The sky is the limit: reconstructing physical geography from an aerial perspective

Abstract

In an era of rapid geographical data acquisition, interpretations of remote sensing products are an integral part of many undergraduate geography degree schemes but there are fewer opportunities for collection and processing of primary remote sensing data. Unmanned Aerial Vehicles (UAVs) provide a relatively inexpensive opportunity to introduce the principles and practice of airborne remote sensing into fieldcourses, enabling students to learn about image acquisition, data processing and interpretation of derived products. Two case studies illustrate how a low cost "DJI Phantom Vision+" UAV can be used by students to acquire images that can be processed using Structure-from-Motion photogrammetry software. Results from a student questionnaire and analysis of assessed student reports showed that using UAVs enhanced student engagement and equipped them with data processing skills. The derivation of bespoke orthophotos and Digital Elevation Models has the potential to provide students with opportunities to gain insight into various remote sensing data quality issues, although additional training is required to maximise this potential. Recognition of the successes and limitations of this teaching intervention provides scope for improving future UAV exercises. UAVs are enabling both a reconstruction of how we measure the Earth's surface and a reconstruction of how students do fieldwork.

Keywords

Aerial imagery, Digital Elevation Model (DEM), fieldwork, physical geography, Structure-from-Motion photogrammetry (SfM), technology, Unmanned Aerial Vehicle (UAV)

Introduction

A key attribute of geography graduates is an ability to acquire, represent and interpret spatial data (e.g. maps, aerial photographs, satellite imagery), and to use these data to interpret the physical and human aspects of landscapes. Over the last decade, the quality and availability of aerial photographs and satellite imagery has rapidly increased following the release of virtual globes such as Google Earth (Tooth, 2006, 2013), and these have provided invaluable resources for learning and teaching in geography in schools and higher education (Tooth, 2015). In physical geography, such resources have been supplemented by increased open access to high resolution (metre and sub-metre in the horizontal, with c. 0.1 m vertical accuracy) three-dimensional Digital Elevation Models (DEMs). For example, LiDAR data is available via OpenTopography in the USA (www.opentopography.org; Krishnan et al., 2011) and via the UK Government Data portal in England (https://data.gov.uk/). Furthermore, the development of Unmanned Aerial Vehicles (UAVs) now enable scientists and environmental managers to acquire high-resolution aerial imagery (Anderson and Gaston, 2013; Carrivick et al., 2103; Eisenbeiss et al. 2011; Hugenholtz et al., 2012; Marris, 2013; Turner et al., 2016), and Structure-from-Motion (SfM) photogrammetry (James and Robson, 2012; Micheletti et al., 2015; Westoby et al., 2012) enables orthophoto and DEM production from a projected two-dimensional motion field that is generated from a set of images. Coupling these data acquisition and processing technologies together thus provides opportunities to generate high resolution digital topographic datasets (Lucieer et al., 2014; Tamminga et al., 2015; Tonkin et al., 2014; Woodget et al., 2014; Westoby et al., 2015) that are generally lower in cost for areas less than c. 1 km^2 than datasets derived from manned aircraft surveys (Glennie et al., 2013; Lillesand et al., 2015). Physical geographers, and in particular geomorphologists, are at the forefront of these technical developments and applications (Passalacqua et al., 2015; Tarolli, 2014). In the social sciences, research is being directed towards examining the use of UAVs in a range of applications, including military (Greene, 2015; Shaw, 2013) and civilian (Culver, 2014; Finn and Wright, 2012), while Birtchnell and Gibson (2015) describe an exercise to explore the reactions of human geography students to using UAVs. Yet within university geography departments, the principles and practices of primary UAV image acquisition and associated data processing have not been widely transferred to the undergraduate curriculum (Jordan, 2015), despite the transformative potential for enhancing student understanding of the nature, rates and drivers of landscape changes.

Following a brief review of the role of technology in physical geography student fieldwork, the aim of this paper is to summarise a teaching procedure whereby students can use a low-cost UAV and off-the-shelf SfM software to produce an accurate, high-resolution orthophoto and DEM. We present the teaching and learning procedure adopted during two case studies undertaken during a physical geography fieldcourse; one is an instructor-led exercise whilst the other is from an independent student group project. We evaluate the outcomes by considering: (i) the results from a questionnaire that was completed after the first case study; (ii) the level of engagement with the technology that was achieved in the second case study; and (iii) our own reflections on student learning.

