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High-altitude kite aerial photography

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Kite aerial photography (KAP) is a low-cost means to acquire large-scale, low-height, high-resolution aerial imagery. It is commonly practiced at low altitude for geological, environmental, and many other scientific applications. The method has been used much less at higher altitudes above 1000 m, however. We present examples of high-altitude KAP from the High Plains and Rocky Mountains in the United States and the Tatra Mountains in Slovakia and Poland. Based on these experiences, we find that KAP is feasible in the altitude range ~1000-2500 m, particularly for those places that are relatively open and have semiarid climates. Such sites include high plains, mountain forelands, and broad intermontane valleys. Mountains, in contrast, have more frequent cloud cover, experience highly variable wind, and often have poor access, which lead to more difficult KAP conditions. Above 2500 m altitude, low air density becomes a significant limitation for kite flying. High-altitude KAP is a means to portray landscape elements and details from vantage points that would be difficult or impossible to achieve by other methods of small-format aerial photography.

Keywords: Small-format aerial photography, High Plains, San Luis Valley, Tatra Mountains, Kansas, Colorado, Slovakia, Poland.

INTRODUCTION

During the past several years, the authors have practiced and elaborated kite aerial photography (KAP) as a low-cost means to acquire large-scale, low-height aerial imagery for geological, environmental, and other applications (e.g. Aber et al. 1999, 2002, 2006; Aber and Gałązka 2000). Others have adopted this approach for landscape studies (Marzolff, Ries and Albert 2003; Tielkes 2003). KAP is one type of small-format aerial photography, which includes various manned and unmanned platforms (Warner, Graham and Read 1996; Bauer et al. 1997; Quilter and Anderson 2000; Ries and Marzolff 2003; Miyamoto et al. 2004).

As tethered, unmanned platforms, kites have certain advantages as well as limitations for aerial photography. Primary advantages include high portability, ease of operation, minimal environmental impact (noiseless), and lowest cost for any means of aerial photography. The primary limitations are the needs for suitable wind (10-25 km/h) and open flying spaces. In addition, the routine flying height above ground is restricted in many countries (150 m in the United States). Thus, the ground coverage is small in area but large in scale for vertical images; the method is best suited for detailed investigations of relatively small sites. Another less obvious limitation is altitude of operation.

Most kite aerial photography is conducted at low altitude, simply because that is where most people, including kite aerial photographers, live and practice most of their work. According to Cohen and Small (1998), more than half of all humans live at elevations below 300 m, and nearly 90% live below 1000 m altitude. Thus, it is no surprise that relatively little kite aerial photography has been attempted at high altitude.

For purpose of this discussion, high altitude is considered to be those regions ~1000 m (3300 feet) or higher in elevation. This includes high plains and plateaus, as well as many mountain ranges, glaciers and ice sheets—places of great scientific interest for diverse subjects. In this paper, we discuss principles and techniques for kite aerial photography at high altitude and present examples from the High Plains and southern Rocky Mountains of the United States and the Tatra Mountains of Slovakia and Poland.

Air density and kite lift

The force that holds a kite up is determined by wind speed and air density acting on the lifting surface of the kite. In most situations, wind speed is the deciding factor for choosing an appropriate kite to carry the camera rig.

Table 1. Standard atmospheric conditions for temperature, pressure, density, and density percentage according to altitude. Adapted from Williams (2005).

Altitude (m)	Temp. (C)	Pressure (hPa)	Density (kg/m^3)	Percent
Sea level	15.0	1013	1.2	100
1000	8.5	900	1.1	92
2000	2.0	800	1.0	83
3000	-4.5	700	0.91	76
4000	-11.0	620	0.82	68
5000	-17.5	540	0.74	62

At high altitude, however, reduced air density also becomes important. Lower air density means there are fewer or lighter molecules (per air volume) to flow over the kite's lifting surface at a given wind speed. Air density is determined by three factors (Williams 2005).

