Geomorphology 270 (2016) 121–133

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Invited review

Technology and geomorphology: Are improvements in data collection techniques transforming geomorphic science?

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ARTICLE INFO

Article history:
Received 1 October 2015
Received in revised form 1 July 2016
Accepted 7 July 2016
Available online 11 July 2016

Keywords:
Remote sensing
UAV
Geophysics
Field methods
Sensors
Molecular taxonomy
Geogenomics

ABSTRACT

In recent years technological developments have revolutionized our ability to collect data in geomorphology. Enhanced data collection not only enables us to provide deeper answers to a wider range of fundamental questions about the Earth's surface, but also encourages us to pose new questions. This paper considers in more detail the relationships between science, technology and the development of geomorphological tools and techniques, reviews the spectrum of tools and techniques now available to geomorphologists, and critically assesses what impact 'new technologies' are having on geomorphology. It focuses on the role of technology in biogeomorphology and weathering research, and how it is advancing theoretical, empirical and applied dimensions of these growing sub-fields of geomorphology. Five areas of important technological development are reviewed: remote sensing, dating, geophysical techniques, field and laboratory based analysis and sensing of physical and chemical characteristics, and field and laboratory based analysis of biological properties. There is good evidence that, taken together, technological developments are revolutionizing geomorphology through opening the doors to better cross-scalar investigations, blurring the boundaries between laboratory, field and computer model, and facilitating cross-disciplinary and democratized research.

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1. Introduction

In a recent paper on the role of fieldwork in today's geomorphology, Mike Church proposed that 'What has happened most recently … – so recently in fact that it is not possible to see what the end may be – is that further technological development has furnished geomorphologists with the tools to return to the grand question, what is the history of the surface of the Earth?' (Church, 2013, p. 192). A recent, more quantitative survey by Piégay et al. (2015) poses the question of whether fluvial geomorphology has entered a new era because of recent technological revolution. Piégay et al. (2015) focus in particular on the plethora of new sources of remotely sensed data, terrestrial laser scanning and new radiometric dating techniques which are being

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http://dx.doi.org/10.1016/j.geomorph.2016.07.011
0169-555X/© 2016 Published by Elsevier B.V.

increasingly deployed to tackle long-standing research questions. They report that, alongside such technological developments, fluvial geomorphology has also been marked in recent years by increasingly internationalized and interdisciplinary approaches to knowledge production. Both Church (2013) and Piégay et al. (2015) go some way towards answering Steven Wainwright's call for a more 'sociologically-aware' history of geomorphology in which developing technology, ideas and professional structures all intertwine to shape the subject (Wainwright, 2012).

Technology and geomorphology have long been intertwined. A recent review by Wohl et al. (2016) highlights the importance of developments in remote sensing technology, as well as geochronologic and isotopic methods to the progress of geomorphology over the last 50 years. An earlier paper on the trajectory of geomorphology (Church, 2010) illustrated the importance of improvements in technologies in remote sensing and survey, revolutions in computing facilities, and developments in absolute dating techniques in shaping geomorphology at the end of the 20th century. This paper builds on and updates Church's observations and argument, whilst providing more detail on the varied uses of improved data collection techniques and how they are re-shaping geomorphology.

The three aims of this paper are: a) to consider in more detail the relationships between science, technology and the development of geomorphological tools and techniques, b) to review the spectrum of tools and techniques now available to geomorphologists, and c) to critically assess what impact 'new technologies' are having on geomorphology. Instead of tackling the issues, as other reviews have done, from the perspective of fluvial geomorphology, I focus here on a 'view from the margins' of geomorphology, through exploring the applications of technological developments to biogeomorphology and weathering. These components of geomorphology are marginal in the sense that they have very close links to other disciplines such as ecology, ecohydrology, engineering and heritage science. They are also marginal in the sense that they have often been neglected in mainstream accounts of geomorphology (Stine and Butler, 2011). But they are also important contributors to the overall status and nature of geomorphology, providing valuable insights into the workings of Earth surface systems. As sub-fields of geomorphology they are also representative of the field as a whole. This paper also focuses on technological developments as applied to data collection and generation in field and laboratory settings, rather than in terms of numerical modeling. In recent years the boundaries between these three core components of geomorphic practice have become blurred, largely as a result of technological innovation. Whilst modeling has been the focus of many papers on geomorphological practice in recent years, field and laboratory practices have been relatively neglected. However, the importance of fieldwork in weathering research has recently been reiterated by Dorn et al. (2013), and the importance of laboratory experimentation to geomorphology in general has been stressed by Bennett et al. (2015).

