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Short Communication

Mapping of Periglacial Geomorphology using Kite/Balloon Aerial Photography

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ABSTRACT

Kite and balloon aerial photography is introduced as a remote-sensing method for periglacial features and vegetation. High-resolution aerial pictures obtained by this method from Alaskan study sites are used for geometric analysis of ice-wedge networks, quantification of patterned ground, and mapping of water and vegetation. High-resolution aerial photographs could be an important data set for monitoring changes in permafrost pattern, periglacial processes and vegetation over time and space. Copyright © 2003 John Wiley & Sons, Ltd.

KEY WORDS: kite/balloon aerial photography; periglacial geomorphology; mapping patterned ground

INTRODUCTION

Kite and balloon aerial photography (KAP/BAP) is a well-known remote sensing method and has been used for scientific surveys, meteorological observations and military surveillance for centuries. With new, light-weight cameras, this method of obtaining remotely- sensed pictures is a lower cost alternative compared to pictures taken from airplanes or helicopters. KAP has been successfully used for mapping old forest on Axel-Heiberg-Island (Bigas, 1997), stereo observations of Antarctic penguins (Becot, 1998), and quantification of permafrost patterns in Northern Alaska (Roth *et al*., 2003). Our interest is the mapping of snow, ice and periglacial landforms, typically of remote areas in the Arctic, where use of helicopters or planes is expensive and logistically cumbersome. We employed heavy duty weather balloons filled with helium (which is readily available) around Fairbanks and Ny-Ålesund, Svalbard. KAP was tested at Ellesworth Mountain, Antarctica; Svalbard, western Greenland and northern Japan; and at various sites in Alaska. In the following, we demonstrate the use of kite and BAP with examples from Alaskan study sites.

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EQUIPMENT

Platform

The basic equipment consists of a kite, line and spool, camera suspension and camera. Payload typically totals about 0.5 to 2 kg. The wind condition determines the size of the kite. Large rigid kites are flown in lighter wind conditions and soft parafoil kites in stronger winds. The kite line should be attached to a firm site and only be handled with gloves. If attached to the waist (for example by a harness), walking and thus choosing the desired location is possible. During the strongest winds (>12m/s), the kite system needs a ground anchor with a figure eight ring, to allow for the retrieval of the kite.

Depending on the application and budget size, there is a wide range of kites, suspensions and cameras available. We tested a variety of equipment with these main concerns in mind: i) weight and bulk

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size; ii) easy handling, especially in cold weather conditions; and iii) stability.

Our favourite kites are the rigid delta kite for light to moderate winds and the parafoil kite for moderate (>6 m/s) to strong winds (Figure 1A, B). The latter has no rigid parts and can be stuffed into a small sack.

BAP is easier to operate than kite-borne, and the camera can generally be positioned, both laterally and in terms of altitude, more easily than with a kite. This setup can be handled by one person, but it requires an environment with little or no wind. Transporting balloon helium to remote areas is difficult, and the helium itself is expensive.

Shutter Control

There are a number of ways in which the pictures can be taken. Radio-controlled exposure enables taking pictures of the desired location, but we found the extra equipment and handling more cumbersome compared to preset interval exposure functions. Some cameras have a built-in interval function (such as 35 mm Braun *trend*, digital Ricoh RDC-6000) or the possibility for a programmable data back (such as MF19 data back for Nikon F501). An option for digital cameras is a remote control accessory (such as DigiSnap), a small light-weight module that enables the external control of the camera via the serial port which provides an interval function.