1. Pressure — The weight or force per area exerted by a column of air. Standard atmospheric pressure at sea level = 1013 hPa (29.92 inches Hg).

2. Temperature — As air is warmed, it expands and thus has a lower density. Standard atmospheric temperature at sea level = 15°C (59°F).

3. Humidity — Water vapor molecules are lighter than are nitrogen and oxygen molecules that make up most of the atmosphere. Humid air has a higher proportion of light water molecules than does dry air. The result is that wet air is lighter than dry air. This humidity effect is relatively small, however, and will not be considered further.

The combination of these factors determines the air density and thus potential lifting power of a particular kite for a given wind speed. The standard atmosphere is an ideal model of atmospheric conditions (Table 1). These values reveal that density decrease is fairly slight up to about 1000 m high, a typical elevation on the High Plains in western Kansas. At higher altitudes, however, air density declines significantly. At 3000 m, for example, air density is only about ¾ that of sea-level density. However, this assumes the standard atmospheric temperature of -4.5°C at that altitude. Few kite flyers are likely to work at that temperature in a brisk wind, and batteries are likely to fail quickly. At higher temperature comfortable for field work and full battery power, say 20°C, air density is considerably less.

Figure 1. Rokkaku kite used most often by the authors for high-altitude kite aerial photography. Kite is 2.3 m tall and 1.8 m wide; shown here with a 6-m-long tube tail.

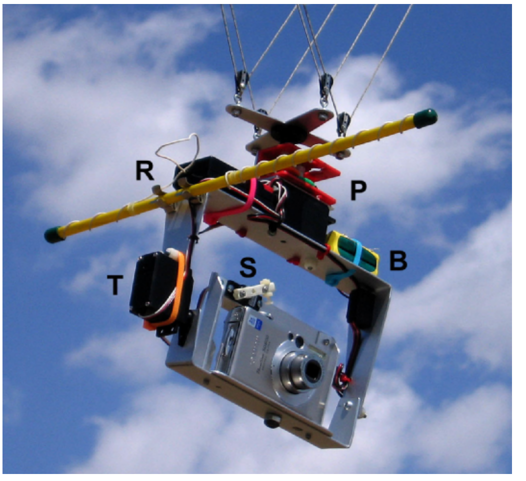

Figure 2. *Canon PowerShot* SD600 camera rig for kite aerial photography. R - radio antenna and receiver, P - pan servo and gear mechanism, T - tilt servo, S - shutter servo, and B - battery pack for rig power.

High-altitude KAP methods

In order to compensate for decreased air density at high altitude, several components could be adjusted realistically for successful kite aerial photography—use a kite with greater intrinsic lift, increase the size of kite, use a train of multiple kites, and reduce the weight of the camera rig. In general, rigid kites, particularly the rokkaku type, provide the greatest intrinsic lifting power compared with other types of kites in the authors' experience. This traditional Japanese design has the highest surface area to weight ratio, and through centuries of design improvements it has achieved an elegant status among kite flyers.

For high-altitude KAP, we employ a large rokkaku with a surface area of 3.3 m^2 (Fig. 1). For gusty or irregular wind conditions, we usually add a long tube tail to improve stability. However, for a steady breeze, the tail can be removed to reduce drag and weight. This is often necessary at high altitude. We also have flown a giant delta kite with a wing span of 6 m and surface area of 8.2 m^2. However, it weighs significantly more and does not provide any more lift at high altitude than does the rokkaku. To further increase lift, a train of kites could be used; however, this is technically more difficult and we do so only rarely.

