USE OF UNMANNED AIRCRAFT SYSTEMS (UAS) IN A MULTI-SCALE VEGETATION INDEX STUDY OF ARCTIC PLANT COMMUNITIES IN ADVENTDALEN ON SVALBARD

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ABSTRACT

Use of Unmanned Aircraft Systems (UAS) gives the opportunity to carry out research with a reduced environmental footprint. Unmanned aircraft, including both fixed wing and multi rotor types (helicopters) allow us to collect very high resolution image data for vegetation mapping without the need for any personnel walking into the site and thereby potentially disturbing the sensitive Arctic ecosystems. The main aim of this project was to explore the feasibility of UAS-based vegetation mapping and extraction of vegetation indices (*NDVI*) for a range of different Arctic plant communities including dense marshes, moss tundra communities and different tundra heaths. The study area of Adventdalen valley on Svalbard, Arctic Norway, is located at 71.2°N 16°E and experiences a dry Arctic climate with a mean July temperature of about 6°C. The UAS was a fixed wing aircraft instrumented with a Red, Green, Blue (RGB) compact camera and a Normalized Difference Vegetation Index (*NDVI*) camera taking pictures from 100 metres altitude with highest ground resolution of 2.5 cm capable of mapping 2-3 km^2 per flight. The study area's two main plant communities; the Arctic bell heath and a graminoid rich Polar Willow heath were easily detected both in the *NDVI* and RGB images. In addition, wet moss tundra and mires were separated from the heath communities. In the *NDVI* image the moss-dominated mires were difficult to separate from the graminoid dominated mires in most cases, but they were well separable in RGB colour space. Also *in situ NDVI* measurements by a handheld passive proximal sensor were simultaneously done during the flight campaign. These measurements were analysed in order to correlate the species level *NDVI* and community level *NDVI* measurements with the *NDVI* images acquired at a variety of spatial resolutions by the UAS. The analysis shows that *NDVIs* of four main plant species at *in situ* leaf and community levels were significantly correlated (R^2 = 0.60, p<0.01). The correlation between the surface (*in situ*) *NDVI* community level and the UAS *NDVI* community level acquired from 100 metres above the surface of four main plant communities was R^2 = 0.75 (p<0.01), and these two scales are considered to be best for extraction of *NDVI* observations in Arctic areas like Svalbard.

INTRODUCTION

Use of Unmanned Aircraft Systems (UAS) gives the opportunity to carry out research that minimizes the environmental footprint of the research activities in sensitive Arctic ecosystems. The main aim of the project was to explore the feasibility of using UAS-based high spatial resolution

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RGB and *NDVI* sensors for multi-scale mapping and measurements of different Arctic plant communities and plant species. In the following we present preliminary results from this study, particularly on the relationship between *in situ* and UAS- based *NDVI* measurements.

METHODS

Study area

The study area of Adventdalen valley on Svalbard (Figure 1), Arctic Norway, located at 71.2°N and 16°E is characterized by dry Arctic climate with a mean July temperature of about 6°C, and nutrient rich soil (1). The rather flat valley is dominated by the braided Adventelva river systems and big alluvial river fans expanding from the many side valleys toward the Adventelva river and flat silty terraces along and close to the Adventelva river. Vegetation is dominated by bryophyte-rich fens and marshes in the lower flat areas, while plant communities characterized by Polar Willow *(Salix polaris*), Arctic bell heather *(Cassiope tetragona),* or Mountain Avens *(Dryas ocopetala*) dominate on more elevated, exposed and dryer sites (1,2,3).

