlesworth, 1928, Rose and Letzer, 1977). To a large extent, this methodology has now been superceded by remote sensing techniques such as aerial photography (Prest et al., 1968), satellite imagery (Punkari, 1982) and the application of digital elevation models (DEMs; Clark and Meehan, 2001).

Aerial photography provides detailed visualisation of surface morphology and is still used extensively for fine resolution landform mapping (Jansson, 2005). However the analysis of landform patterns, as well as individual landforms, requires the study of large areas which generates high costs, a result of flying time and photogrammetric processing. High quality field mapping and aerial photographic interpretation are relatively expensive methods.

In contrast, satellite imagery has large areal coverage, relatively low cost and enables relatively rapid rates of mapping (Punkari, 1982; Clark, 1997). Low to moderate resolution multi-spectral satellite imagery (e.g. Landsat and ASTER) currently offer maximum spatial resolutions up to 15 m, allowing moderate detail to be mapped. If detailed geomorphological mapping is required, then very high resolution sensors (e.g. IKONOS and QuickBird) may offer spatial resolutions comparable to small scale aerial photography (1–4 m). However, data costs are high.

DEMs are perhaps the most promising data source for future research as they record absolute elevation and can therefore be used to visualise landscapes (spatial resolution: 1–90 m). With free access to the near-global Shuttle Radar Topography Mission data (SRTM), DEMs are set to become an important data source for landform mapping.

Despite the number of techniques involved and a general awareness of their benefits and weaknesses, there has been no direct comparison of all the methodologies. In this paper, we test the reliability of seven individual data sets (Table 1) against 1 : 10,560-scale geomorphological field mapping for over 100 km^2 of terrain. The assessment evaluates measures of data set completeness (errors of omission and commission), geometric accuracy, locational accuracy, and landform classification. We conclude with recommendations as to the suitability of different data sets for mapping glacial landforms.

2. Methodology

2.1. Experimental design

In order to assess the quality of different remotely sensed evidence the imagery and interpretation needs to be compared with a reference data set. For the purpose of this study the field data set is used as the reference set. Inevitably, this design has an inherent weakness: namely the quality of the geomorphological mapping that produced the field data. We have attempted to overcome this by testing the geomorphological mapping against a LiDAR (light detection and ranging) derived DEM which has 2-m spatial resolution and provides a very close approximation of relief configuration.

Table 1
Data sources used for landform mapping

	Image number	Nominal resolution (m)	Relative vertical accuracy (m)	Acquisition date
Field mapping	4a	<1.0	1	1965–1970
Digital elevation models				
Shuttle Radar Topography Mission C-band	4f	90	6	02/2000
Landmap	4e	25	20	1995–1996
OS Panorama®	4d	50	5	Maintained until 2002
OS Profile®	4c	10	5	Maintained
NEXTMap	4b	5	1	2002–2003
LiDAR	3	2	0.25	03/2003
Satellite imagery				
Landsat Thematic Mapper	4g	30	–	23/10/1986