

Kite Aerial Photography in High Mountain Ecosystem Research

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Abstract

Mountain environments are characterized by high spatial diversity. One basic problem is the fact that high resolution data for remote mountain areas are usually scanty. This study conducted in Norwegian high mountains addresses the opportunity to derive high quality landform and vegetation data based on low budget and small format kite aerial photography. The quality of the derived data layers and the flexible application of this method contribute to an improvement in fine-scale multi temporal mapping as a basis for spatial ecosystem modeling.

KEY WORDS: Kite aerial photography, landscape ecology, digital elevation model, vegetation patterns, Central Norway

1. Introduction

This paper addresses the potential of kite aerial photography (KAP) for high resolution digital terrain modeling and vegetation analysis. We adopted this remote sensing approach for fine-scale analyses of mountain landscapes within the scope of a more comprehensive research project intending multi scale high mountain system analysis and modeling. Questions addressed within this study were: Does KAP meets the specific circumstances of fieldwork in alpine landscapes? Does the quality of derived data meet demands of fine-scale spatial ecological modeling?

Mountains are of special interest within the discussion of global change (Grabherr et al. 1994; Walther et al. 2002). Environments above the treeline are considered to be particularly sensitive to global change (Holten 1990; Beniston 2003) and are accounted as ideal research objects concerning ecological responses (Becker and Bugman 2001; Diaz et al. 2003).

Some earlier approaches tended to predict the impact of global warming on mountain environments (Saetersdal and Birks 1997; Guisan and Theurillat 2001, Dirnböck et al. 2003). Albeit different procedures they were alike, since the results were based on global and regionalized circulation models addressing a regional scale, consequently. But models appropriate for these scales could not resolve fine-scale differentiations due to complex mountain topography (Noppel and Fiedler 2002). Good simulations of processes are enabled by soil-atmosphere-vegetation-transfer (SVAT) models (Cayrol et al. 2000; Jansson and Karlberg 2001) but have the problem of applicability due to rare availability of required complex input data (Boulet et al. 2000). Simpler physically based energy balance models (Pape and Löffler 2004) were found to be more suitable for spatial modeling since few input parameters are required. Transferring this model approach from single sites to a spatial dimension requires supply of spatial input data such as elevation, slope, aspect, curvature, soil humidity, snow cover, albedo, leaf area index and vegetation structure. Existing remote sensing data would contribute a good starting point. But since many mountain environments are remote areas, the selection of available data is limited. Obtainable official landform data are restricted to medium scales (25 m grid data, 1: 50,000 scale topographic maps with 20 m contour lines). The potential of freely available remote sensing data are restricted due to low spatial resolution (Landsat TM data) or poor spectral characteristics (conventional grey scale aerial photos). The implementation of those data into modeling processes led to insufficient results (Löffler and Wundram 2003). State-of-the-art satellite data (Ikonos, Quickbird) proved good results concerning DEM extraction (Fraser and Yamakawa 2003) but at substantial financial cost. Moreover factors

such as date and time of image acquisition, restrictions to favorable sun angles and atmospheric conditions limit the potential of satellite data (Baltsavias et al. 2001).

High resolution mapping by small format photography approaches possessed high potentials (Warner 1996). Capabilities of balloon- and zeppelin-based aerial photography were proven by Marzloff (1999), Lacroix et al. (2002) and Wollesen and Müller (2003). KAP was widely used in manifold environmental applications (Aber et al. 2002). It fulfilled most of our requirements such as costs, quality, scale, flexibility and wide range of wind speeds.

2. Study area

Central Norway shows a clearly defined oceanic-continental gradient represented by the western and eastern slopes of the mountain chain. The study area Geiranger/ Møre og Romsdal (62°03' N; 7°15' E) within the inner fjords region of western Norway is climatically characterized as sub-oceanic with annual precipitation sums of 1,500–2,000 mm in the valleys (Moen 1999). The most continental climate is found only 150 km east off the coast in the Vågå/Oppland region (61°53' N; 9°15' E). The study area situated within this climatic region is characterized by a lowest annual precipitation of about 300–400 mm per year (in the valleys), i.e. showing the highest aridity found in Norway (Moen 1999). The alpine altitudinal zonation in both areas is differentiated into a low-alpine belt, domi-