Physical geography fieldwork and technology

Teaching students in the field is of paramount importance for inherently field-based disciplines such as physical geography (Fisher, 2001). In the UK's quality code for higher education (QAA, 2014), fieldwork is described as a characteristic and essential element of undergraduate geography degrees. Abundant pedagogical research also suggests that not only are students motivated by fieldwork (e.g. Fuller et al., 2003) but learn more outside than in the classroom (Salvage et al., 2004), particularly because experiential learning in the field also leads to deep learning (Auer, 2008).

Fuller et al. (2006) note that students like using technical equipment in the field, designing their own research projects, and analysing data. Nevertheless, despite some notable exceptions, there are relatively few assessments of teaching and learning when using instruments or other technologies during undergraduate fieldwork (FitzPatrick et al., 2012; Fuller and France, 2016; France et al., 2016; Welsh and France, 2012; Welsh et al., 2012; Welsh et al., 2015). In part, this may be because instruments are not being regularly deployed during fieldwork teaching. Indeed, in a survey of undergraduate fieldwork practitioners, Welsh et al. (2013) found that technology tends to be used before and after fieldwork, but was least used during fieldwork. For those who were using technology in the field, the four most commonly used types of hardware were digital cameras, GPS, smartphones and phones. This situation contrasts with the use of electronic sensors and data recording through remote sensing and digital storage in contemporary physical geography field-based research (Church, 2013) and applied environmental management. A gap is thus emerging between data acquisition and remote sensing in research and the applied environmental workplace, and what is being taught at the undergraduate level. In the UK, ‘technology use’ (e.g. UAVs) in field contexts has even been identified as part of a more general fieldwork “skills gap” by graduate employers in the environmental sector (Natural Environment Research Council, 2012). Embedding more technologically-enhanced learning (JISC, 2011) into geography fieldwork, especially those approaches based around remote sensing, therefore may make a contribution not only to student engagement and learning but also to improving graduate job prospects. Against this backdrop, we undertook an investigation of teaching and learning outcomes based on coupling geomorphological fieldwork with remote sensing technologies.

Context, exercise development and evaluation

All geography undergraduate students at Aberystwyth attend a residential fieldcourse during Semester 2 of their second year. In 2015, two of the authors (RDW and MG) led a fieldcourse to the South Island, New Zealand (Figure 1a), which lasted 10 days and focused upon the themes of fluvial geomorphology, glaciology and natural hazards. Additionally, the long-haul fieldcourse is also intended to engender lifelong experiences, and deep learning (Robson 2002) through a focused independent research project at the end of the course. During the first eight days, the eleven registered students visit a range of fluvial and glacial landscapes and develop practical field skills in geomorphological mapping, sediment analysis and stream gauging. Students use a range of instruments and technologies including handheld GPS, Real Time Kinematic GPS (RTK-GPS), UAVs, interpretation of SPOT satellite imagery, and dilution gauging of river flow. In the final two days, students apply the skills that they have developed to an independent group project of their choice.

Case study 1: Braidplain planform

The first use of UAVs during the fieldcourse was for an exercise on mapping braidplain planform. This exercise takes place on a reach of the Rees River (Figure 1B) where morphological change has been investigated by the lead author (e.g. Williams et al., 2014; Williams et al., 2015), thus enabling research-led teaching. Channels actively erode and deposit sediment, and therefore migrate across the braidplain during high flows. This dynamism provides opportunities for students to analyse how the channels change, by comparing archived aerial imagery to surveys carried out during the fieldtrip. In previous fieldcourses, this exercise had involved students walking along channel edges and using a handheld GPS to record channel positions. However, we recognised that a teaching intervention could be made to enable students to learn how to acquire images using a UAV. The fieldwork featured two tasks. Initially, students distributed plastic targets across the braidplain and surveyed the centre of each target using an RTK-GPS system (Uren and Price, 2006) to obtain a coordinate with c. 0.01 m accuracy. Next, students were given an explanation of the technical components of a "DJI Phantom 2 Vision+" UAV (cost of £965 in 2014) and a demonstration of its controls (Figure 2). In brief, this UAV is a quadcopter with a 14 megapixel camera supported by a three axis gimbal stabiliser. The UAV is operated using a remote control and the camera is operated through the DJI Vision smartphone app, which also gives the operator a live feed from the camera. Each student learnt to fly the UAV and acquire images, at 4 s intervals, from a height of approximately 100 m above the braidplain. Flight speed was adjusted to ensure a minimum of five overlapping images for each pixel of the orthomosaic. Aber et al. (2010) outline standard formulae for calculating photographic scale and resolution, which can be used to plan the image coverage and ground sample distance that can be achieved for a particular flight duration. Before flying, students were briefed on the Civil Aviation Authority of New Zealand's rules for the use of Remotely Piloted Aircraft Systems.