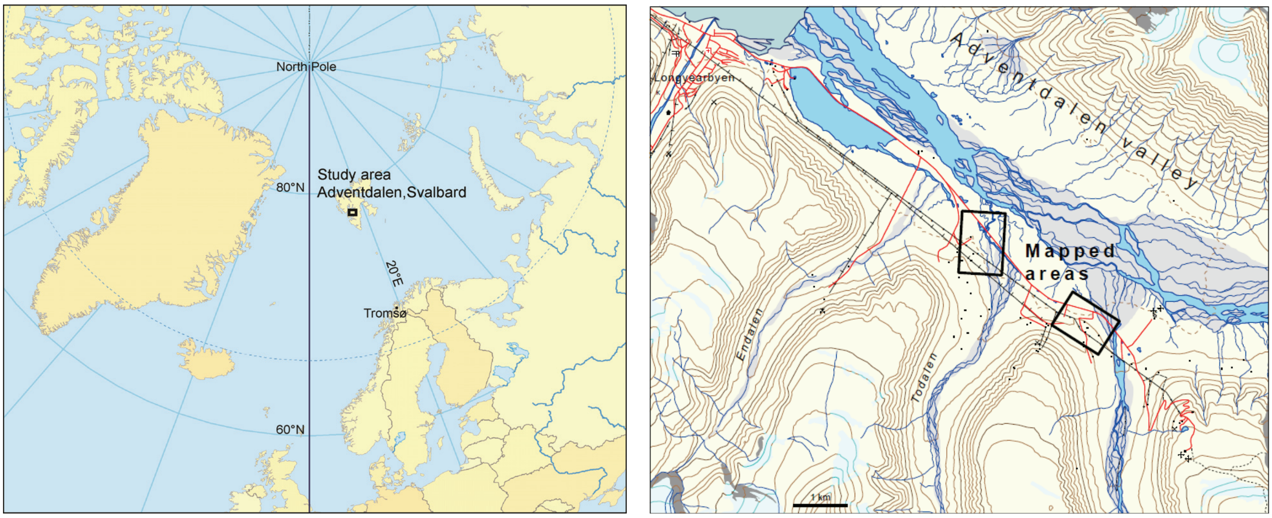

Figure 1: Map over the study area in Adventdalen on Svalbard.

Methods and analysis

The UAS was a fixed wing aircraft (Cryowing Micro trademark) and is inexpensive and simple to operate. The UAS is built on a Skywalker X8 airframe and Ardupilot 2.5 open source autopilot for navigation and control. The aircraft was instrumented with low cost sensors such as a standard Canon Powershot S100 RGB compact camera and a modified Canon Powershot S230 *NDVI* proximal camera taking pictures from 100 metres altitude with ground resolution of 2.5 cm with a fixed wing aircraft capable of mapping 2-3 km^2 per flight. To avoid problems with lighting during the flying session we used a preset setting of the white balance to “cloudy” as suggested by the producer of the camera (www.maxmax.com), since the light conditions were changing during the flight campaign. The flight campaign was carried on July 12th - 15th 2013, a period when most of the plants were well developed.

After the flight, the custom software was used to couple GPS tags to the images with the autopilot log for aircraft altitude that was then added to the image exif headers. Finally, we mosaicked the images using the Agisoft bundle adjustment software to create a 3D image. Simultaneously with the flight campaign, *NDVI* measurements (*n*=12) were carried out at the species level (leaf) and community level by using a handheld passive proximal sensor (MaxMax *NDVI* camera – a modified Canon EOS 450D camera) during the flight campaign. Since both cameras used in this study have silicon-based sensors and the same basic response to light, the biggest factor that will change with the shape of response curves is the White Balance (WB) setting (www.maxmax.com; Dan Llewellyn, pers. com., 2013, 2014). Hence, we used the same white balance settings for the 450 D

NDVI camera as for the S230 *NDVI* camera in order to avoid differences in measurements and to facilitate post processing. The community level measurements were taken 1.5 m above the surface, while measurements of the species level were taken 0.5 m above the surface.

Figure 2: A fixed wing UAS used to measure NDVI over high arctic vegetation communities.