2. Technology, techniques science and geomorphology: underpinning concepts and issues

What do we mean by technology? The European Space Agency (ESA website accessed 10/9/2015) defines it neatly as '...the practical application of knowledge so that something entirely new can be done, or so that something can be done in an entirely new way'. The distinction between technology and science is encapsulated by Andy Lane (Open University website, accessed 10/9/2015) as that: 'Technology is about taking action to meet a human need rather than merely understanding the workings of the natural world, which is the goal of science.' Science and technology are complexly related, and different types of science interface with technology in different ways. Geomorphology is largely seen as a secondary or derivative science and thus its relationship with technology is likely to be very different to that of, for example, theoretical physics. Insights from theoretical physics may, often indirectly, spawn technological innovations; but it is more likely that geomorphology will be a downstream user of such technological advances. Techniques can be defined as the individual tools that utilize technology, and are the entities that geomorphologists engage with. In many cases geomorphology adopts and adapts techniques developed for other uses – leading to many challenges for best practice use and for understanding the meaning of results. A science such as geomorphology may, indeed, be shaped by technological change and development because new research questions may be able to be answered with the advent of new techniques.

Despite the clear distinctions between science and technology made above, technology and science are both complexly related to innovation, and these relationships change over time (Brooks, 1994). The need for innovation in industry and society provides a key driver of development in technology and science. Such external drivers of both science and technology have been noted in many historical studies (Jacob, 1997). For example, Merton (1938) points out how in 17th century England rising population and the concentration of people into towns and cities led to many problems such as poor sanitation and the need to provide and transport sufficient food, coal and building materials. As Merton (1938, p. 572) notes these challenges 'serve to direct technologic and scientific research into fields appropriate for the solution of these problems.' A similar situation may be identified more recently, with environmental problems such as soil erosion and flooding influencing both technology and science. In today's world, however, the drivers for developments in science and technology are often medical and military, and many of the techniques geomorphologists now use originated in these fields (including space exploration). Aerial photography, for example, developed as a surveillance technique in the first world war, with early imagery now of great use in tracking geomorphological change (Fig. 1). Whilst geomorphology is often a relatively late user of technologies developed as a response to medical, military or space exploration needs, geomorphological problems can contribute to the further development of technological solutions where these problems relate to societal challenges large enough to stimulate innovation.

Technological innovations in the late 19th and the 20th centuries which influenced geomorphological fieldwork and laboratory experimentation have been effectively reviewed by Church (2013) and Bennett et al. (2015). Bennett et al. (2015), for example, note increasingly sophisticated equipment for experimentation (such as flumes and environmental cabinets) contributing to 'transformative research' over this period. Transformative research is where research is driven by ideas that have the potential to radically change interpretations or understanding. For example, Ralph Bagnold's pioneering work on aeolian processes from the 1930s onward which greatly enhanced understanding in this area was assisted by his engineering skills in building wind tunnels and the multiple portable manometer (Fig. 2). The examples of transformative research that Bennett et al. (2015) give show the need for visionary leadership, scientific and/or societal need, involvement of a federal agency or institution, new or repurposed facilities, and straddling disciplines. Technological developments are thus a necessary but not sufficient basis for transformative research.

So what are the main technological developments in the last few decades likely to be having an influence on the nature and practice of geomorphology? Underpinning most of the techniques discussed later in this paper is the move from analogue to digital, and in particular developments in image capture devices (such as cameras) to allow rapid collection of imagery over many different wavelengths. From military and surveillance fields there are a whole raft of new platforms on which to mount such image capture devices – from new satellites in Earth orbit, to unmanned aerial vehicles (UAVs or drones), time lapse and surveillance camera set-ups, and microscopes. Comparable data can now be collected at widely differing spatial scales and at high temporal resolution. Miniaturization, automation (both of data collection and data storage), field portability and robustness, and ever decreasing costs are all making a huge difference to the ability of