Image Media

We experimented with various films (Fuji Color negative film, Kodak Ektachrome Professional, Infrared EIR Film, high speed infrared and Tri-X—i.e., black/white) with different bandwidth filters (ultraviolet, visible, infrared transparent or block). Our favourite camera is the Olympus C2020 (digital), triggered by the DigiSnap 2000 module. Benefits of this camera include its bright lens, small lens distortion, standard communication protocol, small size and robustness, suitability for filter attachment, and wide range CCD sensibility (ca. 300–1200 nm). Generally, the benefits of digital cameras are (1) images obtained immediately that can be evaluated and retaken on the spot, (2) wider wavelength sensibility than film, (3) cost performance, and (4) no waste of film. The image quality has become very close to conventional film; however, minimum target size and distance (elevation) should be adjusted. For example, set on maximum resolution the Olympus C2020 records a 1600 × 1200 pixel image. For recognition of a pattern, such as a 1 metre ice-wedge-trough depression, a minimum of 20 pixels is required, thus limiting the camera height to about 52 m:

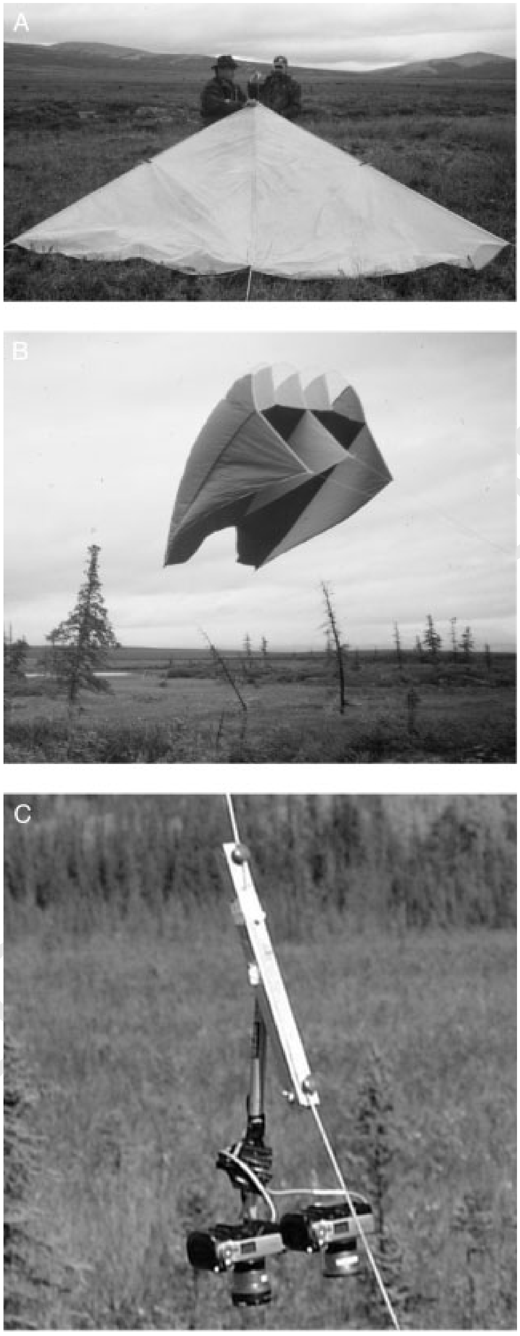

Figure 1 (A) Parafoil kite, (B) delta kite and (C) T-suspension attached with balloon.

$$H = L * \rho / (\rho_{min} * 2\tan(\theta/2))$$

where: H: camera height (m); L: recognition for threshold (m; 1 m in this example); ρ: camera resolution (pixel; 1200 in this example); ρ_{min}: minimum of required resolution (20 pixels for this study); and θ: camera lens angle (60 in this example)

With flying altitude and lens setting, the optimal subject size can be chosen. Increasing altitude decreases the overall contrast and brightness due to the increase of atmospheric backscatter.

Mount and Stabilization

Usually, a self-leveling apparatus, Picavet, helps to dampen the effects of vibrations and sudden movements of the kite or balloon. Another possibility is a universal joint suspension that allows rotation around the vertical and horizontal axes. Both suspensions can be built from materials available at hardware stores. Improved camera stabilization can also be attained by attaching two or three additional lines to the camera suspension (a triple system would enable controlled pictures). However, based on our field experience, handling with several lines—even with several people—is difficult. Furthermore, sudden line movement is still possible and/or the system can move altogether. We found the use of a simple T-shaped pendulum suspension (made from a camera tripod), directly attached to the kit line (Figure 1C), easiest and most effective to use. Simultaneous photographs of the same area with different band pass filters can be taken using a double or triple camera suspension. Two (or three) Olympus cameras mounted on a 22 cm long bar 10 cm apart, pointing in the same direction, are triggered simultaneously using one DigiSnap (Figure 1C). The bar can either be attached directly to the kite line or via a suspension.