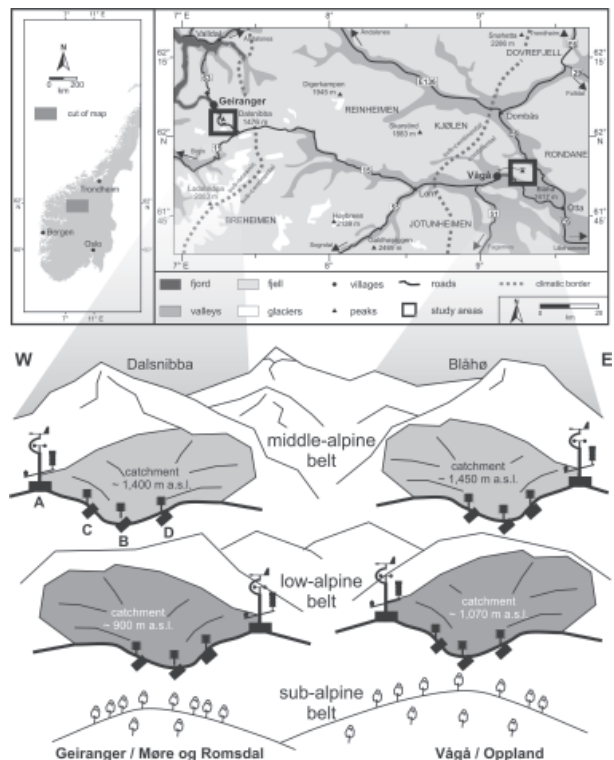


Figure 1: Location and topography of the study area in Central Norway.

nated by shrub and heather communities, and a middle-alpine belt, dominated by patchy grassy vegetation (Dahl 1986). It reaches from the tree-line at about 840–880 m a.s.l. (Geiranger) or 1,000–1,050 m a.s.l. (Vågå), to the highest peaks, i.e. the Dalsnibba (1,476 m a.s.l.) in Geiranger, and the Blåhø (1,618 m a.s.l.) in Vågå. The transition zone between low- and middle-alpine belts is found at around 1,150 (Geiranger) or 1,350 m a.s.l. (Vågå). Four investigation areas were chosen as representative mountain catchments of central Norway and delimited in each altitudinal belt so as to represent the conditions within a large-scale (Fig. 1). Results presented in this study are based on surveys within the low alpine catchment in the continental region.

3. Methods and techniques

3.1. Equipment

Widespread among amateur photographers KAP could be developed to a rich source of knowledge and resources (Leffler 1999). The equipment consisted of kite, camera, rig, camera suspension to the kite line, and remote control. A video downlink was helpful, not essential. Two different kites were used: a Dopero (6 m²), a special low wind kite (Beutnagel 1995), and a Flowform (2 m²) without spars for higher wind speeds. The camera was attached to the kite line via mount and self leveling picavet suspension (Beutnagel et al. 1995).

The availability of digital cameras strongly enhanced the capabilities of KAP. Considering price, resolution and setting capabilities, it was estimated that a four-megapixel-Nikon-Coolpix-camera fulfilled all basic requirements. Original focal length was reduced to 22 mm (equivalent to conventional analog camera) by a wide angle converter.

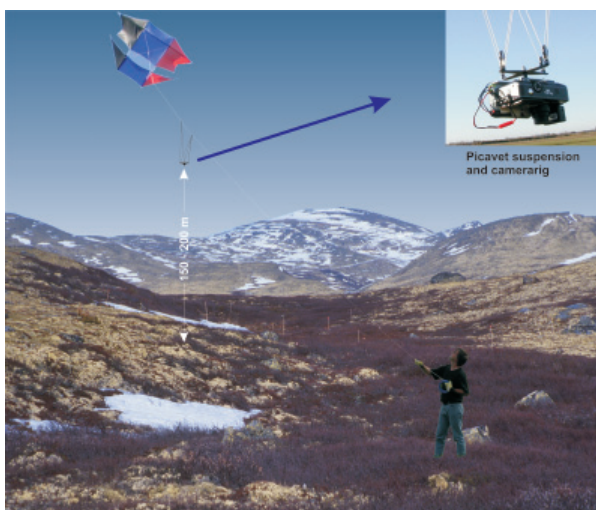


Figure 2: Fieldwork with the Dopero and equipment (photomontage).

