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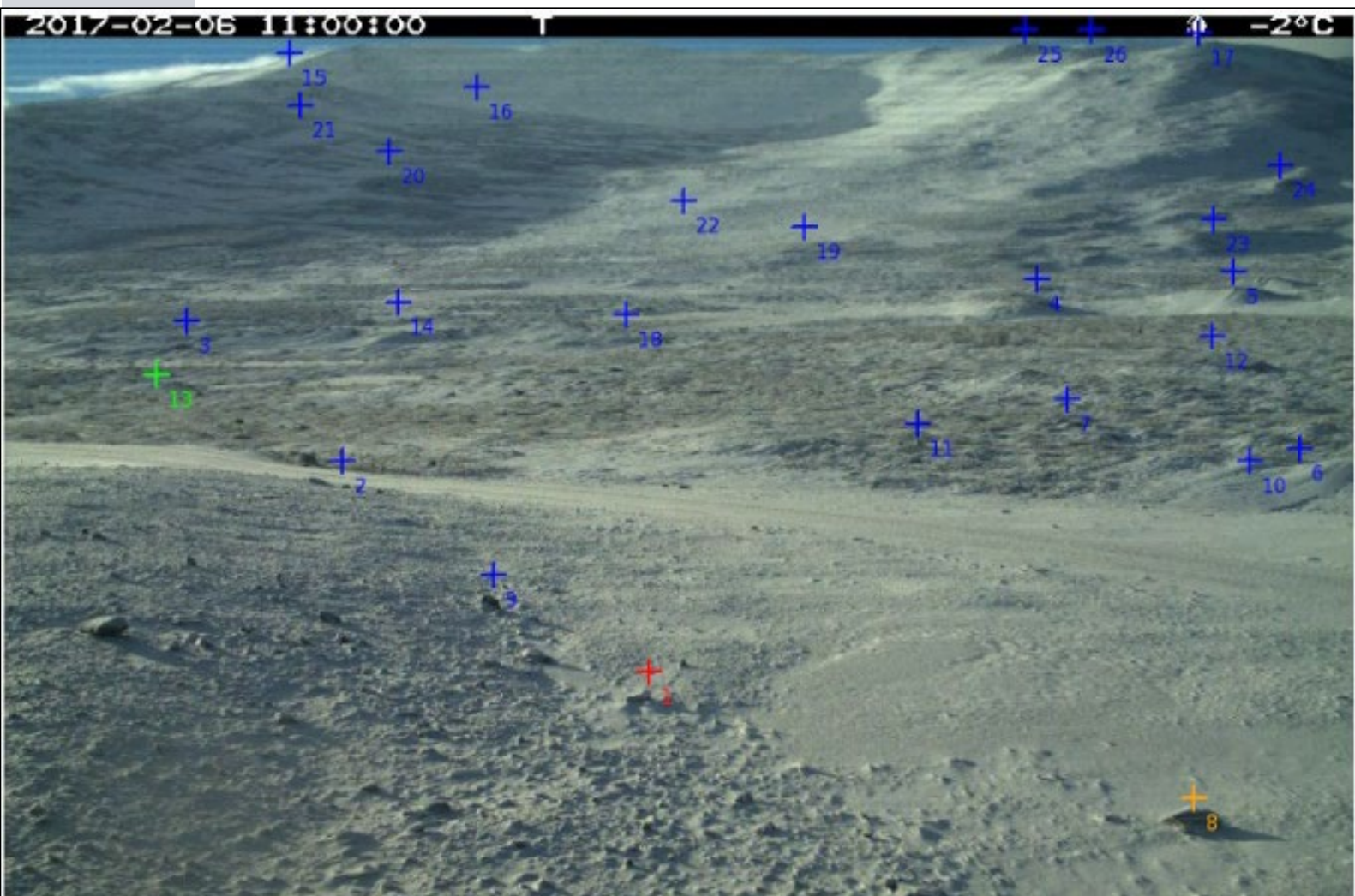
Using wildlife camera traps to collect in-situ data for remote sensing applications with high temporal resolution

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Stefan Blumentrath, Zofie Cimburova, Lars Rød-Eriksen

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Blumentrath, S., Cimburova, Z. & Rød-Eriksen, L. 2018: Using wildlife camera traps to collect in-situ data for remote sensing applications with high temporal resolution. NINA Report 1584. Norwegian Institute for Nature Research.

Oslo, November 2018

AVAILABILITY
Open

PUBLICATION TYPE
Digital document (pdf)

QUALITY CONTROLLED BY
John Odden

SIGNATURE OF RESPONSIBLE PERSON
Kristin Thorsrud Teien (sign.)

CLIENT(S)/SUBSCRIBER(S)
European Space Agency

CLIENT(S) REFERENCE(S)
C4000111621 Sentinel4Nature

CLIENTS/SUBSCRIBER CONTACT PERSON(S)
Veronique Dowson

COVER PICTURE
Camera trap image w. ground control points © Stefan Blumentrath

KEY WORDS
Wildlife camera traps, orthorectification, sensor data, time series, in-situ-data, remote sensing, PRODEX, ESA, NRS

NØKKELORD
Viltkamera, ortorektifisering, sensordata, tidsserie, in-situ-data, fjernmåling, PRODEX, ESA, NRS

Abstract

The high frequency of revisits of esp. the Sentinel satellites provides a challenge for collecting real time ground truth or validation data. To be able to match the temporal resolution of the remotely sensed data, at least semi-automatic processes for generating in-situ data seem necessary. In this report an approach is tested and documented where daily time-lapsed, oblique wildlife camera trap images with "fixed-angle" are orthorectified to generate data with a spatial precision below pixel size of the used satellite imagery. Even if the on-site experiment did not achieve the required accuracy in the orthorectification, a conducted laboratory experiment shows that the approach in general is feasible. In conclusion, a set of challenges and requirements is identified for a successful deployment of time lapse cameras for such a purpose as well. These relate mainly, to how and how many Ground Control Points are measured in the field as well as how the camera is mounted. Those challenges can be addressed during the planning and implementation phase of a campaign.

The report does not cover legal questions regarding monitoring using wildlife camera traps as these are highly dependent on context and deployment and legal advice is not part of the authors expertise.

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Sammendrag

Blumentrath, S., Cimburova, Z. & Rød-Eriksen, L. 2018: Using wildlife camera traps to collect in-situ data for remote sensing applications with high temporal resolution. NINA Report 1584. Norwegian Institute for Nature Research.

Den høye frekvensen av passeringer fra Sentinel-satelitter er utfordrende ved innsamling av in-situ data eller valideringsdata i sanntid. Halv-automatiske tilnærminger til datafangst, f.eks. med lokale sensorer kan være en løsning på denne utfordringen. I denne rapporten testes og dokumenteres en delvis automatisert metode til dette formålet, som tar i bruk tidsutløste og skråstilte viltkamerabilder med fast kameravinkel som matcher dem med terrengoverflaten. Denne matching prosessen kalles ortorektifisering. Formålet har vært å generere tidsserie data med en høyere romlig oppløsning enn piksel størrelsen i satellittbildene. Selv om felt-eksperimentet ikke oppnådde den grad av nøyaktighet som var ønskelig i ortorektifiseringen, viste et laboratorie-eksperiment at metoden generelt er anvendbar. Basert på erfaring fra disse to eksperimenter identifiseres i rapporten de vesentlige tekniske utfordringene og kravene for en vellykket gjennomføring av overvåkingsopplegget skissert ovenfor. Utfordringene og kravene er i hovedsak knyttet til hvordan og hvor mange kontrollpunkter som måles inn for et kamera og hvordan kamera har blitt montert. Disse utfordringene kan håndteres allerede under planleggings- og gjennomføringsfasen av arbeidet.

Rapporten dekker ikke juridiske spørsmål knyttet til bruk av kameraer i miljøovervåking. Juridiske kravene varierer med kontekst og måten overvåkingen er satt opp på juridisk råd er ikke en del av forfatternes kunnskapsområde.

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Contents

Foreword

This report has been produced as part of the Sentinel4Naure project, financed by the European Space Agency (ESA). We considered technical details about and experiences with the tested approach of collecting in-situ data using wildlife camera traps to be valuable information to document. However, they are not the main focus of the Sentinel4Nature project and including this documentation in the final report would have blurred the latter. We therefore decided to present them in this separate methodological and technological report, while main results of this project are published in the following NINA report:

Blumentrath, S., Salberg, A.-B., Cimburova, Z., Bakkestuen, V., Erikstad, L., Nowell, M., Kermit, M. 2018. Sentinel4Nature: Estimating environmental gradients and properties using remote sensing. NINA Report 1545. Norsk institutt for naturforskning.