Rapid development of digital cameras in recent years has brought high quality to quite small cameras in terms of megapixel resolution, good lens, and fast-shutter action. Our approach is to keep the camera rigs as light, simple, and robust as possible. We employ a *Canon PowerShot* SD600 camera, popularly known as the *Elph* or *Ixus*. It has six-megapixel resolution with high shutter-speed capability (ISO 800) and a standard field of view. It is operated in a radio-controlled rig that can pan and tilt the camera in any position, oblique or vertical (Fig. 2). The entire camera and rig assembly weighs

Figure 3. Cumulus clouds building over the High Tatra Mountains, while the adjacent foreland remains cloud free in this mid-day, summer view near Strané pod Tatrami, Slovakia. Similar conditions prevail in the southern Rocky Mountains during the summer monsoon season.

only 0.6 kg. We also utilize a slightly heavier rig based on the *Canon PowerShot* S70 camera, which is seven megapixels and has a wide-angle lens. This camera and rig weigh 0.8 kg. Both cameras record a high percentage of well-exposed, sharp pictures.

High-altitude kite flying often takes place in mountains. Mountain ranges typically create strong local climatic effects, which include colder temperature, enhanced cloud cover (Fig. 3), and more precipitation than for adjacent lowlands. Mountain peaks and valleys are well known for rapid weather changes. Swirling winds funnel along valleys and over passes with frequent and abrupt changes in direction and strength. Alternating updrafts and downdrafts are routine. Finding a large enough open space for kite flying can be a challenge in forested mountains, and access to alpine areas above timberline may be quite limited. Areas with good access are often sites with other human structures and activities that could prove dangerous for kite flying. The combination of cloud cover, variable wind, and limited access makes for difficult kite aerial photography in many mountain settings.

Case examples

The following examples of high-altitude kite aerial photography are drawn from the High Plains of western Kansas and eastern Colorado, the Rocky Mountains of south-central Colorado, and the Tatra Mountains of Poland and Slovakia. KAP was conducted in these places for various research and

Figure 4 (right). Remains of Amache Japanese Internment Camp dating from World War II. A (upper) - overview toward the northeast. Foundations of the high school are in the center foreground, and the city of Granada can be seen in the distant background. B (lower) - vertical detail of high school remains. Elevation ~1100 m (3600 feet).