For remote control of rig (tilt, rotation) and camera a simple four-channel-transmitter and a receiver were used. Since the camera had a video output the pictures were transmitted via a miniature 2,4 GHz video transmitter (max. outdoor range about 300 m). The received signal was visualized by special video glasses which allowed high flexibility in the field. A newer more compact design consists of a Canon Powershot S70 camera which is automatically triggered by an IR-interval timer.

3.2. Fieldwork

First of all, field control points were defined over the investigated area and their exact position was measured by ground-based nivellements. Afterwards the kite was launched up to an altitude where winds were stable (15 – 20 m above ground), followed by the attachment of the rig to the kite line. Then the kite was lifted up to destination altitudes. The latter depended on the desired resolution and ground cover. We decided to fly as high as possible. Considering maximum line length of 200 m and a vertical angle of 50 – 60 degrees the resulting camera altitude was approx. 150 m above ground. Moving the kite across the field we took overlapping pictures of the entire area.

3.3. Image analysis

According to the low budget approach we chose the software package LISA (Linder 2003) as a tool for photogrammetric image analysis. The FOTO-module contains a capable digital photogrammetric workstation. The main features were camera definition, camera calibration, interior and exterior orientation, bundle block adjustment and aerial triangulation, as well as stereo correlation (area based matching) for automatic DEM generation. The result of digital terrain modeling was a surface model, i.e. the surface of vegetation, stones etc., not an elevation model. This might be of less relevance in mountain environments above the treeline where the vegetation cover rarely exceeds 1 m of height, but the result of the matching process was noisy and it was strongly recommended to conduct some filter routines (e.g. mean or low pass) to smooth the surface. Vegetation structure analysis was accomplished based on common approaches of remote sensing image interpretation (Eastman 1999). Accessing terrestrial mappings, training areas were defined. Supervised as well as unsupervised classification approaches were conducted using IDRISI (2004) software package.

4. Results

4.1. Fieldwork

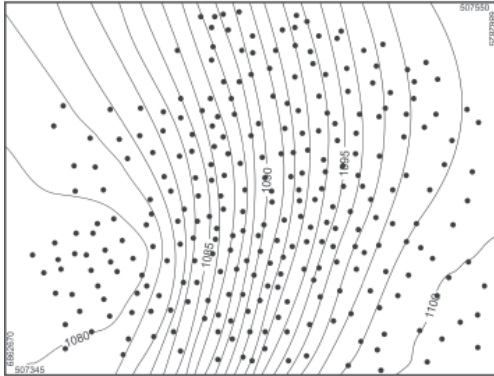
The workflow in the field widely met our expectations. Measuring control points proved to be the most time consuming process, while launching kite and camera setup was time effective and enabled flexible reaction to atmospheric conditions. Due to line length and weather condition the control of the kite was limited. Consequently, the task of capturing overlapping pictures did not coincide with the theoretical idea of exact picture sequences and parallel stripes as it is possible by using planes. Instead,

picture orientation and overlapping was random and it was a good idea to take as much pictures as possible. Since the kite sometimes pulled hard and the line length resulted in a noticeable offset between camera position and ground control, fieldwork was best conducted by two persons, one controlling the kite, another freely operating the remote control in the field.

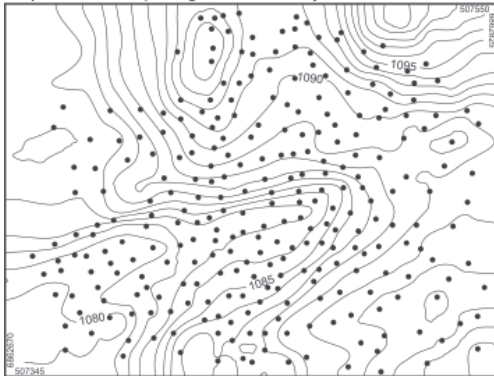
4.2. Data processing – landform

Though the geometric preconditions of image data were low, photogrammetric analyses with LISA caused no problems. Based on only two (approx. 70%) overlapping photos taken at an altitude of 160 m above ground (resolution approx. 10 cm) a digital surface model (0.25 m grid size) was generated covering about 30,000 m². Improvements of generated data layers could best be estimated compared with other data. Fig. 3 shows the contour lines generated based on the topographic map 1: 50,000 (Fig. 3a) and those extracted from the generated DEM (Fig. 3b). As expected the difference is abundantly clear. In contrast to the map 1: 50,000 that only show superior landforms, the generated relief model is more differentiated. Even though filter routines were conducted to the product of photogrammetric stereo correlation the main micro-relief structures were preserved and the final result (Fig. 3c) looks similar to the elevation model generated by kriging interpolation of about one thousand measured field points.