We are very grateful to Jo Skorem and Villreinsenteret for their support of the on-site experiment at Hjerkinn. We also thank Lucas Bergsland Meyer for his help with setting up this on-site experiment and mounting the camera traps.

Furthermore, our thanks go to Yann Chemin, Moritz Lennert and Markus Neteler from the GRASS GIS Development team for their help, comments, and feedback regarding technical questions about the orthorectification algorithm in GRASS GIS. Especially updating the i.ortho.photo tools and introducing them to GRASS GIS 7, conducted by Yann Chemin, has been very valuable for our work.

Oslo, November 2018

Stefan Blumentrath
Principal investigator

1 Introduction and aim

The high frequency of revisits of the Sentinel satellites provides a challenge for collecting real time ground truth or validation data. Semi-automatic processes for generating in-situ data seem necessary to be able to match the temporal resolution of the remotely sensed data from the Sentinel satellites. The potential of combining camera trap images with remote sensors in biodiversity research has been described by Steenweg et al. 2017.

In the Sentinel4Nature project (Blumentrath et al. 2018, funded by ESA and conducted by NINA and NR) the usage of wildlife camera traps for generating spatial training data for satellite imagery has been tested in the field. The idea is to acquire daily oblique images from the study site using time-lapsed, "fixed-angle" wildlife camera traps and to reference them on the surface of the earth. The aim is to generate data with a spatial precision below pixel size of the used satellite imagery that can help to validate especially models developed for the environmental gradient "Reduced growing-season due to prolonged snow-lie" from the description system Nature in Norway (NiN).

Since oblique images - like those acquired from wildlife camera traps - are especially subject to geometric distortion, geometric correction of the photographs is required to match content of wildlife camera trap and satellite images. Here, orthogonal projection of all points of the image to a reference surface (called orthorectification) can be used to correct the distortion in the photos (Rocchini et al. 2012). The possibility to orthorectify oblique, tilted images from hand-held digital cameras has been demonstrated by Neteler et al. (2005). They used the orthorectification-algorithms of GRASS GIS, a Free and Open Source GIS. There orthorectification functionality is provided by the *i.ortho.photo* module suite (GRASS Development Team 2017). The context Neteler et al. applied this approach to was perspective rendering (see **Figure 1**).

Figure 1: Orthorectification of oblique, tilted digital images. Left: the proof of concept by Neteler et al. (2005) Right: wildlife camera image with colour marked GCPs.

Orthorectification is not only a precondition for spatially matching of satellite and in-situ camera images. It would also provide new possibilities for more advanced spatial measurements in vegetation and phenological monitoring where the use of time lapsed cameras has been introduced (see Richardson et al. 2018). Because orthorectification would add a new dimension of spatial referencing to the camera generated image time series.

However, transferring Neteler et al.'s (2005) recipe to monitoring the phenology of the landscape in the Norwegian mountains using wildlife camera traps, introduces additional challenges regarding, amongst others,
- the identification of Ground Control Points (GCPs),
- the underlying terrain model,
- camera position and exposure,
- practical issues.

The aim of this report is to evaluate a possible methodology for orthorectification of a time series of oblique, "fixed-angle" images from time-lapsed cameras, as well as to document and discuss experiences and possible improvements of the approach, based on a first try-outs.

The try-outs were conducted in the Hjerkinn study site at Dovre using a Reconyx PC800 wildlife camera trap, and a second time - for methodological refinement - in laboratory settings using a Sony Alpha 5000 hand-held digital camera.

The report does not cover legal questions regarding monitoring using wildlife camera traps as these are highly dependent on context and deployment and legal advice is not part of the authors expertise.

2 Methodology

Time lapsed wildlife camera traps can generate time series of in-situ images, which allow for at least a visual analysis of the phenological (as well as long-term) development of the represented landscape. However, these images have usually no or just a quite rough geo-reference (camera coordinates and viewing angle). To be able to place the content of a tilted image more precisely on the surface of the earth, it has to be orthorectified. Orthorectification "is the only method which guarantees low spatial error in the geometric properties (e.g., object displacement) of remotely sensed images, taking into account the geomorphological complexity of the landscape under study" (Toutin, 2004 in Rocchini et al. 2012). The distortion effect of the terrain is especially important with regards to the duration of snow cover in the Norwegian mountains.

The required precision depends on the purpose of the later analysis of the data. The precision of the orthorectification result will vary within the image due to the perspective and thus varying camera angles. The quality of the underlying terrain model plays a crucial role for the quality of the orthorectification process.

The orthorectification was performed using *i.ortho.photo* module in GRASS GIS version 7.3. The orthorectification procedure in GRASS places the image pixels on the surface of the earth by matching
- the coordinate system of the digital image in pixels ("image coordinate system") and the coordinate system of the camera sensor in millimetres ("photo coordinate system") for the interior orientation of the image,
- and further to the real-world coordinate system defined by projection parameters ("target coordinate system") for exterior orientation and rectification.

2.1 Input data

Along with the oblique images, three sets of input data are required for an orthorectification of an oblique image (Rocchini et al. 2012):
- positioning, exposure, characteristics of the camera,
- reference surface and reference maps,
- ground control points.

Given that the basic principle of the monitoring approach with wildlife camera traps is to use a fixed camera angle, these three types of information will have to be given only once per site / camera setup, for the first image in a series, and can then be applied to all other images from that time series. An example for the technical procedure described below is available in Section 5.3.

In this section, the methods of individual input datasets acquisition, as well as encountered problems and their possible solutions will be described.

2.1.1 Oblique images
The oblique images were acquired using a Reconyx PC800 wildlife camera trap in the Hjerkinn case study site at Dovre. Images were taken with a 1-hour frequency between 9am and 16pm from 3rd February to 24th May 2017. Altogether, 876 images were acquired.
Several issues with the collected images were identified. Some of these can be avoided beforehand, e.g. camera placement and camera exposition. Other issues are of natural causes and cannot be avoided (see Figure 2).

Table 1 Issues of collected oblique images

Problem	Solution
Different white balance of each image (e.g. snow appears white, blue, yellow)	Manual adjust white balance.
Different exposure of each image (e.g. if sun shines directly into image, sun appears white and rest of image black)	Manual adjust exposure.
Moisture and condensation on lens	Exclude images from analysis.
Camera angle is not constant (possibly reaction of wood on humidity and/or temperature)	Attach camera to a weather re-sistant surface.
Shadows cause high contrast between different parts of im-age	Use terrain corrections or mask shadows based on sun position.
Sun reflects in camera lens or shines directly into the cam-era.	Mask saturated pixels. Orientate camera towards north.

Figure 2: *Examples of issues – Upper left: condensation, Upper right: sun shining into lens, Lower left: shadows and Lower right: reflection of sun on ice*

2.1.2 Exposure and characteristics of the camera

Camera parameters used in the orthorectification include camera exposure, measured directly in the case study site:

- coordinates X, Y, Z + height above terrain,
- roll,
- pitch,
- yaw,

and internal characteristics of the camera:

- focal length,
- photo coordinates of principal point,
- image and photo coordinates of fiducial marks.

Roll (omega) represents the raising or lowering of the wings (turning around the aircraft's axis), pitch (phi) is the raising or lowering of the aircraft's front (turning around the wings' axis) and yaw (kappa) is the rotation needed to align the aerial photo to true north, denoted as +90° for clockwise turn and -90° for a counter-clockwise turn (see Figure 3; (Neteler & Mitasova 2008).

Positioning of the camera is the first and essential step when setting up a monitoring site. Here both thematic and technical aspects must be taken into account. In principle, the algorithm in the *i.ortho.photo* suite allows for oblique (tilted) images with angles between +-3 and +-90 degree from the nadir direction (GRASS Development Team 2017). That means a digital camera can be rotated around lateral (pitch) and longitudinal axis (roll). However, camera position and exposure should be chosen in a way that the both pitch and roll angles are as small as possible (in other words the camera should be mounted as much as possible down-facing and otherwise parallel to the horizon). Especially minimizing pitch can help to reduce the pixel misplacement, as it leads to less flat camera angle at the surface. Also objects not present in the terrain model have less effect with less pitch. Position and exposure should be measured in the field as precise as possible.

The roll was set to 0 when mounting the camera. The pitch was set so that the camera is as much as possible down-facing, but still captures a sufficient amount of the surrounding landscape for the monitoring purpose. For technical reasons, the camera was facing slightly below the horizon (see Appendix 6.2). Camera exposure was measured manually with a handheld Garmin GPSMap 62S, protractor and metering rule. Cameras x/y position was validated and adjusted using orthophotos.