A
B
North ->

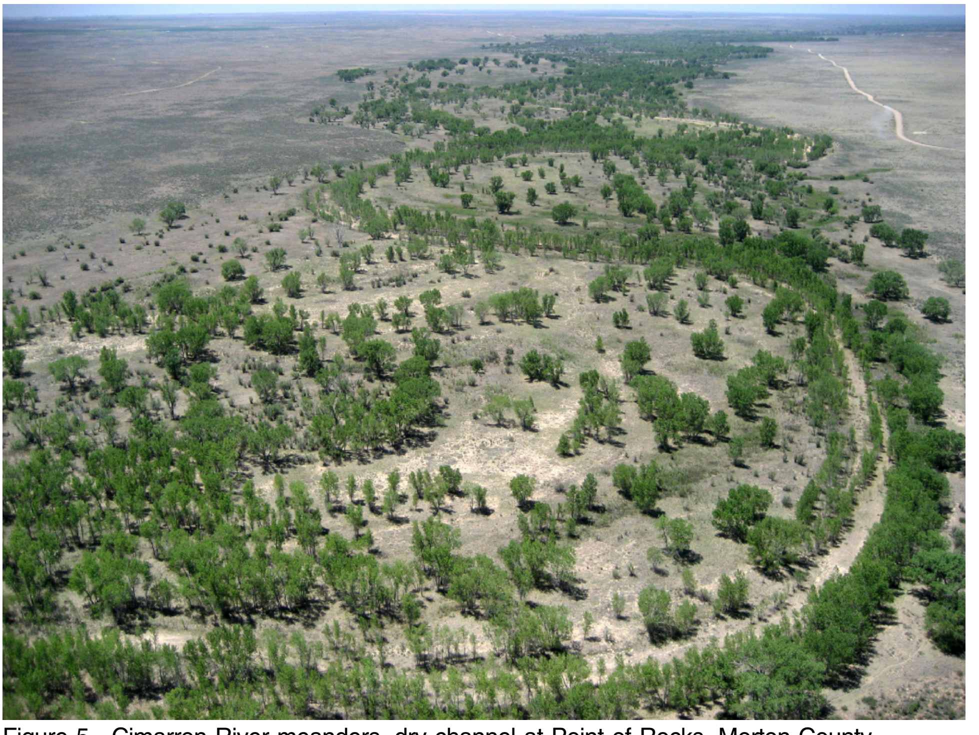

Figure 5. Cimarron River meanders, dry channel at Point of Rocks, Morton County, southwestern Kansas. Elevation ~1080 m (3540 feet).

Figure 6. Russell Lakes State Wildlife Area wetland in the northwestern portion of the San Luis Valley, Colorado. Pools and marshes are fed by springs and artesian wells that tap the underlying aquifer. Elevation ~2310 m (7580 feet).

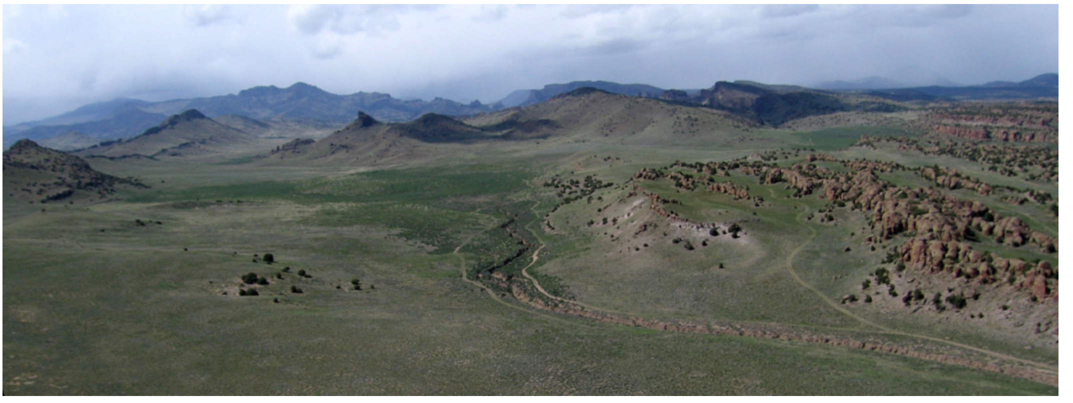

Figure 7. Panoramic view of Elephant Rocks in the foreground and the San Juan Mountains in the background on the western edge of San Luis Valley, Colorado. Elephant Rocks are erosional features in granite and rhyolite on the edge of the San Juan igneous province. Elevation ~2440 m (8000 feet).

