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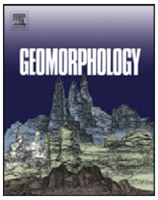

'You are HERE': Connecting the dots with airborne lidar for geomorphic fieldwork

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ABSTRACT

The emergence of airborne lidar data for studying landscape evolution and natural hazards has revolutionized our ability to document the topographic signature of active and ancient surface processes. Notable lidar-facilitated discoveries, however, would not have been possible without the coupling of fieldwork and lidar analysis, which contradicts the ill-considered notion that high resolution remote sensing technologies will replace geomorphic field investigations. Here, we attempt to identify the primary means by which lidar has and will continue to transform how geomorphologists study landscape form and evolution: (1) lidar serves as a detailed base map for field mapping and sample collection, (2) lidar allows for rapid and accurate description of morphologic trends and patterns across broad areas, which facilitates model testing through increased accuracy and vastly increased sample sizes, and (3) lidar enables the identification of unanticipated landforms, including those with unknown origin. Finally, because the adoption of new technologies can influence cognition and perception, we also explore the notion that the ongoing use of lidar enables geomorphologists to more effectively conceptualize landforms in the field.

1. Introduction

For early geomorphologists, field observations were central to how they investigated study sites and perceived the evolution of landscapes. Although this statement may seem obvious, upon considering the recent proliferation of maps and digital geospatial data, it invites an exploration of how technology influences how geomorphologists develop intuition about landscape development. As one of the forefathers of geomorphology, G.K. Gilbert's dependence on field observation and expedition living was so embedded in his psyche that he included a drawing entitled 'Ways and Means' depicting his mule, Lazarus, Duke of York, in his seminal 1877 report on the Geology of the Henry Mountains. Although whimsical at first blush (note that the illustration only appears in the first printing of the report), this drawing reflects Gilbert's reliance on and reverence for (what we now consider) 'old-school' technology that facilitated his protracted and far-flung field campaigns. In a related vein, Luna Leopold's contributions firmly establish the primacy of field observations, especially quantitative ones. Many of Leopold's publications begin with a simple statement about a fundamental landscape property that can be readily noted in the field, even with the untrained eye. For example, his 1966 article on river meandering begins with "Is there such thing as a straight river? Almost anyone can think of a river that is more or less straight for a certain distance, but it is unlikely that the straight portion is either very straight or very long" (Leopold and Langbein, 1966).

Decades later, digital topographic data, remote sensing imagery, and computing power afford the opportunity to readily witness many of the most captivating features on Earth not only via field observation but also from one's office. Initially, coarse-scale maps and data sets enabled geomorphologists to analyze broad landscape patterns, thus, facilitating collaboration with structural geologists and geophysicists concerned with large-scale geological problems, such as plate boundaries and fold-thrust belts. For process-scale studies of hillslope processes and valley network organization, however, the standard topographic data sets generated from aerial photos (with point densities of 1 point per 900 m^2) proved to be too coarse. Maps or imagery, such as shaded relief models generated from these early DEMs (digital elevation models), revealed landforms, but they systematically failed to portray features that are readily identifiable in the field (Fig. 1). For example, the finest scale of channels and interfluves, which defines drainage density, as well as potential shallow landslide sources in steeplands, is typically not resolved by 30-m DEMs (Montgomery et al., 2000). As a result, the most readily available and widely used topographic data sets failed to portray landforms that reflect fundamental geomorphic problems regarding the organization of the surface of Earth as well as potential natural hazards (e.g., Duffy et al., 2012). More so, contour maps derived from these data often proved intractable for successful identifying one's

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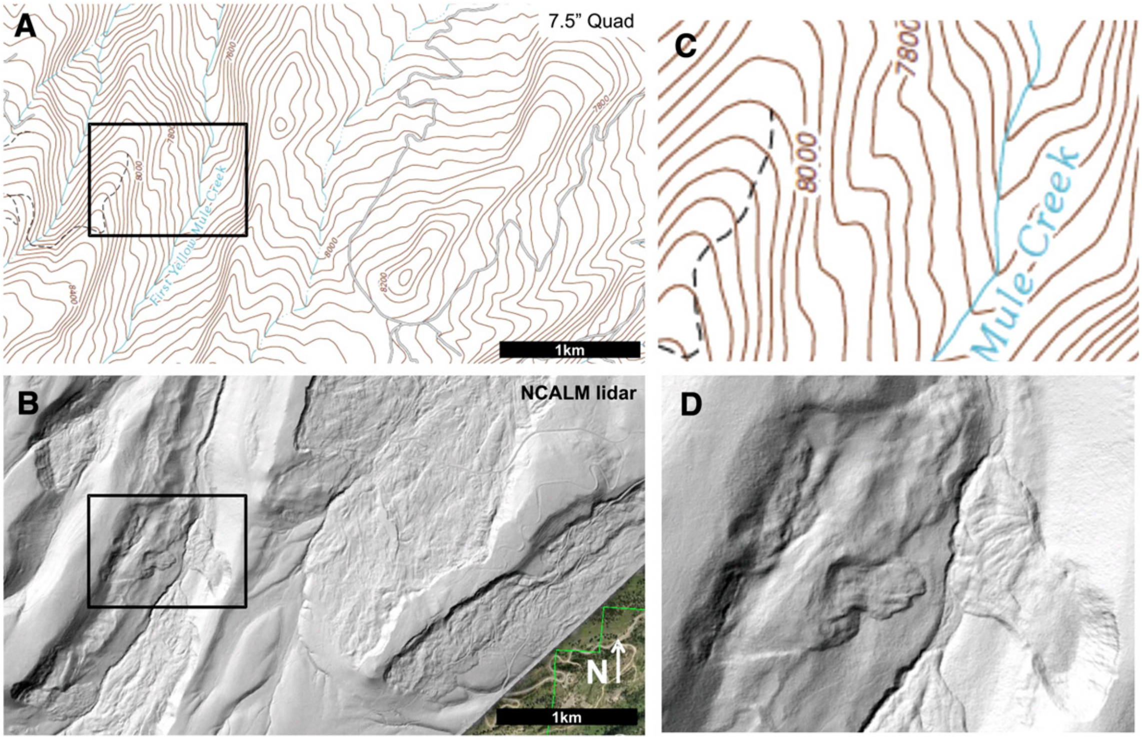