In the evening, while the students observed, the lead author used Pix4D SfM processing software to produce orthophotos and DEMs of the 0.15 km^2 study area (Figure 3). After image processing was complete, the students were asked to complete an anonymous questionnaire (Table 1) that asked what they thought they had learnt from the exercise as a whole, the links they could make to other undergraduate modules, whether they enjoyed the exercise, and what they thought could be improved.

Case study 2: Glacial lake outburst flood topography

Three students decided to use the UAV for their independent group project, which aimed to reconstruct the channel morphology and peak discharge of the 1913 Mueller Glacier lake outburst flood (GLOF) at Kea Point (Figure 1c). The students' objectives were to describe the outburst flood channel by generating a topographic map and to quantify peak discharges using empirical relations similar to the methods of Kershaw et al. (2005). The procedure was similar to that employed for the first case study, with the students initially laying out 50 ground targets across the study area and each target location being surveyed using an RTK-GPS system. Set up of the GPS base station was supervised by a staff instructor prior to target emplacement but flying of the UAV was undertaken by students once all targets were placed. To complement the UAV data, the size of 50 transported sediment clasts was measured to provide additional information for input into empirical peak flow calculations. After data collection, and once back in the UK, the students were supervised in the production of an orthophoto and DEM using SfM processing software (Figure 4). The students then calculated cross-sectional area of the GLOF channel using the SfM-derived DEM.

Results

Case study 1: Braidplain planform

Nine out of eleven students answered the survey. Table 1 summarises the results and lists example responses to the qualitative questions. Overall, the results show that students were engaged with the use of technology in the field. The first question asked students what they learnt from the exercise. Most students stated they learnt how to fly a UAV and they learnt how to use an RTK-GPS system (Table 1). The second question asked students to list whether they thought that anything they learnt linked to other modules they were taking. While the students on the fieldcourse could be following a variety of module combinations, this question was designed to give an indication of the broader connections that students could identify. All students listed at least two other second year modules. Two students listed the third year dissertation module, indicating that some students were also thinking about future research projects (Table 1). The third question asked each student whether they enjoyed the fieldwork and to explain their answer. All nine students answered yes. The explanations (Table 1) suggest that students were engaged with the use of fieldwork technology. The fourth question asked what could be improved. In common with answers to the third question, which demonstrated enthusiasm for the UAV technology, seven out of nine students responded by saying that they'd like to spend more time flying the UAV. One respondent commented that they would like to use the UAV to monitor other environments, such as glacial landscapes. In their answers to the final question, which asked students to make any other comments, students commented both on their engagement with the exercise and their broader experiences (Table 1).

In addition to the student survey, the exercise was also reviewed by an independent member of the fieldwork teaching team as part of Aberystwyth University's Peer Observation of Teaching procedure. Their comments also provide a useful evaluation of student learning and engagement during the field exercise: "The exercise engaged all students at several levels, even to the point that they were extremely keen to lay out targets across the floodplain to act as points of ground truthing - normally a somewhat mundane task. This innovative class appealed to several learning modes, including tactile, visual and audible." This review therefore reinforces the results from the student questionnaire and illustrates how technology can be deployed during fieldwork to engage students.

The main drawback to the first case study was that whilst students were engaged with collecting field data, there was not an opportunity for students to process the data themselves. This was due to a lack of laptop processing capacity in the field camp, which meant that students had to be shown how to process the data by the lead author. As a result, the responses to the survey focused upon data collection rather than processing.