These measurements were analysed in order to relate the species level and the community level *NDVI* observations with the UAS *NDVI* measurements taken from an altitude of 100 metres with a ground resolution of 2.5 cm. During and after the flight campaign we analysed the RGB and the *NDVI* imagery in the lab as well as in the field. We assessed the applicability of imagery obtained from UAS to detect different plant communities. During the analysis of imagery we used the Landsat-based vegetation map over Svalbard (1) and a Landsat based *NDVI* map for the study area (2) as reference data.

RESULTS

Detection of different plant communities

Main plant communities of the study area were easily detected in both the *NDVI* and RGB images; an Arctic Bell heather dominated heath, Mountain Avens heath and a graminoid rich Polar Willow heath (Figure 3). In addition, wet moss tundra and mires were distinguishable from these two communities mentioned above (3). Within the plant Arctic bell dominated heath community (Figure 3), three different stand subtypes could be identified from the *NDVI* image. These were: a) patches where graminoids and bryophytes dominate, b) patches with a mixed dominance of Mountain Avens and Polar Willow, and c) moss-stripes dominated by the black liverwort *Anthelia juratzkana*. In addition, in the RGB image, the areas dominated by subtype *A. juratzkana* were identified, but the other two subtypes were not identified. The graminoid rich Polar Willow heath plant community (Figure 3) occurs on flat areas, with dry and silty soil conditons. This plant community covers large areas on the valley floor and is rich in species with several snow-bed indicators. Within this plant community, homogeneous patches of the brownish Arctic bell heather could be identified and detected in both the RGB and the *NDVI* image. In the *NDVI* images, homogeneous patches dominated by Mountain Avens, Polar Willow, or graminoides were identified in most cases, but this was not possible in the RGB image.

Moss tundra occurs in the valley in areas with gentle slopes, and with a water table in the range 8 - 25 cm below the bryophyte level (bottom level). Fens and marshes occur in flat areas with a water table level of about -2 cm (under) and above the bryophyte surface, respectively (3). All these ‘mire types’ are characterised by yellow-brownish coloured bryophytes, as *Tomentypnum nitens, Aulacomnium turgidum, Ortothecium chryseon, Calliergon richardsonii, Catoscopium nigritum, Scorpidium cossoini and Warnstorfia sp*. These bryophyte-dominated areas are important to map, as they constitute most of the plant biomass of Svalbard. During the campaign we measured that the biomass of these communities could be up to 1.7 kg dry weight per square metre.

In the *NDVI* image, areas dominated by the bryophyte *Aulacomium turgidum* were in most cases difficult to separate from the graminoid-dominated areas, since both have high *NDVI* values (Table 1). However, in the RGB image, these yellow-brownish bryophyte-dominated communities were easier to separate from the graminoid-dominated parts. We are currently conducting further analyses of the collected data in order to draw broader conclusions on the capacity of simple UAS borne sensors, such as the ones used here, to distinguish High Arctic plant and vegetation types. In addition, we will assess different classification procedures in order to map the different plant communities and vegetation types in the most accurate and efficient way.