EXAMPLES OF APPLICATIONS

Location of Ice-Wedge Polygons and Geometric Analysis of Polygonal Ground, Goldstream Creek, Fairbanks

Figure 2 shows the Goldstream Creek area near Fairbanks. We needed an aerial picture of this area for locating ice wedges for sampling (the ice-wedge depressions were not visible at ground surface) and for geometric analysis of the polygonal network. For the transformation of the original image into an orthonormal picture, a correction is carried out based on aspect ratio and UTM• projection. Correction is applied using northing and easting transects of defined lengths (as shown in Figure 2) or several ground control points (GCP). The geometric analysis of the polygonal network rendered an average span of ice-wedge cracking of 17 m (standard deviation 2.9 m) and an aspect ratio of 1.5 (standard deviation 0.2).

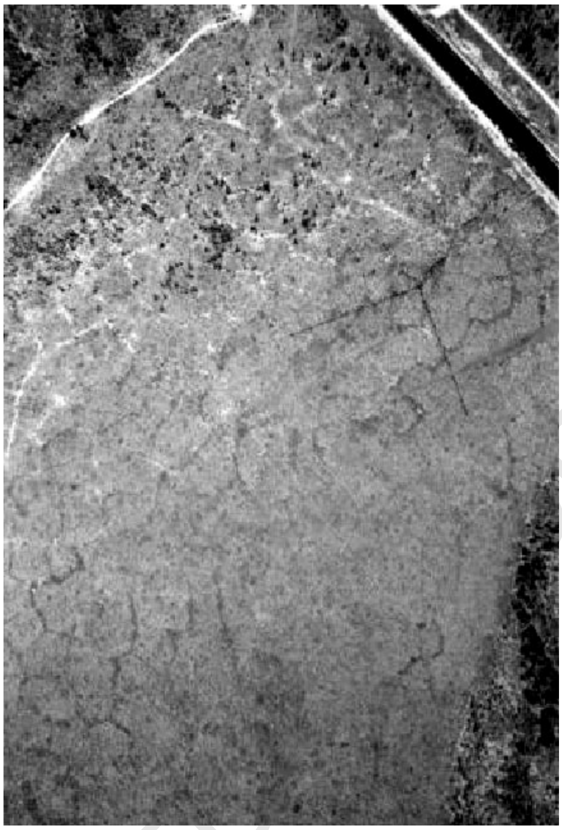

Figure 2 The Goldstream valley site in Fairbanks, Alaska, 2001. The picture was taken in November 2001 using balloon aerial photography with a Nikon camera and Fuji Color negative film (ASA 400). The marked angle on the ground in the right picture is 60 × 60 m to the north and west. Original RGB• colours are converted to a grey-scale image.

Quantification of Patterned Ground, Howe Island, Alaska

Aerial pictures made with KAP on Howe Island (located off the Alaskan Arctic coast northeast of the Prudhoe Bay oil fields) were taken for the quantitative analysis of permafrost patterned ground. The patterned ground forms present on the island are flat-centred polygons, non-sorted circles and small non-sorted polygons (Figure 3). Using Minkowski numbers (Roth *et al*., 2003), it was shown that two adjacent sites had distinctly different