Since the Reconyx Wildlife camera traps are equipped with a fixed focus, the relevant characteristics of the camera type are entered once, for all images taken with the respective camera type (GRASS Development Team 2017). Information on the focal length and sensor size of the Reconyx PC800 was collected from the manufacturer. The fix focal length of this camera type is 8,5mm. The 1/2-inch sensor is 6,4 mm wide and 4,8 mm high. Given that the images have 2048 x 1536 pixels, each pixel is 3,1 µm in size.

In contrast to cameras used for taking aerial photos, wildlife camera traps or handheld digital cameras have no fiducial (or reseau) marks. These can be set arbitrary to the middle of the left, upper, right and lower sensor border. Hence, interactive placement in *i.photo.2image* is not required (GRASS Development Team 2017).
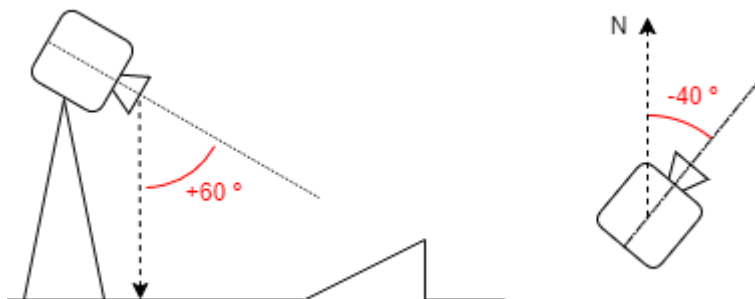
Figure 3: Pitch and roll of camera

2.1.3 Reference surface
The quality of the underlying terrain model plays a crucial role for the quality of the orthorectification process. Ideally high-quality terrain models, e.g. from laser scanning, should be used. In mountainous areas, the official, country-wide available terrain model with 10m resolution are usually of relatively poor quality in the Norwegian mountains, where standard deviation in altitude is 4 to 6 meters (Kartverket 2013). Generating high precision terrain models for the camera viewshed from e.g. LiDAR or UAV generated 3D-data can help a lot to improve the orthorectification and therewith quality of the obtained in-situ data.

In this study, high resolution terrain data could be obtained for the camera location and viewshed from hoydedata.no.

Additionally, detailed terrain models, along with existing, recent orthophotos can be utilized as reference maps in supplemental ground control point detection and adjustment of GPS-measured ground control points.

2.1.4 Ground control points
Ground control points (GCPs) are required for georeferencing of the tilted images. GCPs in the Hjerkinn study area were measured manually at the beginning and at the end of the imaging period. Usually, crossings and other fixed man-made objects are used as GCPs when georeferencing orthoimagery. The orthorectification algorithm in GRASS GIS 7 requires at least 12 to 16 GCPs, which should be distributed evenly across the image. Identifying usable (in terms of quality and quantity) ground control points from ortho-imagery in natural environments like the Norwegian mountains proved to be quite challenging, due to a limited number of fixed structures or objects that can be reliably identified in both the tiled camera trap image and a reference map (e.g. an existing orthophoto or high precision terrain model). Here also the change of perspective complicates the robust and reliable identification of minor landmarks in both camera and reference image.

In the field, coordinates of distinct landscape structures, such as single boulders or tops of hills, were measured with a handheld GPS and then manually detected in acquired images. In order to optimize the precision of the GPS measurements as far as possible, the "Waypoint averaging" technology of the Garmin GPS 62S was used. However, deviation of the GPS measurements from the reference ortho-imagery was ~3m in the XY-direction.

In the office, additional ground control points were detected from a terrain model and an existing orthophoto of the case study site to obtain a sufficient number of points and good coverage of the entire area. A visibility raster from the camera position was computed to estimate which portions of the terrain were visible. A shaded relief (with sun position set according to the orthorectified image) was then derived to detect significant terrain features (**Figure 4**).

When mounting the camera in February 2017, 18 GCPs were measured, out of which 12 were used in the orthorectification. When un-mounting the camera in May 2017, 7 GCPs were measured, some of which were identical to the GCPs measured in February. All of them were used in orthorectification. Finally, 14 GCPs were added additionally based on terrain data and ortho-imagery, totalling to 26 GCPs to be used in orthorectification.
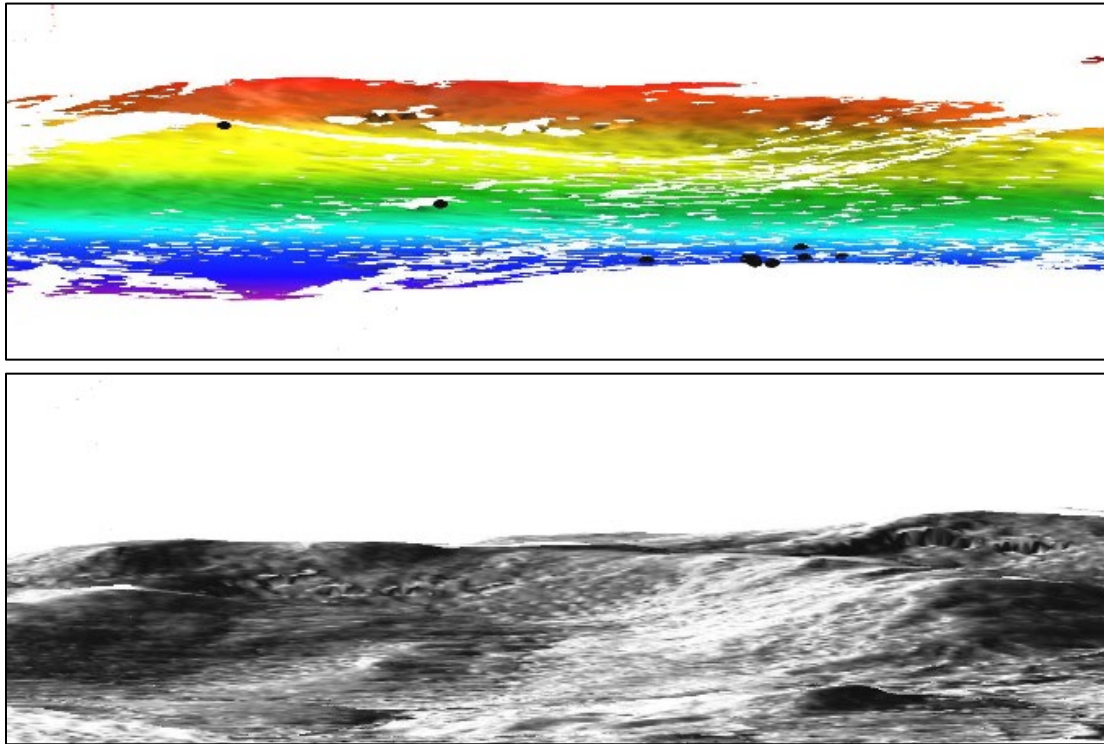

Figure 4: *Principle of additional detection of GCPs – visibility and terrain shading - in 3D view*

2.2 Orthorectification

Orthorectification was performed using *i.ortho.photo* module in GRASS GIS version 7.3. The entire procedure of orthorectification of oblique images is described in Appendix 6.3.