Case study 2: Glacial lake outburst flood topography

Since each student's independently-written project report was part of their fieldcourse assessment, evaluation of the skills they gained through using the UAV and associated data processing software could be made by reviewing the assessed work. All three students processed the image dataset (299 photos) to produce an orthophoto and DEM of the 0.13 km^2 study area (Figure 4). The DEM enabled calculation of the cross-sectional area of the GLOF channel, which was subsequently used as an input to slope-area methods to estimate peak discharge through the channel. The students' reports demonstrated a clear understanding of the application of the technology-based results, linked these results with the more conventional clast analysis data effectively, and showed how the results could provide insight into flood-related landscape dynamics. However, the students did not acknowledge the uncertainties involved in collection and post-processing of imagery (e.g. positioning of targets, spatial overlap of photos over the study area), an omission that was particularly evident in their discussion sections. To address this omission in future exercises, it may be appropriate to provide training before embarking on data collection in the field, and then hold a supervised, student-led workshop on post-processing following the first data collection exercise. By doing this, students would gain a greater insight into the data collection and processing, uncertainties in these methods, and ways in which they can be overcome. Complementing use of such technologies in the field with technical skill development in class-based work would further students' understanding of methods whilst undertaking fieldwork, and get them thinking more deeply about the post-processing that is involved to achieve the final data product. In addition, they would also gain a greater understanding of appropriate uses of these technologies and the extent of their application in other aspects of the curriculum.

Reflection and discussion

The two case studies on the application of UAVs to acquire aerial imagery provide examples of how technologically-enhanced learning can be achieved during fieldwork. Student comments in the questionnaire that was completed as part of the first case study (Table 1) illustrate that they engaged in the exercise and enjoyed the research-led nature of the activity. However, higher-level cognitive skills were only developed by those students who applied the techniques they had learnt during the first field exercise to develop an independent group project that applied the technology. Through their independent project reports, this small group of students demonstrated that they were synthesising information gained from their geomorphological- and technological-based training to address a specific research question associated with deriving a topographic model. This model was then used to extract information (e.g. cross sections) for input into empirical formulae to estimate peak discharge during an outburst event.

In the student questionnaire, almost all students identified that they had learnt new skills through flying the UAV and using an RTK-GPS system to survey the ground targets. The exercise is similar to that described by Sander (2014), who developed an exercise for students to use a digital camera mounted on a kite to acquire imagery. Whilst a UAV cannot be used on wet and windy days, it is generally more versatile than a kite across a range of environments and seasons. Although Birtchnell and Gibson (2015) describe a UAV demonstration to students, they did not provide students with the opportunity to acquire data. Giving students control of the UAV and the experience of placing and surveying targets presents opportunities for learning about the principles and practice of remote sensing, ranging from georeferencing, acquiring imagery, photogrammetry and image analysis. It also maintains an environment – associated with more traditional forms of fieldwork – where students can work in small groups to solve problems. In the first case study, students did not have the opportunity to process their data due to limited processing capacity; this could be addressed by designing practicals where students process lower resolution images or fewer images and thus a smaller geographical extent. Issues associated with data quality, such as the optimum target layout and the application of the output orthophoto and DEM to investigate particular physical geography research questions, can also be explored by students, and there are also social science applications (Birtchnell and Gibson, 2015). Students who were engaged in processing the imagery and target locations through their independent projects extended and deepened their learning. They also gained additional skills in processing large datasets. This indicates that learning is most effective when technology that is used in the field is also supported by broader engagement with processing software immediately after data acquisition, and in classroom practicals before and/or after fieldwork. Such knowledge is likely to equip students with the skills needed for future careers that are closely related to geography, such as in applied environmental management.

Conclusion

Over the last decade, the vastly enhanced availability of aerial photography and satellite imagery has been invaluable for teaching and learning in geography, particularly by providing new perspectives to advance students' perceptions of physical and human phenomena on the Earth's surface (Tooth, 2013, 2015). Nonetheless, a lack of connection commonly exists between use of remote sensing products and the associated principles and practices of remote sensing data collection and analysis in field contexts. In a fieldcourse in New Zealand, we attempted to address this disconnect. During fieldwork, all students gained skills in using UAVs and associated electronic instrumentation that is commonly used in research and applied environmental practice, as well as knowledge about the production of orthophotos and DEMs. Students who were involved with processing imagery for their independent group research projects deepened their learning. They also gained additional knowledge and skills by processing the large dataset, and applying the technology to address a specific research question about landform configuration and flood discharge reconstruction. Reflections on the field exercises indicate that an additional processing component could be embedded into pre- or post-fieldwork classes to maximise the opportunity for learning and further analysis of the derived products. This will increase career opportunities for geography graduates and more broadly will contribute towards realising visions of a Digital World, one in which increasing numbers of people are engaged in exploring and learning about the Earth using geospatial technologies (Goodchild, 2012; Craglia et al., 2012).