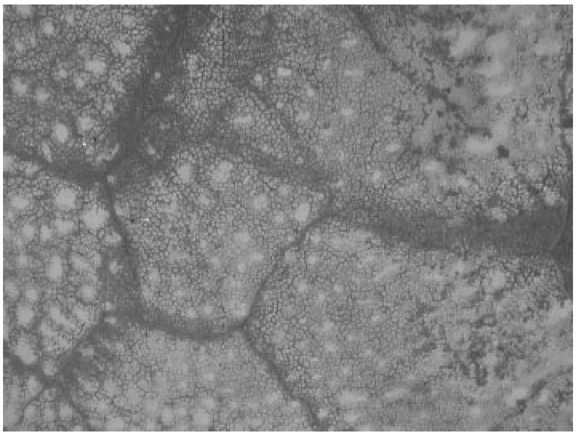

Figure 3 Kite aerial photograph using Olympus C2020 of Howe Island, August 2002. Polygonal ground, non-sorted circles, and small non-sorted polygons can be distinguished. The resolution, calculated using two white paper plates (diameter 26 cm) as ground control markers, is 38 mm per pixel.

characteristics, namely single-scale and multi-scale organization. The analysis of high resolution aerial photographs thus provides information about changes in permafrost patterns and periglacial processes over time and space.

Vegetation Mapping, Goldstream Creek, Fairbanks

We experimented with filters at the Goldstream polygonal site in Fairbanks, working to distinguish between different vegetation covers and water-saturated zones. The vegetation growing on the raised tussock mounds (*Eriophorum vaginatum*) differs from the surrounding, lower water-logged vegetation mainly comprising mosses (*Sphagnum spp.*). Isolated black spruce trees (*Picea marinara*) are widespread. Figure 4 shows the spectral reflectance characteristics of vegetation and water on a September 2002. Active vegetation mainly reflects the near-infrared spectrum. Water has the lowest albedo (around 0.2), while blueberry (*Vaccinium uliginosum L.*) and tussocks have the highest. Using an infrared filter (>800 nm, bandwidth B in Figure 4) thus allows distinguishing between water-logged (darker) and drier (whiter) areas (Figure 5A). Through filter arrangements, particular band patterns of the specific object can be chosen. We used a combination of yellow (> ∼520 nm) and hot mirror filter (<∼720 nm), narrowing the wavelength transmittance between 520 to 720 nm (Figure 5B; bandwidth A in Figure 4). Processing of Figure 5B consisted of subtracting the red channels minus the green channels, thus visualizing spruce trees as dark spots (Figure 5C).

OUTLOOK

In addition to being fun, kite flying is a simple and relatively inexpensive way to obtain remotely-sensed pictures. GCP or other land marks, such as transect lines and direction, are required for most of the post-image processing. Using illumination markers,

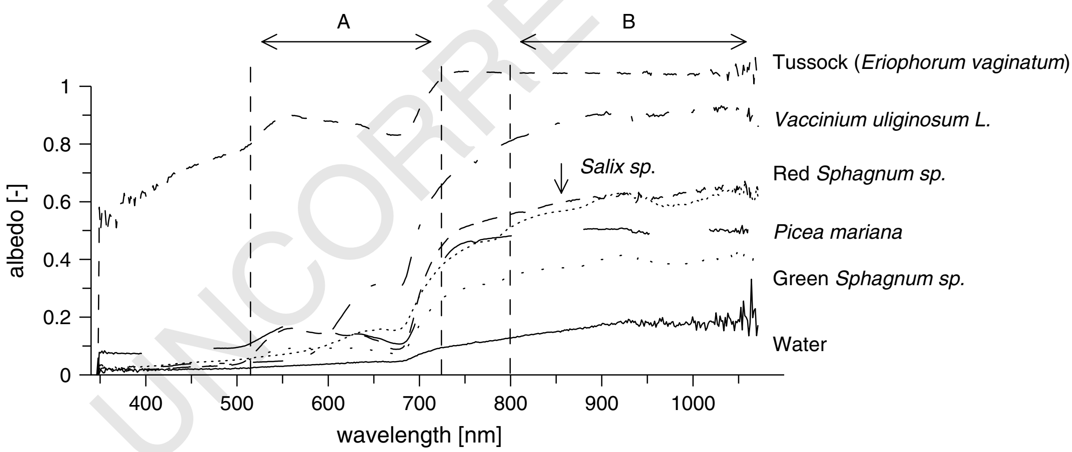

Figure 4 Major surface materials wavelength patterns (350–1050 nm) on 9 September 2002 at the Goldstream valley site, collected using a spectrometer (FieldSpec Pro, Analytical Spectral Devices, Inc). Bandwidths (A) (520–720 nm) and (B) (>800 nm) were chosen through filter arrangement and are used for the analysis in Figure 5.