The input parameters, as defined above, turned out to lead to inaccurate and distorted results (see the orthorectification result in Figure 5).
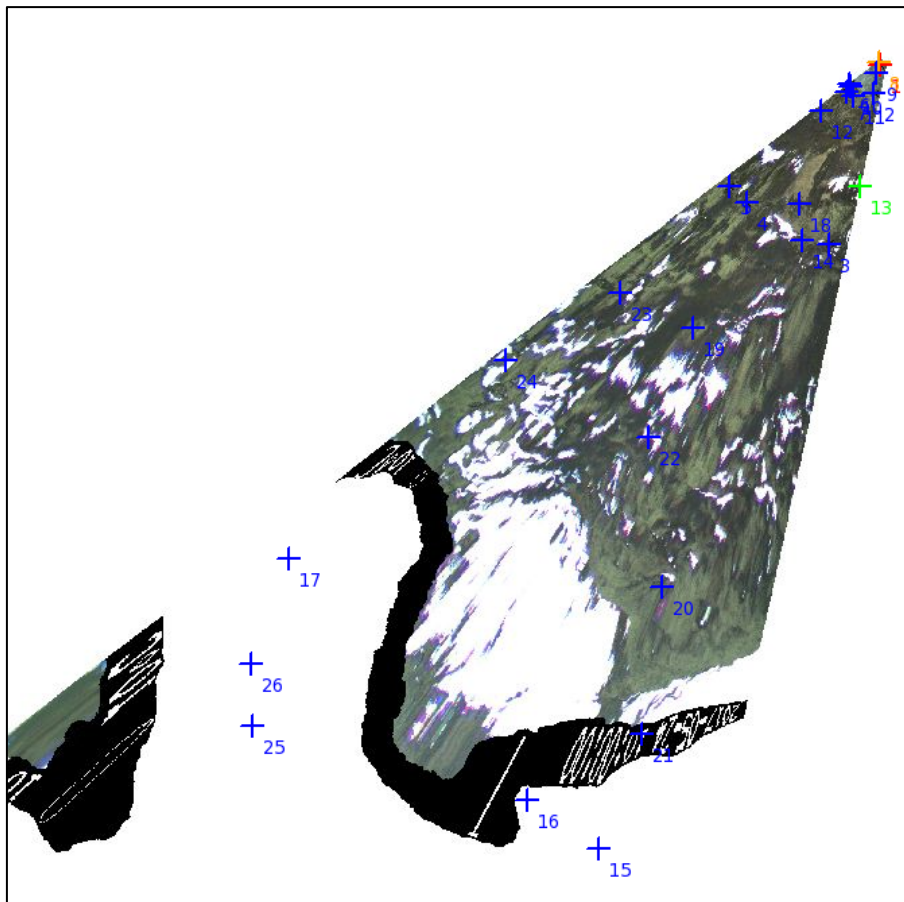
Figure 5: Result of the orthorectification using above-defined input data

2.3 Sensitivity analysis to input parameters

To find the sources of inaccuracies and distortion of the resulting image, a sensitivity analysis of different input parameters was carried out.

2.3.1 No camera parameters

A test orthorectification without specified camera exposure (X, Y, Z, h, Ω, Φ, K) was performed (see Figure 6). Surprisingly, the results seemed to be the best (yet still insufficient) out of all obtained results.
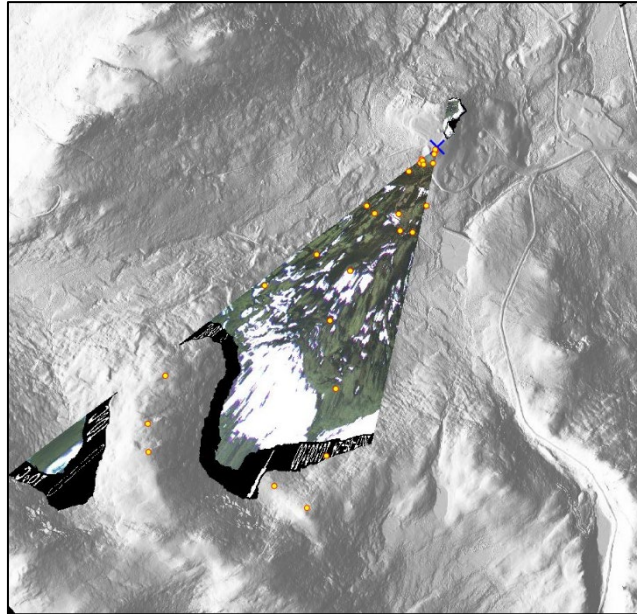
Figure 6: Result of orthorectification with no specified camera parameters

2.3.2 Focal length

The focal length of the Reconyx PC800 is not documented in the manual. The manufacturer specifies that the camera is equipped with a focal length of 8.5 mm as well as adjustable focal length. Therefore, orthorectification with different settings for focal length have been tested (see Figure 7). With increasing focal length, the view angle decreases. Based on the observations, the most likely value of focal length is between 7 mm and 10 mm.
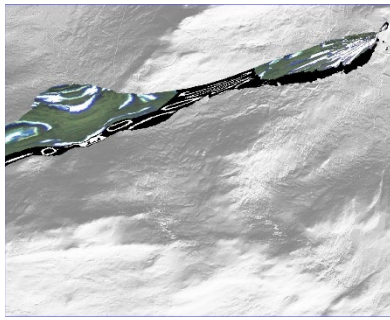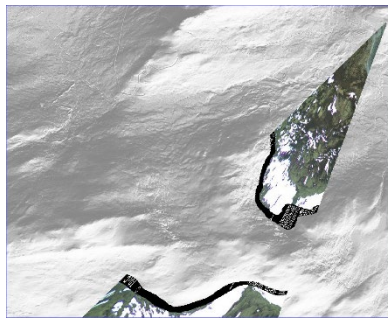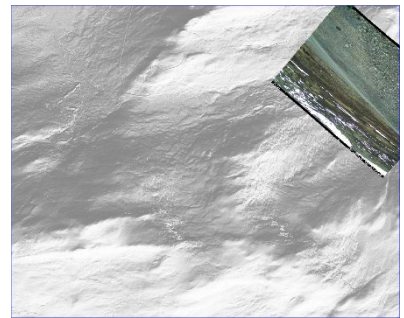
F = 1 mm
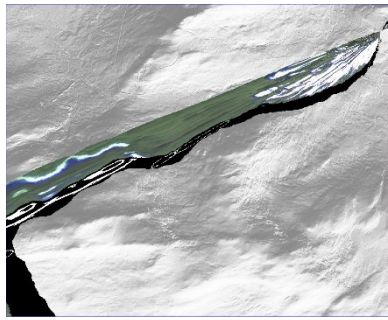
F = 3 mm
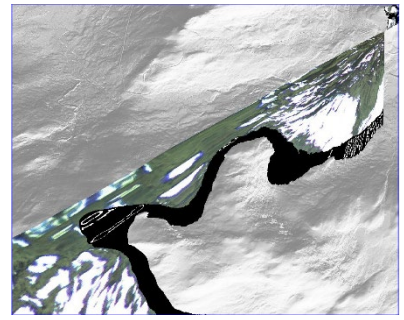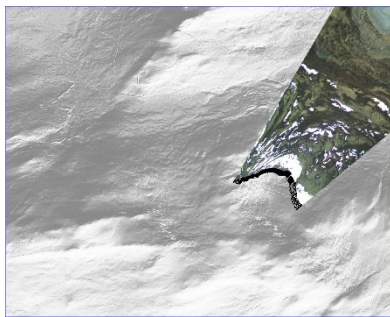
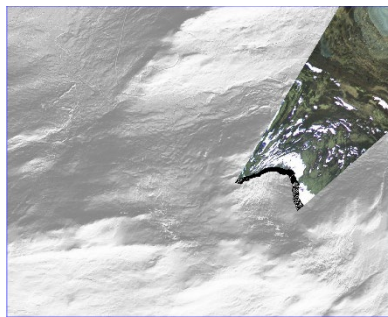F = 5 mm
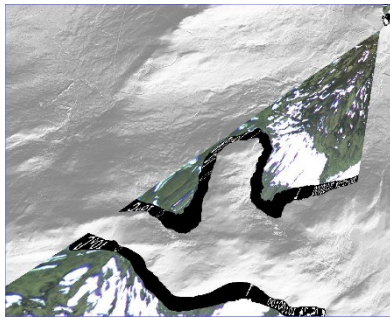
F = 7 mm
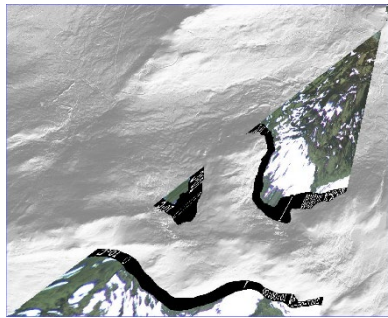
F = 8.5 mm
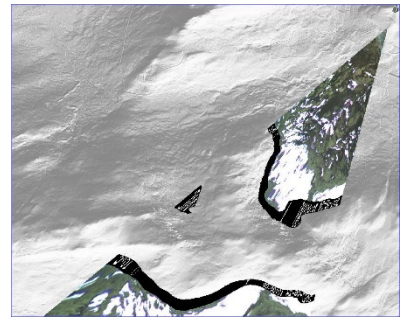
F = 10 mm
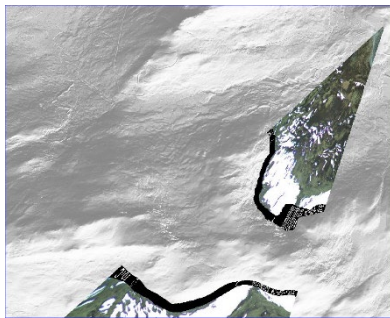
F = 12 mm