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Table 1 Questions from the survey that was given to the eleven students after case study 1. Nine students completed the survey.

Number	Question	Summary of responses
1	What did you learn from the exercise?	How to fly a UAV: identified by eight students How to use RTK-GPS: identified by seven students The laws surrounding UAV flight: identified by one student How to place ground targets: identified by one student How to post-process the data and produce a DEM: identified by one student
2	Did anything you learn from the exercise relate to other modules you are taking? If so, which ones?	All responses listed least two other second year modules, including catchment systems, research skills, sedimentary environments, GIS, geohazards and remote sensing. Two responses listed the third year dissertation module.
3	Did you enjoy the fieldwork? Please explain your answer	Nine out of nine responses replied “yes”. Examples of explanations include: (i) “it was interesting because I was able to actively engage in cutting edge research”; (ii) “it was much easier to learn seeing processes in action and make learning more interesting”; (iii) “the session [was] interactive and the topic and technology was exciting”; and (iv) “it was interesting to see the method behind map production and aerial photography”
4	What could be improved?	More time flying the UAV: identified by seven students Using the UAV in other landscapes (e.g. glacial): identified by one student
5	Do you have any further comments?	Example responses include: i) “I really enjoyed all aspects of the fieldwork, have learnt loads and find it helpful being able to ask questions all of the time”; ii) “I made a new friend”; and iii) “I enjoyed it and learnt a lot”