a) DEM interpolated based on topographic map 1:50,000 contourlines (20m)



b) Result of the photogrammetric analysis



c) DEM interpolated based on measured fieldpoints

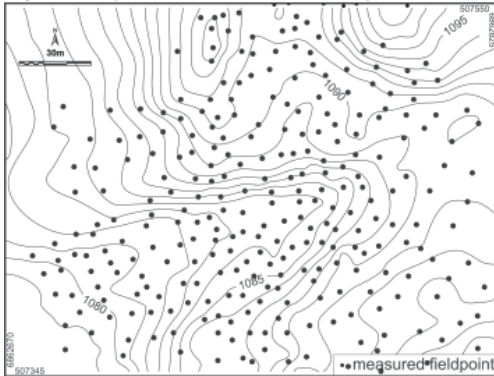


Figure 3: Comparison of different surface models.

The absolute minimum and maximum altitudes of all models range within the same span of 1,080 – 1,100 m above sea level. A statistical correlation analysis of 280 points extracted from every model and measured field points offers a quantitative quality assessment (Fig. 4). Unsurprisingly deviations are least significant (mean deviation: 3 cm, standard deviation: 14 cm) comparing measured field points and the model based on interpola-

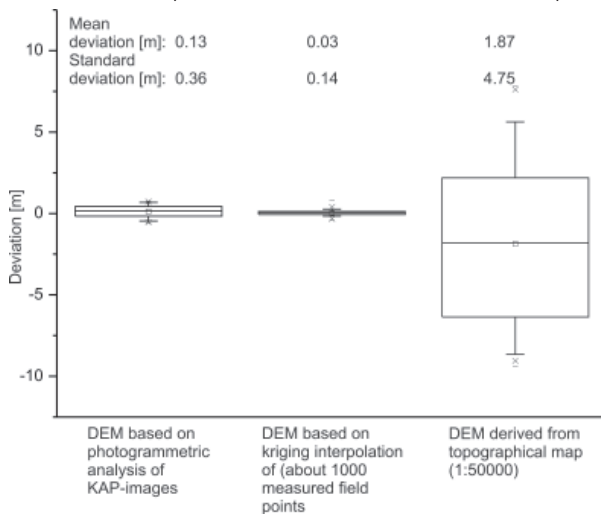
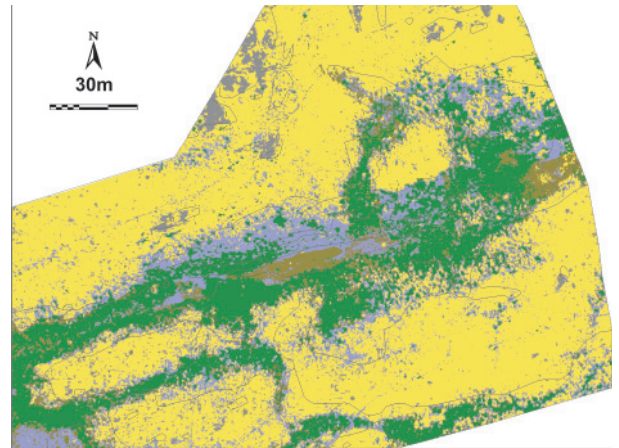


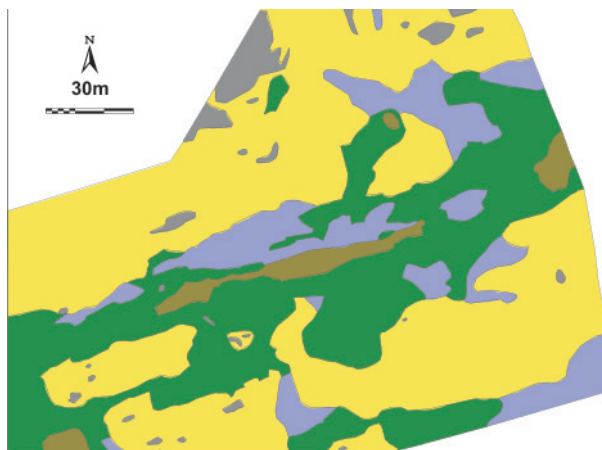
Figure 4: Statistical analysis based on 280 field points.