F = 14 mm
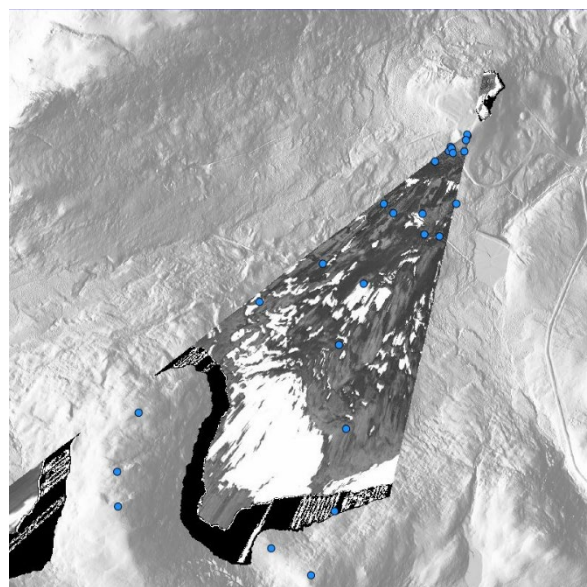
F = 16 mm

F = 18 mm

F = 20 mm

Figure 7: Effect of different settings for focal length on the orthorectification result

2.3.3 Interpolation

The *i.ortho.rectify* module offers seven different interpolation methods (nearest, linear, cubic, lanczos, linear_f, cubic_f, lanczos_f). To explore the influence of interpolation method on the result, orthorectification was computed with different interpolation setting (see Figure 8). However, there have not proved to be any significant differences.
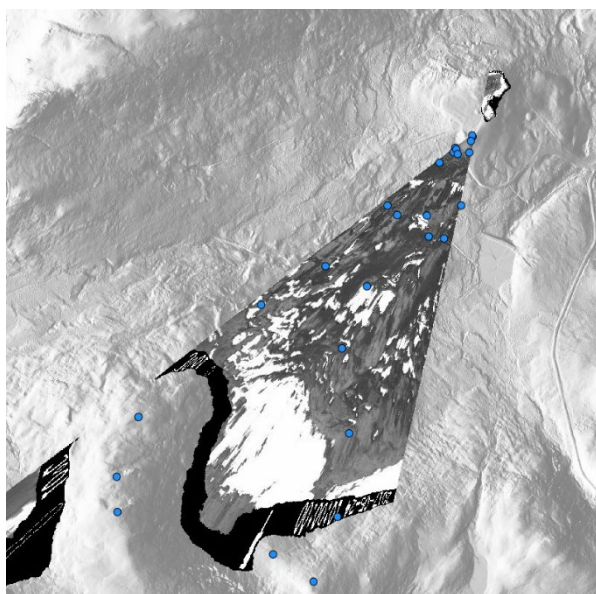
Nearest neighbor interpolation   **Cubic interpolation**

Figure 8: Effect of different interpolation methods on the orthorectification results

3 Results and discussion

The accuracy of the orthorectification of the images at Hjerkinn did not achieve the required precision level for use as in-situ reference data to e.g. satellite imagery. The main reason for that are the deployment of the camera in the test case, in particular the relatively horizon parallel viewing angle, as well as the lack of accuracy in measurement of the input parameters.

After clarification of all input parameters through a laboratory test case (Appendix 5.1), it can be concluded that with so strongly tilted images, the orthorectification algorithm is very sensitive to small inaccuracies, and very distorted results are produced even with minor changes of the (correct) input parameters.

The main sources of inaccuracies are:
1. **Camera pitch**. The camera viewing angle (pitch) turned out to be a crucial factor. When mounting the camera, the pitch should be as much as possible downfacing and it should be avoided that (also parts of) the cameras viewing angle cross the horizon. A higher pitch increases the distortion of the image and thus also the sensitivity for the other, following possible sources for inaccuracies. In praxis, a downfacing camera position can be better achieved - while keeping a useful size of the field of view, if the camera can be mounted at elevated structures (e.g. human infrastructure or natural peaks, slopes, …).
2. **Number of ground control points**. A significant number of evenly distributed ground control points is required. A high density of GCPs is important especially with increasing distance from the camera. Low number of GCPs turned out to be the main reason of failure of orthorectification in the Hjerkinn case.
3. **Precision of ground control point coordinates** (both in the global and image coordinate system). It is difficult to accurately identify points in the oblique image, if they are not adequately signalized. Additional signalization (e.g. a person holding a yellow paper) would be an optimal solution. A submeter GPS for taking field measures can greatly help to improve accuracy of the GCPs.
4. **Accuracy of camera exposure parameters**. Small changes in any of the camera exposure parameters (X, Y, Z, h, Ω, Φ, K) turned out to have a significant impact on the results.
5. **Stability of camera exposure parameters**: Additionally, the camera should be mounted to a weather and temperature resistant surface that does not expand, contract or swell (too much), so that these parameters remain constant over time.
6. **Accuracy of internal characteristics of camera**. In case of the used wildlife camera trap Reconyx PC800, the accurate focal length is not documented in the camera manual. This parameter significantly influences the orthorectification.
7. **Accuracy of the terrain model**. The terrain model is an important input to the process and needs to be adequately accurate.

However, the laboratory test case (Appendix 5.1) together with the experiment in Hjerkinn confirms that the chosen approach in principle is feasible. Preconditions for a successful campaign would be that extra care is taken to tackle the challenges documented in this report with regards to the way the camera is mounted, and the data on input parameters are collected. Those issues can be addressed during campaign planning and implementation. If that is done, the conducted experiment gives reason to believe that the presented approach can provide unique environmental information in an efficient way, esp. in combination with remote sensing.

Possible further improve would be to use more targeted sensors with higher resolution (compared to the wildlife camera traps used in this test) and sensors that also cover infrared (IR) wave length, which is particularly helpful in vegetation monitoring (see Richardson et al. 2018). If cameras could be mounted to existing human infrastructure (e.g. grid poles, buildings, or other constructions), that would be the most efficient way to deploy cameras and at the same time simplify addressing the issues mentioned above.
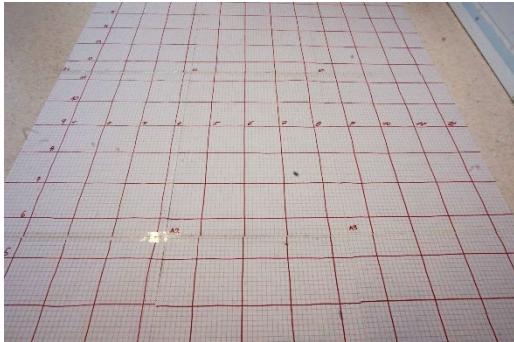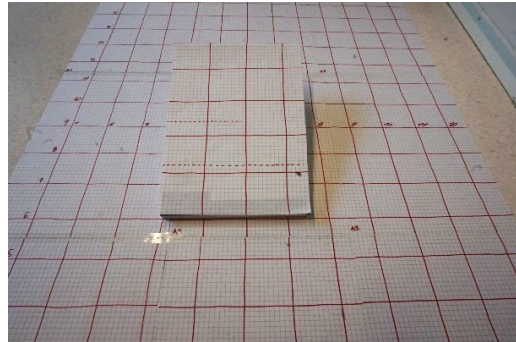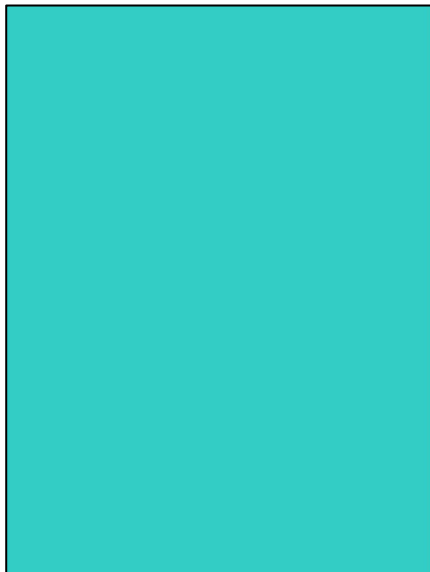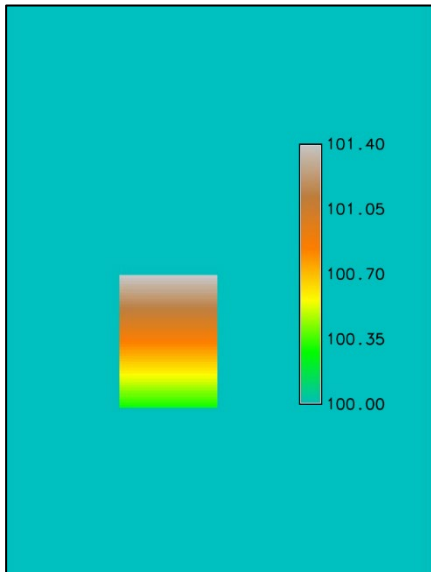
4 References