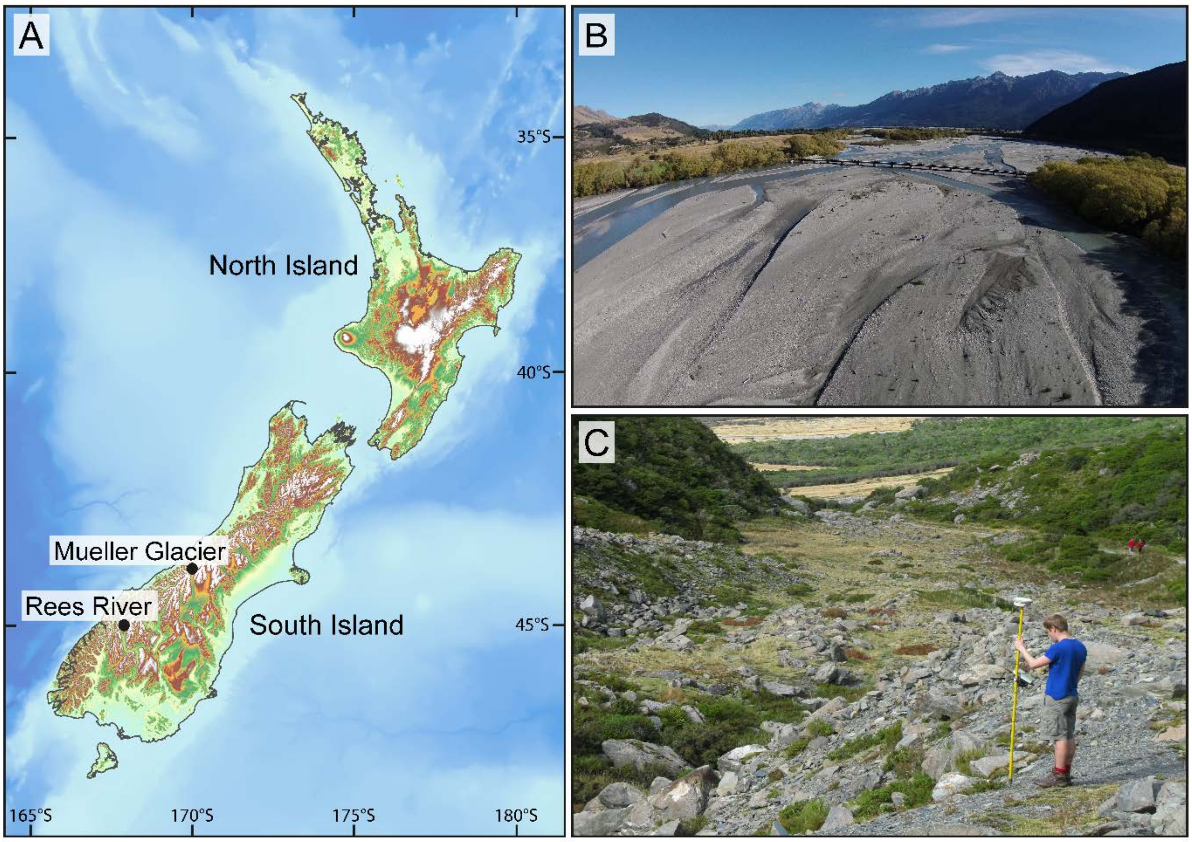

Figure 1 (A) The location of the two case study sites in New Zealand, (B) The Rees River braidplain. Oblique image taken using the UAV described in this paper. (C) Mueller Glacier outburst flood valley, showing a student using RTK-GPS.