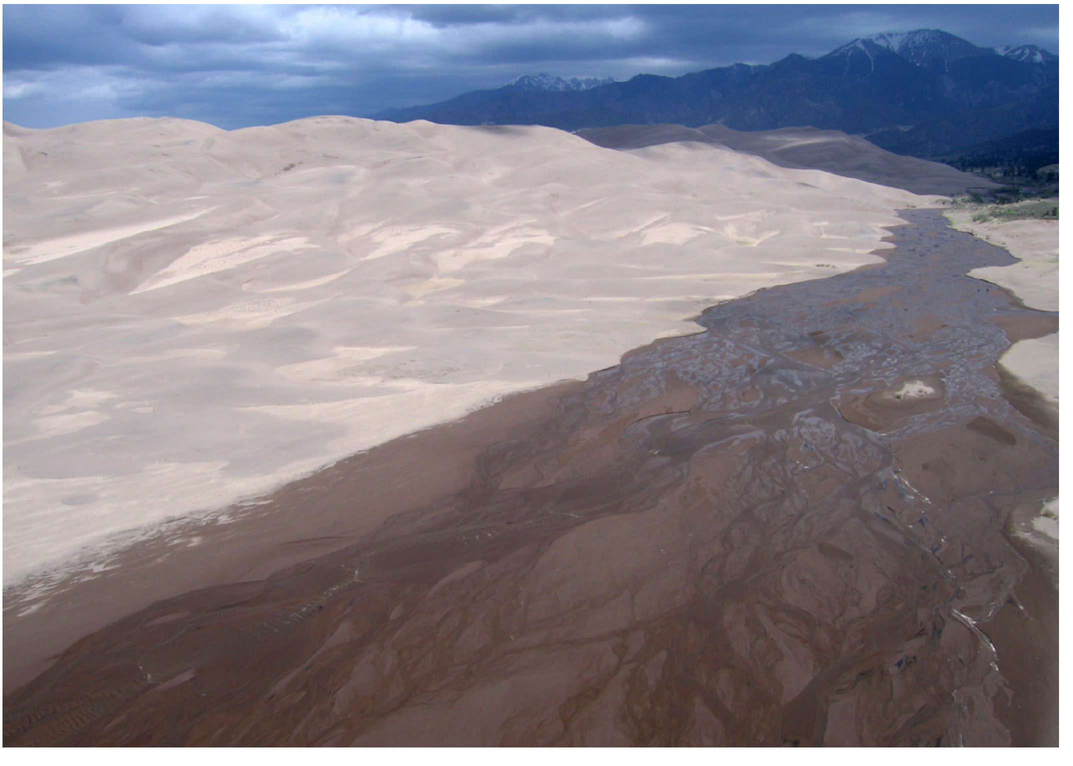

Figure 8. Eastern edge of the Great Sand Dunes and Medano Creek to right with the Sangre de Cristo Mountains under cloud shadows in the background. Variations in dune sand color are evident, and braided channels of Medano Creek are well displayed. Elevation ~2450 m (8040 feet).

Figure 9. Panoramic view looking northward from Kopa Królowa Wielka in the Polish Tatras. The ridge in center foreground is Skupniów Uplaz, composed of Triassic dolostone, and Giewont Peak (1894 m) appears at left edge of scene. This picture was created by stitching together two *Canon Elph* images using *D Joiner* software.

Figure 10. Panoramic view of the Slovak Tatras looking toward the northwest from near Stará Lesná. Peak in center is Lomnicky štit (2634 m), second highest peak in the Tatras. Alluvial fans are evident in the foreground and left background. This picture was created by stitching together two *Canon Elph* images using *D Joiner* software.