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5 Appendix

5.1 Laboratory case

5.1.1 Input data

Case with flat surface		Case with slope	
Oblique images			
Exposure and characteristics of the camera			
X	6.0 ± 0.5	**Focal length**	16 mm
Y	0.0 ± 0.5	**Principal point**	[0.0 mm, 0.0 mm]
Z	107.8 ± 0.5	**Fiducial points**	[0 pix, 1816 pix] [-11.6 mm, 0.0 mm]
h	7.8 ± 0.5		[2728 pix, 3632 pix] [0.0 mm, 7.7 mm]
Ω	0.0 ° ± 1.0 °		[5456 pix, 1816 pix] [11.6 mm, 0.0 mm]
Φ	41.0 ° ± 1.0 °		[2728 pix, 0 pix] [0.0 mm, -7.7 mm]
K	0.0 ° ± 1.0 °	**Camera name**	Sony Alpha 5000
Reference surface			

Ground control points
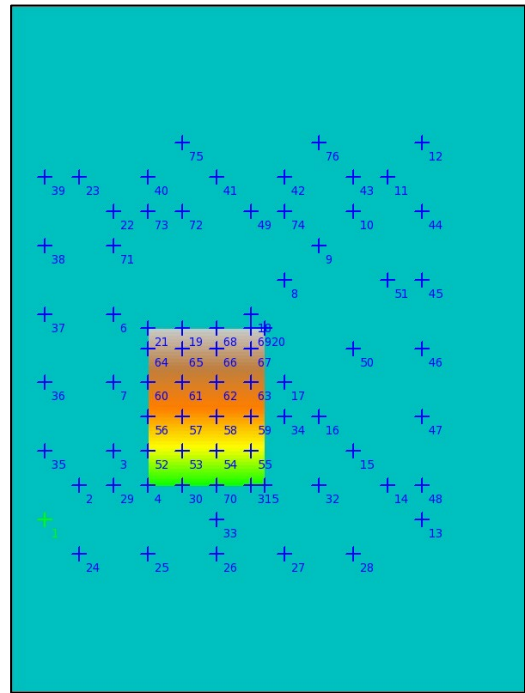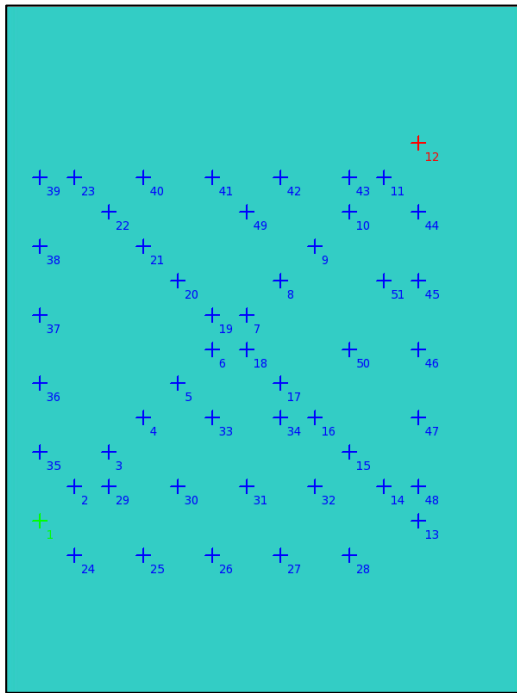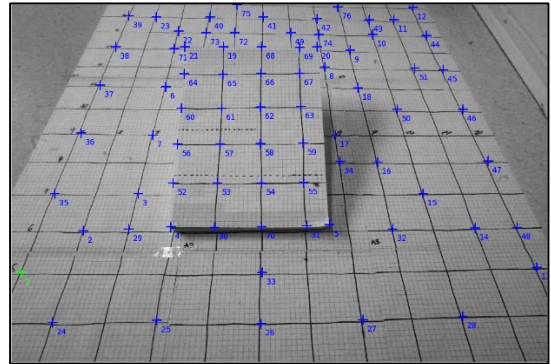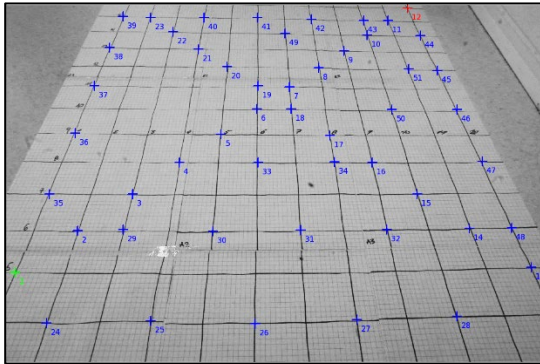
5.1.2 Results

Orthorectification
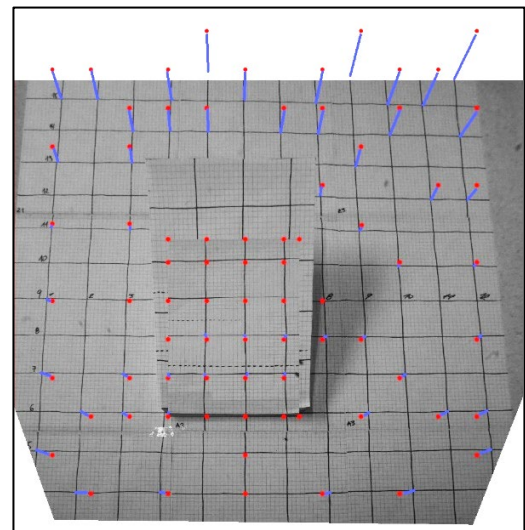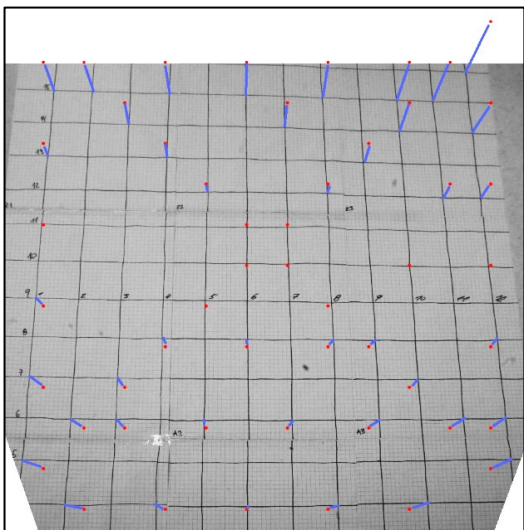
5.2 Hjerkinn study site