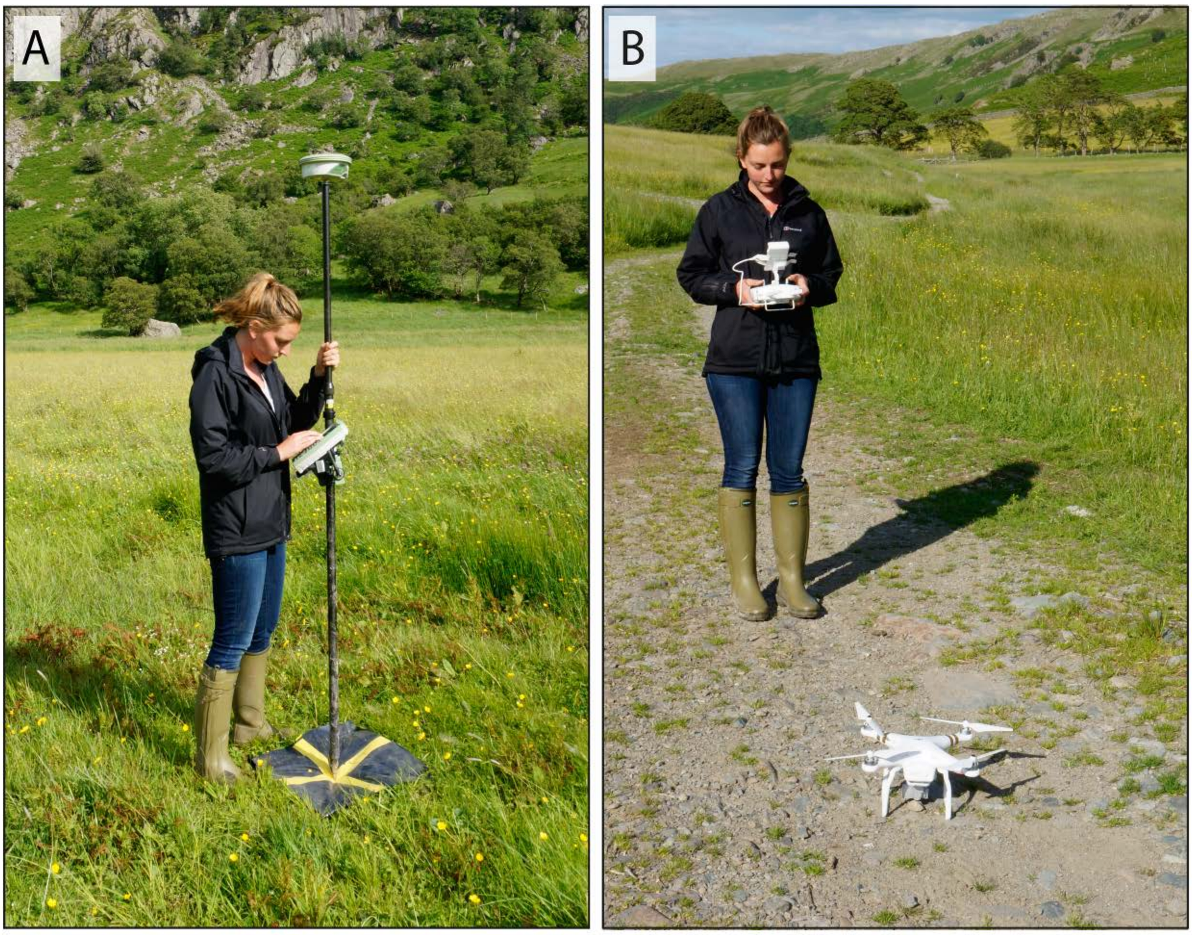

Figure 2 Fieldwork procedure for students to acquire aerial images: (A) RTK-GPS survey of a ground target; (B) Operation of the remote control for a DJI Phantom UAV. Note that these photographs were taken during undergraduate fieldwork in the UK rather than during the New Zealand fieldtrip but they illustrate the same procedure.

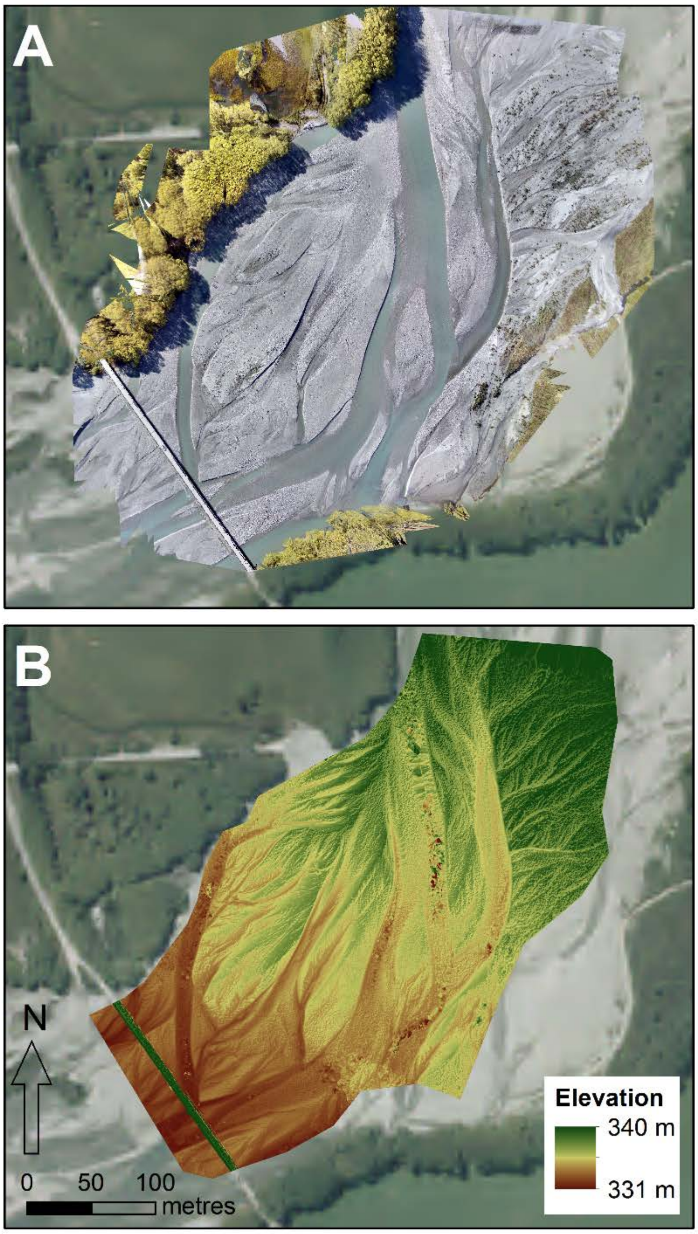

Figure 3 (A) Orthophoto and (B) Digital Elevation Model of the braided Rees River, New Zealand (flow direction from top right to lower left). The maps were produced using images acquired from a “DJI Phantom 2 Vision+” UAV and Structure-from-Motion photogrammetry, processed using Pix4D software. Artefacts, such as the bridge decking on lower left and the errors in derivation of bed levels along some wet channels on centre right of the image, could form the focus of discussion about DEM editing tools. Underlying aerial photography has been made available by Otago Regional Council.