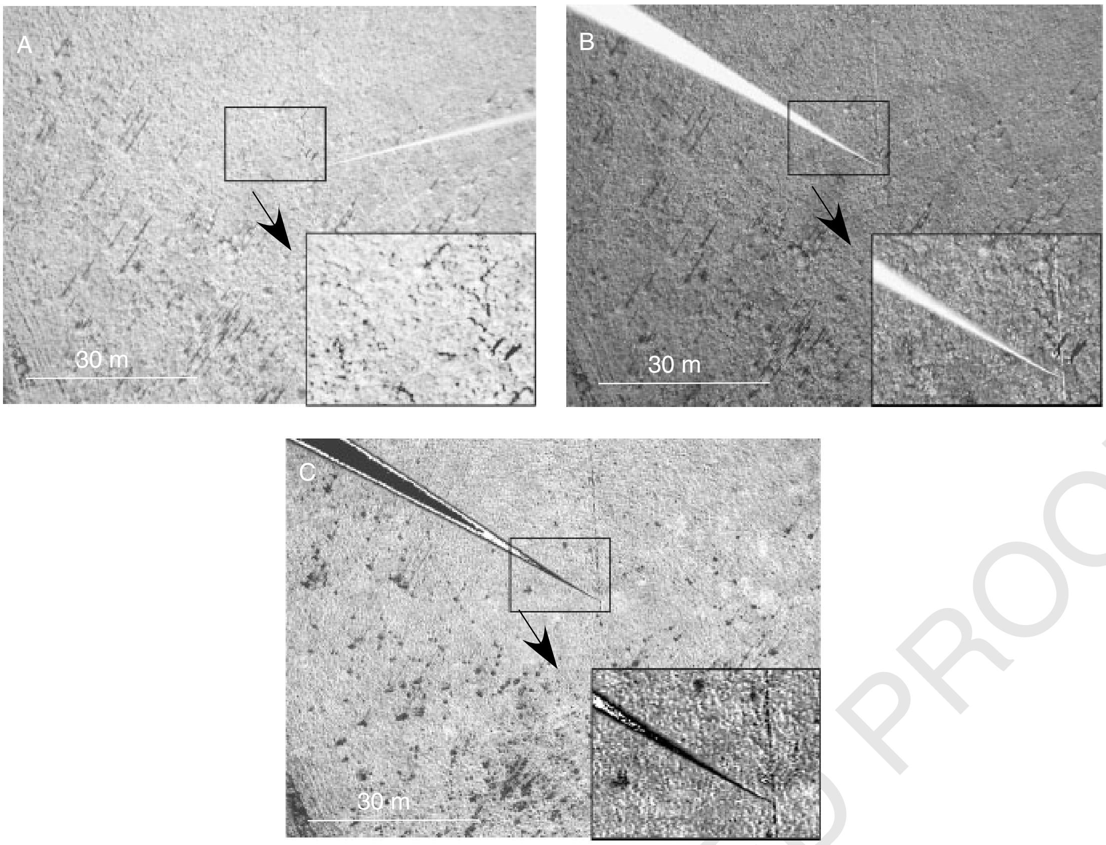

Figure 5 Balloon aerial photographs of Goldstream area taken 9 September 2002, using (A) an infrared filter (>800 nm), and (B) a yellow and hot mirror filter (520–720 nm), converted to grey scale image. (C) is processed by subtracting the red minus green channels of image (B), visualizing spruce trees as dark, isolated spots. Whiter areas are tussock mounds, partly covered with leafless branches. Enlargement of the centre box on each picture is shown in the lower right corner.

differences in light and shade could potentially be corrected. Other benefits of KAP/BAP are that wavelength transmittance can be controlled using filters, particular objects can be monitored, and high-resolution images can be compared to commercial aerial photographs. Further potential application could be stereo photography to produce digital elevation models (DEM).

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