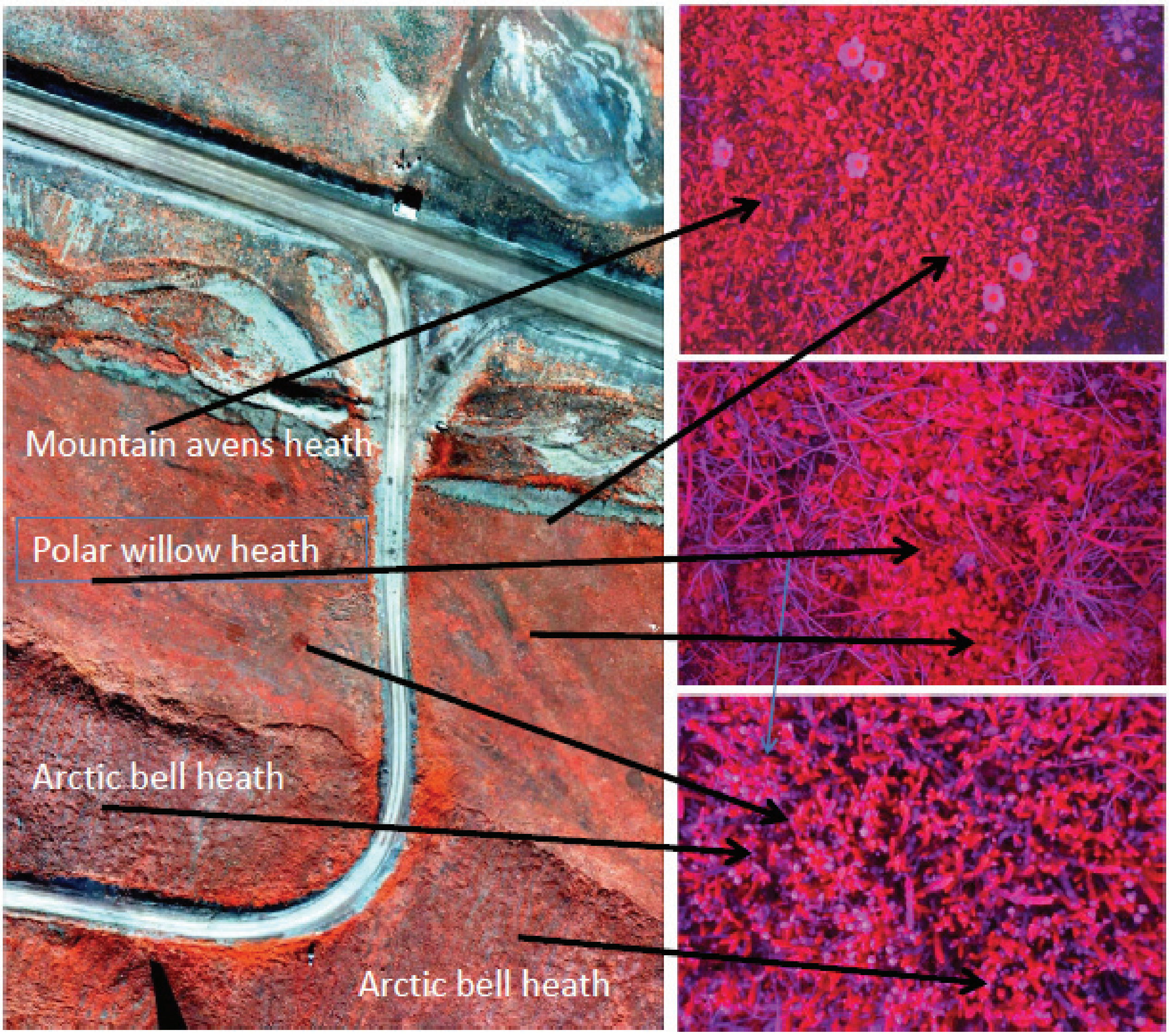

Figure 3: NDVI image acquired by UAS (left) with the different plant communities identified. To the right: NDVI images taken by the proximal camera for the plant species communities; Mountain avens heath (upper right) with flowers (large round light purple), Polar willow heath (middle right) with leaves and Arctic bell heath (lower right) with flowers (small light pink dots).

Comparison of *NDVIs* on species, community and UAS levels

In Table 1, we present *NDVI* values measured at the leaf level and community level for four species that also are the characteristic and dominating species in the main plant communities of the study area. The *NDVI* values for the different species (Table 1) measured at the surface were higher at leaf level than at the community level, because the image on community levels integrates shadows, soil and other species that may reduce the signal. The UAS based *NDVI* values for the species level were higher than the community level indicating the difficulties in separating different sub-community levels within or between plant communities and vegetation types (e.g. the wet moss tundra and mires dominated by the mosses *Aulacomium turgidum* and *Tomentypnum nitens* and the sedges *Carex saxatilis, Eriophorum triste* and *Eriophorum scheuchzeri*). The latter is also a challenge in the Landsat-based study of the study area (2).