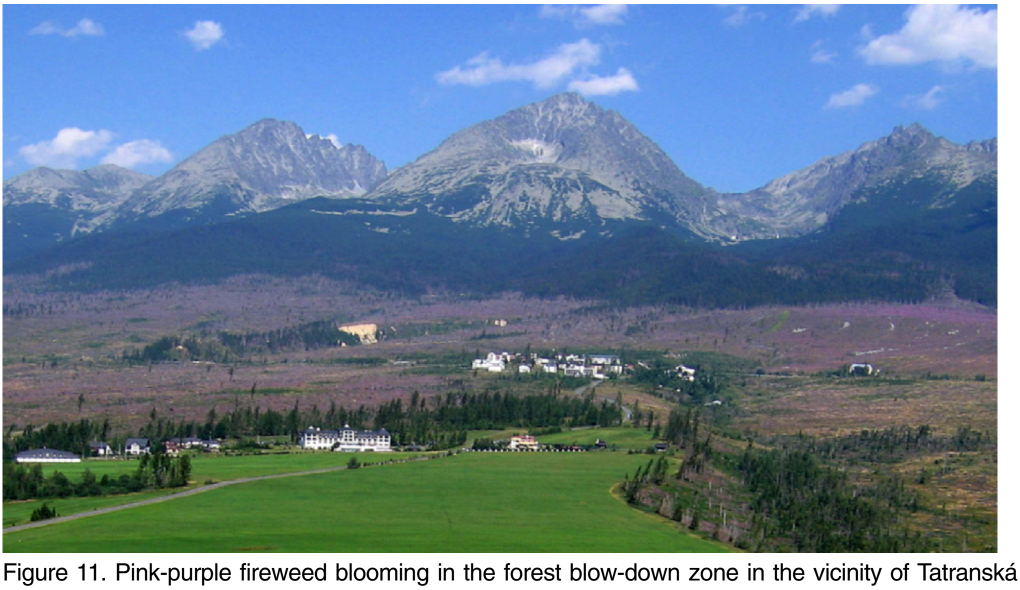

Figure 11. Pink-purple fireweed blooming in the forest blow-down zone in the vicinity of Tatranská Polianka. Peak near center is Gerlachovsky štit (2654 m), the highest peak in the Tatras.

educational applications in geology and geomorphology, historical documentation, and biological studies.

High Plains — The High Plains slope up gradually toward the west from ~1000 m elevation in western Kansas to ~1800 m altitude next to the Front Range of the Rocky Mountains in central Colorado. The climate is semiarid, which means many cloudless days, and the wind blows most of the time. However, wind speed and direction are subject to gusty variations, particularly during mid-day and early afternoon hours of maximum heating. The landscape is open with generally low relief and few obstacles. Conditions for KAP are quite favorable overall, particularly in the spring and autumn when temperature is moderate.

We earlier reported on kite aerial photography for monitoring a biocontrol experiment at Pueblo, Colorado (Aber, Eberts and Aber 2005) at elevation ~1450 m (4750 feet). Examples of other KAP applications include historical remains of the Amache Japanese Internment Camp at Granada, Colorado (Fig. 4) and display of geomorphic features (Fig. 5). Thus, high altitude is, by itself, not a limiting factor for kite aerial photography on the High Plains, given other favorable circumstances of semiarid climate and relatively open land cover.

Rocky Mountains — Our KAP efforts in south-central Colorado have focused on the San Luis Valley, a large intermontane basin that is part of the Rio Grande Rift system (James 1971). It has been called the highest, largest, mountain desert in North America (Trimble 2001). Its best-known attraction is Great Sand Dunes National Park. Average elevation of the valley is ~2350 m (7700 feet). The valley is bounded on the east by the Sangre de Cristo Mountains and on the west by the San Juan Mountains, in which highest peaks exceed 4270 m (14,000 feet). These mountain ranges receive abundant precipitation and are frequently cloud covered, whereas the San Luis Valley is a true desert (~20 cm precipitation per year) with much sunshine. Primary KAP applications are for depicting water resources (Fig. 6), geological formations (Fig. 7), and the sand dunes (Fig. 8).

At this altitude, we find that relatively strong wind (20-30 km/h) and large kites are necessary to lift our camera rigs. Wind direction is generally stable, given the broad open area of the valley; however, weather conditions can change quickly as thunderstorms develop. We also have attempted KAP in the Sangre de Cristo Mountains at elevations ~2750 to >3000 m, albeit with much less success. Thin air reduces kite lift significantly, and the wind is often turbulent with frequent gusts, which makes kite flying quite risky.

Tatra Mountains — Most recently in 2007, we undertook KAP for applications in geomorphology in the Tatra Mountains, which are part of the Carpathian Mountain system of central Europe. We focused our attention on the High Tatras in north-central Slovakia and southernmost Poland, in which peaks exceed 2500 m (8200 feet) altitude. We also targeted the surrounding foothills and foreland areas. The Tatras have experienced significant late Cenozoic tectonic uplift, which is marked by extensive alluvial fans along the southern flank (Nemčok 1994). They also were modified by Pleistocene alpine glaciation that cut deep valleys and deposited extensive moraines and outwash gravel (Lukniš 1968). Much of the Tatras is forested below ~1500 m, and access to the alpine zone requires considerable hiking to reach suitable sites in national parks.