c) Orthorectified kite aerial photo



b) Result of unsupervised classification



a) Result of terrestrial vegetation mappings (after Löffler 1998)

- Bedrock / Boulder
- Lichen heath
- Dwarf-shrub heath
- Mire
- Dwarf birch and willow shrubbery
- Boundaries of mapped vegetation units

Figure 5: Mapped and classified vegetation units.

tion of measured field points. Discrepancies are most pronounced (mean deviation: 187 cm, standard deviation: 475 cm) compared to the model based on the topographical map. Mean deviation of the KAP based model is 13 cm and standard deviation is 36 cm. These values are affected by filter routines and areas of low image contrast where the image matching process failed and gaps were filled via interpolation within LISA.

4.3. Data processing – vegetation

The captured KAP-pictures provided high resolution in combination with real color depths resulting in a good visual differentiation (Fig. 5a). Partly, single plant individuals were identifiable. However, vegetation analysis was less effective than expected and conventional supervised classification approaches proved to be unsuitable.

Spectral characteristics within each vegetation type, and even within one plant individual, varied within a wide range due to cloudiness, leaf surface structure and cor-

responding shadow. Additionally, homogenous vegetation stands are the exception in our study area. Different vegetation types contain same species inventory (lichens, mosses and dwarf-shrubs) and vegetation type delimitations are defined by the shift of the dominance, abundance and frequency of species. Therefore the definition of homogenous training sites was difficult. Furthermore a principle component analysis (IDRISI 2004) of separated single bands of the original RGB-pictures showed very high correlations. One red band alone carried 95% of information. From this it follows that the spectral characteristics of the captured RGB-photos are poor. A semi-automatic image processing provided best results. Following first unsupervised clustering procedures (IDRISI 2004) a manual reclassification (cluster aggregation) based on ground checks was conducted. Notwithstanding the embarrassments, compared to terrestrial mapped vegetation types the results show pronounced similarities in wide areas (Fig. 5b and 5c).

5. Discussion and conclusions

Within this study we used and proved the KAP technique (Bigras 1997; Perkins 2000) for a new application of high resolution mapping in mountain landscapes. Our experiences documented that KAP was well suited. Despite low costs, KAP ideally matched requirements for the use in severe mountain terrain. The entire equipment was transported in a backpack and the campaign could be aligned spontaneously to weather conditions. Furthermore, the flexibility of the system also enabled repeated applications.

KAP limitations to a spatial extend of 1 – 10 ha were balanced by outstanding high resolution. Though satellite remote sensing capabilities were subject to notable improvements particularly concerning DEM extraction (Jacobsen 2004), substantial limitations emerge in mountains (Kocak et al. 2004) not to mention restricted accuracy of free or low cost data (Gamache 2005).

In contrast to the spatial importance of mountain temperature differentiation (Barry 1992; Löffler and Pape 2004) little attention was paid on topography determined process variability within modeling approaches (Saetersdal and Birks 1997; Zimmermann and Kienast 1999; Guisan and Theurillat 2001; Dirnböck et al. 2003). Considerations taking the fine-scale topography into account led to higher model accuracy (Lookingbill and Urban 2003; Pape and Löffler 2004). Since topography proved to be significantly scale sensitive, high resolution remote sensing offers new opportunities for modeling perspectives on the micro-scale.

Restrictions concerning automatic vegetation pattern analysis might be solved when expanding the sensor-spectrum to near infrared ranges, e.g. applying a modified digital CCD off-the-shelf camera. Altitudinal and spatial limitations due to kite control by a line could be eliminated employing remote controlled platforms by the price of a more complicated and expensive system.

Acknowledgements

The authors would like to thank Prof. Dr. Dietrich Hagen (University of Oldenburg, Germany) for support of equipment and software LISA and Jörg Wundram for assistance in the field.

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