Fig. 1. Comparison of terrain near Big Sky, Montana, represented with USGS 7.5″ topographic map (A, C) and airborne lidar (B,D). The boxes in A and B correspond to the enlarged areas shown in C and D, respectively. Large landslides have shaped the vast majority of the area, including slumps and flow-like features. The topographic signature of individual landslides is clearly visible in the lidar imagery, but not apparent in the USGS contour data.

location in the field, further limiting the utility of available DEMs for process-scale geomorphic research.

Instead, investigations of process-scale geomorphology required extensive fieldwork, particularly surveying, to document and analyze spatial patterns of landscape morphology at the relevant resolution. The advent of total stations (theodolites and lasers) and global positioning system (GPS) receivers provided critical tools for topographic surveying even though acquisition rates were slow, costly, limited in scope, and challenging in remote and steep regions. Dense vegetation and steep terrain, in particular, can render total stations and GPS ineffective by blocking sight lines and satellite signals. As a result, the pressing need for high resolution topographic information guaranteed that process-oriented geomorphologists remained actively engaged with their study sites through extended field campaigns.

In the late 1990s, the increasing availability, affordability, accuracy, and point density of airborne lidar data sets constituted a monumental advance in our ability to resolve process-scale landforms. The importance of this technological innovation for geomorphic research cannot be overstated. Airborne lidar does not represent an incremental increase in data density: it enabled a more than two orders of magnitude increase in topographic information (Fig. 2). Research-grade, lidar-derived bare-earth point densities commonly exceed 1 point per square meter (Slatton et al., 2007); at this resolution, features such as gully heads, landslide scars, channel banks, and bedrock tors can be readily identified and mapped from afar. Remarkably, geomorphologists were suddenly given the ability to work with maps that portrayed an arguably complete depiction of channel networks. This technology has been used in scores of geomorphic papers, including many that tackle the same fundamental questions that challenged Gilbert, William Morris Davis, and subsequent generations of field-oriented geomorphologists.

In this contribution, our goal is not to simply highlight scientific discoveries enabled by lidar. Rather, we explore how the availability of airborne lidar has changed how geomorphologists go about their work, particularly their field investigations. In undertaking these tasks, we emphasize many of our own lidar-enabled contributions because we possess first-hand knowledge of how the availability of lidar imagery influenced our research process, including the fieldwork. The list of lidar-facilitated findings is vast and includes the identification of previously unmapped faults in metropolitan areas and the discovery of paleo-landslide dammed lakes. The complete context of these discoveries, however, would not have been realized without significant fieldwork in concert with lidar analyses. The perception that desktop, virtual geomorphic investigations fueled by lidar and an array of other remote sensing imagery will replace ‘Boots on the ground’ geomorphic observation simply has not come to fruition, and we contend that it will not. Instead, scientific investigation using both lidar and targeted field observation has strong potential as an efficient and effective means of geomorphic analysis (Church, 2013).

Our survey of the literature suggests that airborne lidar has influenced geomorphic research in the following ways: (1) lidar serves as a detailed base map for field mapping and sample collection, (2) lidar allows for rapid and accurate description of morphologic trends and patterns across broad areas, which facilitates model testing through increased accuracy and vastly increased samples sizes, and (3) lidar enables the identification of unanticipated and sometimes unexplained landforms. Lastly, we will explore the notion that exposure to lidar data affects how geomorphologists perceive landscapes in the field. Recognizing that lidar now enables geomorphologists to easily map subtle differences in hillslope convexity or surface roughness, has this enhanced morphologic knowledge increased our awareness of reality? In other words, does lidar stimulate new ways for us to conceptualize natural landscapes?

2. Pre-lidar technologies for documenting topography

Prior to the advent of lidar, geomorphologists relied primarily on field techniques, such as sketches, plane table/alidade surveys, inclinometers, pressure altimeters, and total stations, to quantify local landform morphology. Gilbert (1877) described the geology and surface processes of the Henry Mountains using field sketches and