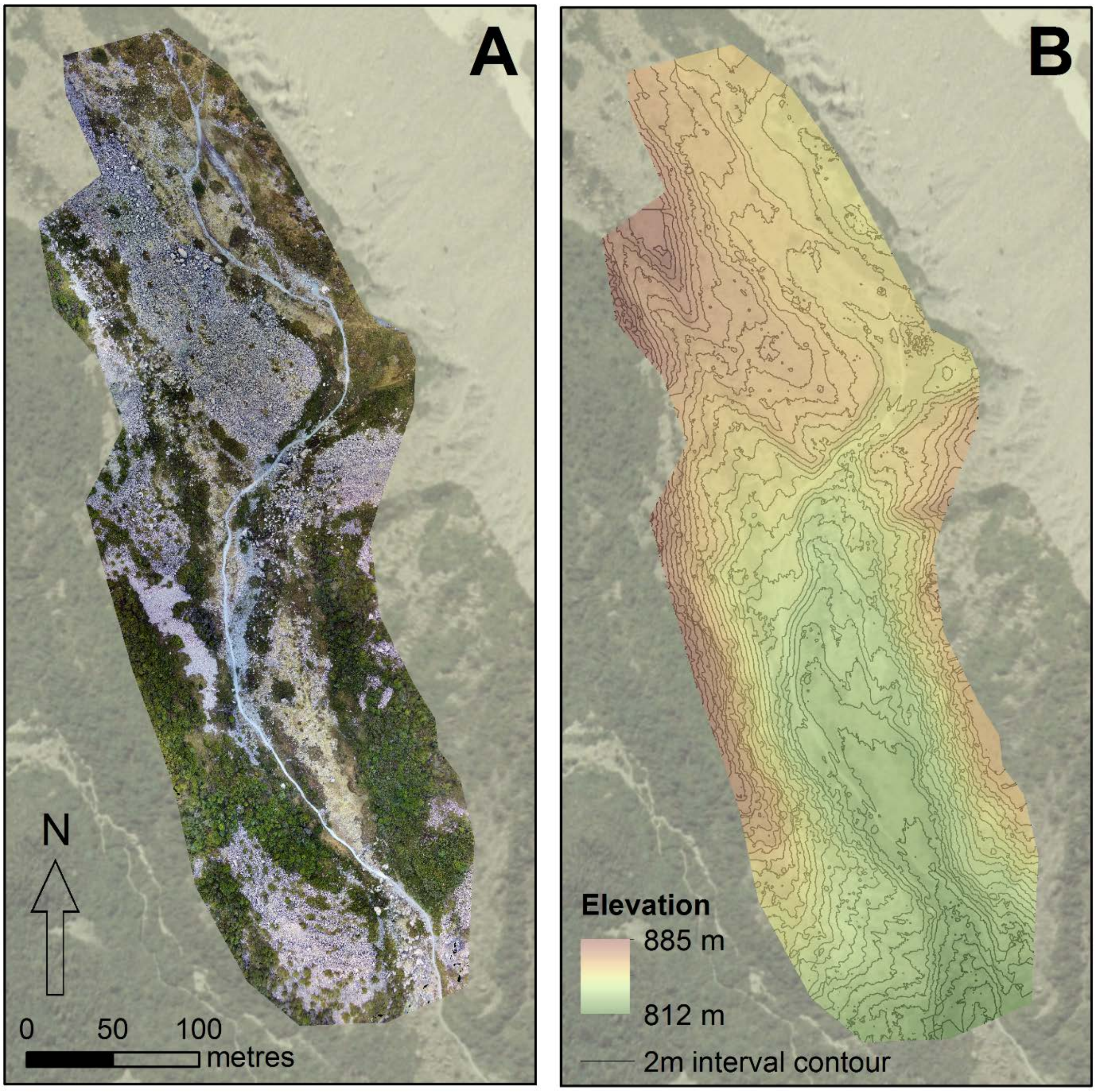

Figure 4 (A) Orthophoto and (B) Digital Elevation Model of a valley formed by a glacial lake outburst flood at Kea Point, New Zealand (flow direction from top left to lower right). The maps were produced using images acquired from a "DJI Phantom Vision+" UAV and Structure-from-Motion photogrammetry, processed using Pix4D software. Underlying aerial photography has been made available by Environment Canterbury through ArcGIS Open Data, licensed under a Creative Commons Attribution 3.0 New Zealand License.

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