Figure 4: Fen with yellow-brownish coloured bryophytes (mainly Aulacomnium turgidum) and the graminoids Tundra grass (Duponitia fisheri) and Arctic Cotton grass (Eriophorum scheucheri). This plant community was better separated in the RGB image than in the NDVI image.

The *NDVI* measurements were also analysed in order to correlate the species level *NDVI* and the community level *NDVI* measurements with the *NDVI* measurements taken by the UAS system. Analysis showed that the surface leaf and community level *NDVI* of four main plant species were significantly correlated (R^2 = 0.60, p<0.01). The correlation between the surface community level *NDVI* (in-situ) and the UAS *NDVI* community level acquired from 100 meters above the surface of four main plant communities was R^2 = 0.75 (p<0.01), indicating a satisfactory relationship between surface and UAS based measurements. However, the range and standard deviation from species/community surface level to UAS levels is relatively large due to characteristic properties for the different species/communities. For instance, the species *Cassiope tetragona* (Arctic Bell Heather) has a *NDVI* value of 0.862 at UAS species level, but internal properties of the Cassiope-dominated community (Arctic Bell Heather dominated heath) due to shadow effects and texture decrease the *NDVI* UAS level to 0.49, while the other species do not show such variation. The next UAS campaigns in Svalbard will include multi- and hyper-spectral sensors and these are expected to greatly increase the accuracy and the application range of UAS-based vegetation mapping in High Arctic environments.

*Table 1: NDVI values (n=12) from the surface species level and community level and the UAS levels. The two first categories are measured on the ground, while the third and fourth ones are measured by the UAS. *Communities: [1] Arctic Bell Heather dominated heath; [2] Mountain Avens heath; [3] Polar Willow heath; and [4] Wet moss tundra. **Landsat based NDVI values from Johansen & Tømmervik (2).*

Plant species/ community*	*NDVI in situ* Species level (0.5 × 0.5 cm²)	*NDVI in situ* Community level (0.5 × 0.5 m²)	*NDVI* UAS Species level (10 × 10 cm²)	*NDVI* UAS Community level (0.5 × 0.5 m²)	*NDVI* Landsat ETM+ Vegetation type level** (30 × 30 m²)
Cassiope tetragona[1]	0.525+/-0.205	0.441+/-0.304	0.862+/-0.091	0.494+/-0.132	0.220
Dryas octopetala[2]	0.612+/-0.220	0.387+/-0.290	0.462+/-0.030	0.372+/-0.072	0.190
Salix polaris[3]	0.648+/-0.166	0.443+/-0.284	0.638+/-0.099	0.509+/-0.078	0.350
Aulacomium turgidum[4]	0.387+/-0.100	0.304+/-0.157	0.550+/-0.078	0.367+/-0.105	0.410

CONCLUSIONS

This study is one of the first attempts using UAS on Svalbard and shows that data from UAS vehicles equipped with low-cost sensors can be valuable for mapping of high Arctic plant communities. UAS-based *NDVI* measurements showed a satisfactory agreement with ground truth *NDVI* data but the range of change of *NDVI* is relatively wide between the different scales from surface species level to UAS community levels, especially for the Arctic Bell Heather dominated heath.

Further analysis including comparison of the modified *NDVI* sensors with spectral reference data using spectrometers (e.g. ASD) and different classification procedures for vegetation mapping including accuracy assessments will be performed, before broader conclusions can be drawn on the capabilities and limitations of UAS for high arctic vegetation mapping. The next UAS campaigns in Svalbard will include multi- and hyper-spectral sensors that are expected to greatly increase the accuracy and detail of the *NDVI* analysis and vegetation mapping in such environments.

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