5.2.1 Input data

Oblique images			
Exposure and characteristics of the camera			
X	215 258.35 m ± 1.00 m	**Focal length**	8.5 mm
Y	6 911 444.02 m ± 1.00 m	**Principal point**	[0.0 mm, 0.0 mm]
Z	1 104.46 m ± 1.00 m	**Fiducial points**	[0 pix, 768 pix] [-3.2 mm, 0.0 mm]
h	2.47 m ± 1.00 m		[1024 pix, 1536 pix] [0.0 mm, 2.4 mm]
Ω	0.0 ° ± 1.0 °		[2048 pix, 768 pix] [3.2 mm, 0.0 mm]
Φ	80.3 ° ± 1.2 °		[1024 pix, 0 pix] [0.0 mm, -2.4 mm]
K	165.0 ° ± 1.0 °	**Camera name**	Reconyx PC800
Reference surface and viewshed			
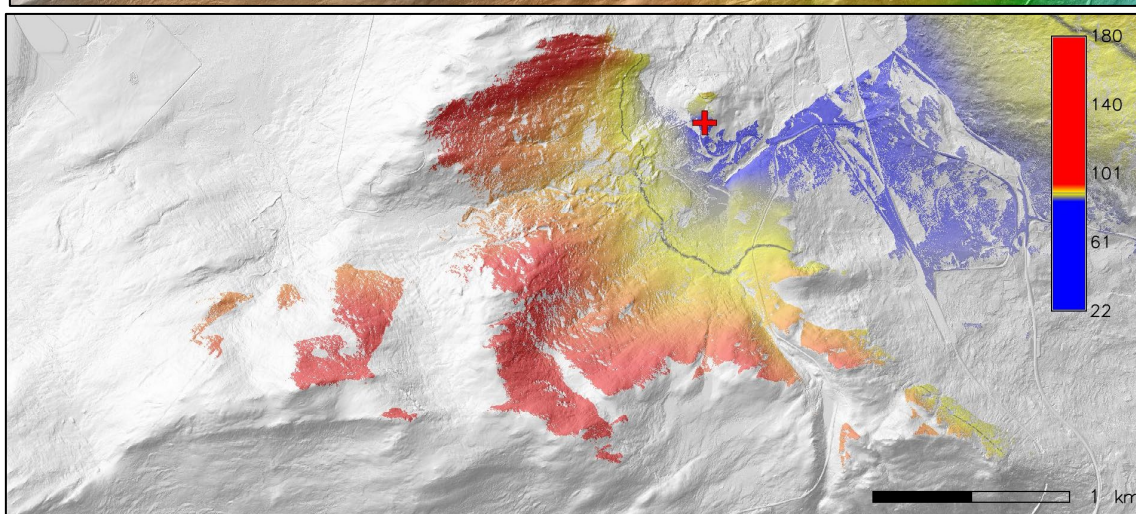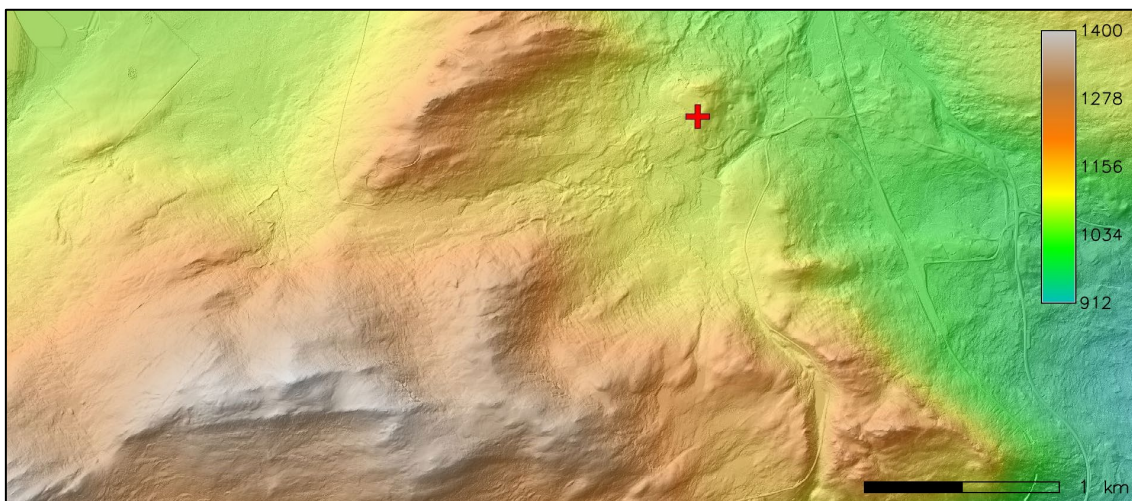
Ground control points
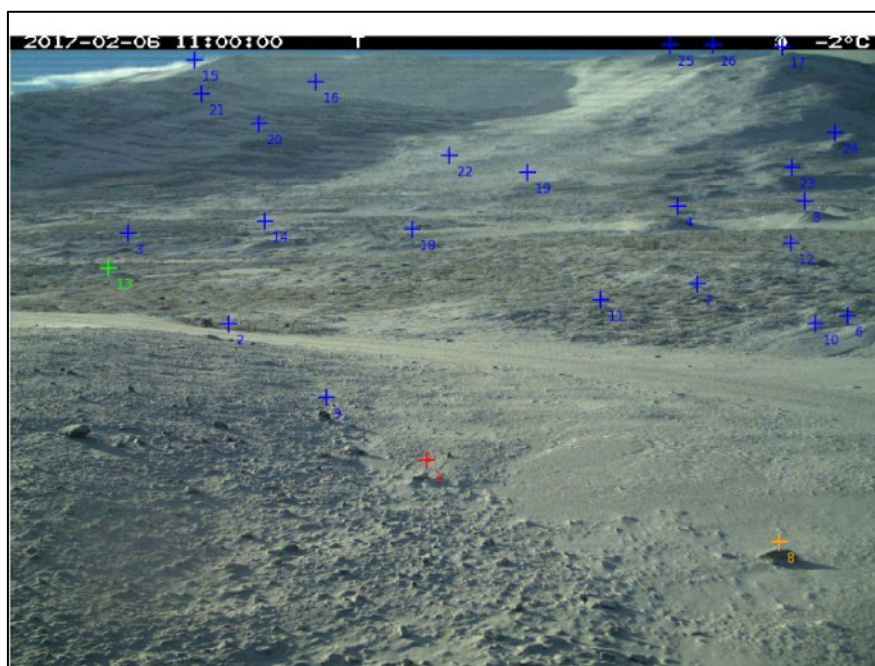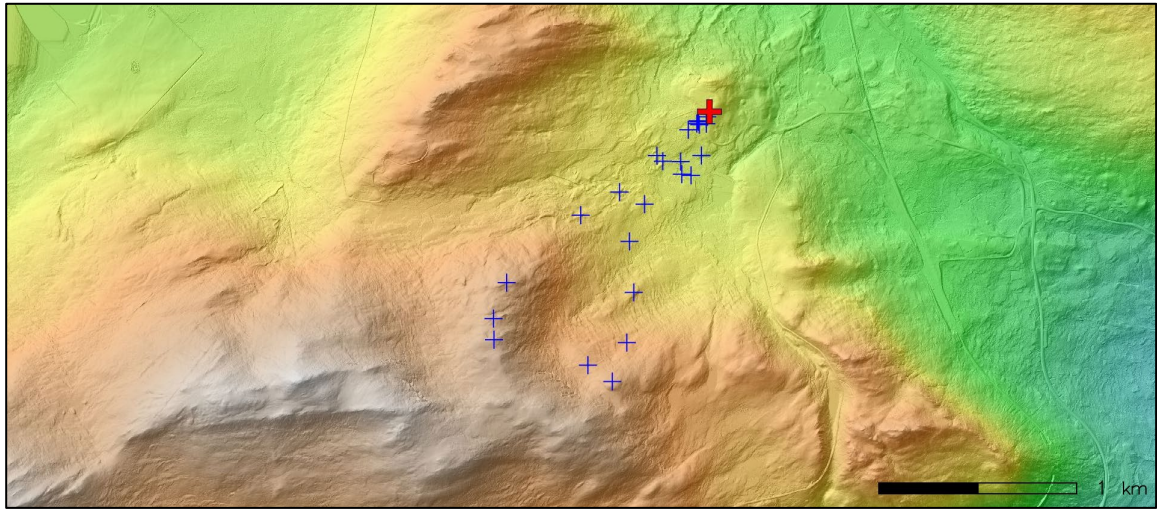
5.2.2 Results