Our highest KAP site was Kopa Królowa Wielka at altitude 1530 m (just over 5000 feet) in the Polish Tatras (Fig. 9). Here and at other alpine sites we experienced difficult flying conditions, mainly because of irregular wind. Kite flying was risky because of frequent changes in wind direction and strength combined with occasional updrafts and downdrafts. In the foreland areas at elevations below 1000 m, in contrast, flying conditions were relatively routine. We were able to document the extent and well-preserved character of alluvial fans on the southern flank of the Slovak Tatras (Fig. 10).

A severe wind storm blew down a large portion of the conifer forest in the foreland of the Slovak Tatras in 2004. After considerable debate, a decision was made to salvage the fallen timber to minimize insect infestation of the damaged forest. Thus, a broad zone along the southern flank of the Tatras is now open. We had hoped to take advantage of this opportunity to examine landforms closely in the blow-down zone; however, continued logging and extremely rough terrain made this impossible. Nonetheless, the blow-down zone appears quite distinctly in our images taken from the foreland. Common fireweed (*Epilobium angustifolium*) was blooming pink-purple throughout the blow-down zone; this color contrasted vividly with the still-standing dark green conifer forest (Fig. 11). This was the first year since the storm that fireweed had appeared in such abundance.

Discussion

High-altitude kite aerial photography is quite feasible under certain conditions. In general, thinner air with increasing elevation is not a serious problem for the range ~1000 m to ~2500 m. Thin air does become more significant above 2500 m, particularly at usual temperatures (20-30°C) for typical field work during the growing season. Larger kites and/or lighter camera rigs are necessary for success at high altitudes. Of more concern is wind constancy, which is best at sites with few obstacles or topographic variations. Treeless plains, broad hill tops, wide valleys, or other open sites are generally most suitable for stable wind in our experience, regardless of altitude. High topographic relief in mountains or nearby forest cover often generates a great deal of wind turbulence near the ground, which makes for difficult kite flying.

Another important factor is ground access. This is rarely a problem in high plains or mountain forelands, where a vehicle may be driven directly to suitable flying sites. However, this is often not possible in the alpine zone. In this regard, KAP portability is an important advantage. Two people can carry all necessary equipment up foot trails. It should be noted that manned aircraft would be exceptionally dangerous at low height in montane settings, and few pilots would be willing to take such risk.

A further limitation in mountain settings is frequent cloud cover. Clouds are undesirable for most types of aerial photography, as they may cast shadows, diminish ground illumination, or obscure the ground. The number of relatively cloud-free days is quite limited in mountains compared with nearby lowlands, which reduces chances for effective kite aerial photography. On the other hand, high plains, mountain forelands, and intermontane valleys offer excellent KAP situations with relatively open terrain, stable wind, and abundant sunshine.

High-altitude kite aerial photography offers potential benefits for many possible scientific applications. Vertical views provide highly detailed images suitable for microstructural analysis at scales 1:100 to 1:1000 (Masing 1998). In oblique views, panoramas depict the relationships of various landscape elements, which may be difficult to interpret from conventional maps or standard airphotos. In other words, kite aerial photographs are a means for scientific visualization from a vantage that is difficult or impossible to achieve by other methods.

Conclusions

Kite aerial photography may be undertaken routinely at high altitudes in the range 1000-2500 m. At higher altitudes, however, thin air becomes a limiting factor. In many situations, wind turbulence and cloud cover are more important factors than is air density for successful KAP. High plains, mountain forelands, and broad intermontane valleys offer excellent KAP situations with relatively open terrain, stable wind, and abundant sunshine. Kite aerial photography is more difficult in mountains because of frequent cloud cover, gusty wind, and limited access. Kite aerial photography represents a low-cost and environmentally friendly means for depicting high-altitude landscapes from vantages that would be difficult or impossible to obtain by other techniques.

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