Orthorectification

5.3 Orthorectification in GRASS

Orthorectification in GRASS consists of 8 steps. The aerial photos shall be stored in a *source location* - a local Cartesian coordinate system (XY). Digital elevation model and a map reference (topo sheet or other map used for ground control point matching) shall be stored in *a target location* in a global coordinate system (e.g. ETRS33). Sample data and a script are provided in the electronic appendix[1].
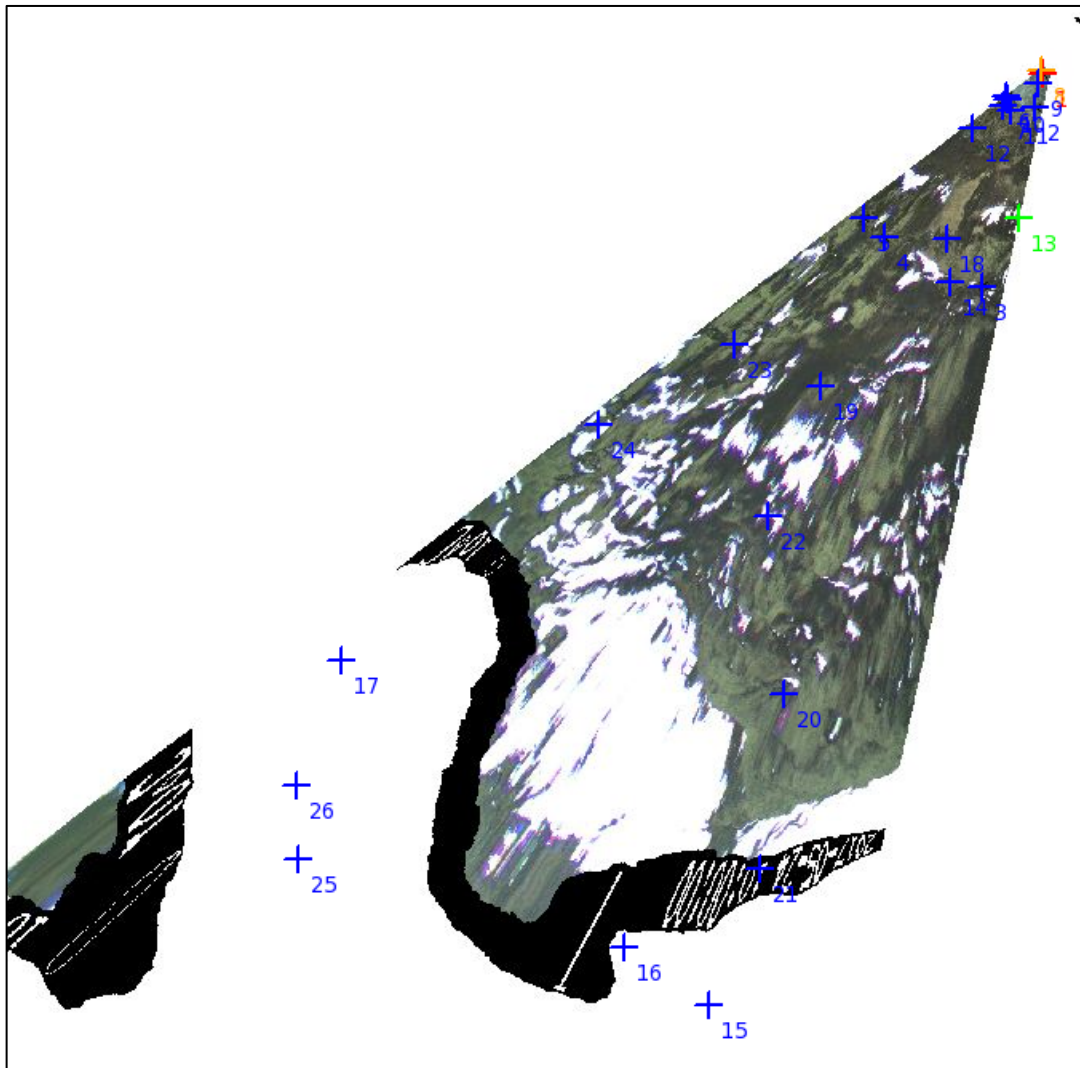
1. Create/Modify imagery group to be orthorectified: i.group
This step is to be run in the *source location*.

In this first step an imagery group of aerial images for ortho-rectification is created or modified. The current imagery group is displayed at the top of the menu. You may select a new or existing imagery group for the ortho-rectification. After choosing this option you will be prompted for the name of a new or existing imagery group.
As a result, a new file *mapset/group/name_of_group/REF* is created containing the names of all images in a group.

```
IMG_0020 source_mapset
IMG_0021 source_mapset
IMG_0022 source_mapset
```

2. Select/Modify target location and mapset for orthorectification: i.ortho.target
This step is to be run in the *source location*.

The target location and mapset may be selected or modified in Step 2. You will be prompted for the names of the projected target location and mapset where the ortho-rectified raster maps will reside. The target location is also the location from which the elevation model (raster map) will be selected (see Step 3).
In Step 2, a new file *mapset/group/name_of_group/TARGET* is created containing the names of target location and mapset.

```
ETRS_33N
target_mapset
```

3. Select/Modify target elevation model used for orthorectification: i.ortho.elev
This step is to be run in the *source location*.

Step 3 allows you to select the raster map from the target location to be used as the elevation model. The elevation model is required for both the computation of photo-to-target parameters (Step 6) and for the ortho-rectification of the imagery group files (Step 8). The raster map selected for the elevation model should cover the entire area of the image group to be ortho-rectified. DTED and DEM files are suitable for use as elevation model in the ortho-rectification program. In Step 3 you will be prompted for the name of the raster map in the target location that you want to use as the elevation model.
As a result of this step, a new file *mapset/group/name_of_group/ELEVATION* is created containing the name and mapset of the chosen DEM.

```
elevation layer :ELEVATION
mapset elevation:target_mapset
location        :ETRS_33N
math expression :(null)
units           :(null)
no data values  :(null)
```

---

[1]   https://brage.bibsys.no/xmlui/bitstream/handle/11250/2575975/1584%20vedlegg.zip?sequence=3&isAllowed=y

4. Create/Modify camera file of imagery group: i.ortho.camera

This step is to be run in the *source location*.

In Step 4 you may select or create a camera reference file that will be used with the current imagery group. A camera reference file contains information on the internal characteristics of the aerial camera, as well as the geometry of the fiducial or reseau marks. The most important characteristic of the camera is its focal length. Fiducial or reseau marks locations are required to compute the scanned image to photo coordinate transformation parameter (Step 5).
Two new files are created in this step: a file *mapset/group/name_of_group/CAMERA*, containing the name of the reference camera and a file *mapset/camera/name_of_reference*, containing the camera parameters.

```
CAMERA NAME    ReconyxPC800
CAMERA ID      ReconyxPC800
CAMERA XP      0
CAMERA YP      0
CAMERA CFL     8.5
NUM FID        4
      0 -3.2 0
      1 0 -2.4
      2 3.2 0
      3 0 2.4
```

5. Compute image-to-photo transformation: g.gui.photo2image

This step is to be run in the *source location*.

The scanned image to photo coordinate transformation parameters, i.e. the "interior orientation", is computed in Step 5. In this interactive step you associate the scanned reference points (fiducials, reseau marks, etc.) with their known photo coordinates from the camera reference file.
A new file *mapset/group/name_of_group/REF_POINTS* is created, containing a list of pairs of coordinates in image and photo coordinate systems.

```
# Ground Control Points File
#
# target location: XY
# target mapset: source_mapset
# source  target  status
# east north east north (1=ok, 0=ignore)
#-------------------------------------------------------------
0.000000       768.000000      -3.200000  0.000000 1
1024.000000    1536.000000      0.000000 -2.400000 1
2048.000000    768.000000       3.200000  0.000000 1
1024.000000    0.000000         0.000000  2.400000 1
```

6. Initialize parameters of camera: i.ortho.init

This step is to be run in the *source location*.

In Step 6, initial camera exposure station parameters and initial variances may be selected or modified.

- X: East aircraft position;
- Y: North aircraft position;
- Z: Flight height above surface;

- Omega (roll): Raising or lowering of the wings (turning around the aircraft's axis);
- Phi (pitch): Raising or lowering of the aircraft's front (turning around the wings' axis);
- Kappa (yaw): Rotation needed to align the aerial photo to true north: needs to be denoted as +90° for clockwise turn and -90° for a counter-clockwise turn.

In Step 6, a new file *mapset/group/name_of_group/INIT_EXP* is created, containing camera parameters.

```
INITIAL XC    215258.345387
INITIAL YC    6911444.022270
INITIAL ZC    1101.991120
INITIAL OMEGA 0.000000
INITIAL PHI   1.401499
INITIAL KAPPA 2.879793
VARIANCE XC    5.000000
VARIANCE YC    5.000000
VARIANCE ZC    5.000000
VARIANCE OMEGA 0.017453
VARIANCE PHI   0.020159
VARIANCE KAPPA 0.017453
STATUS (1=OK, 0=NOT OK) 1
```

7. Compute orthorectification parameters from ground control points: g.gui.image2target

This step is to be run in the *target location*.

The photo to target transformation parameters, i.e. the "exterior orientation", is computed in Step 7. In this interactive step, control points are marked on one or more imagery group files and associated with the known standard (e.g. UTM) and elevation coordinates. Reasonable rectification results can be obtained with around twelve control points well distributed over the image. In this step, a new file *mapset/group/name_of_group/CONTROL_POINTS* is created, containing a list of pairs of coordinates of ground control points in photo and target coordinate systems.

```
# Ground Control Points File
#
# target location: ETRS_33N
# target mapset: target_mapset
#    source                      target                status
#   east    north   height      east   north  height   (1=ok,
0=ignore)
#----------------------------    ----------------------   --------
98.3679932698 906.327649515 0.0  1.0 5.0   100.0        1
733.293023813 1329.61100321 0.0  2.0 6.0   100.0        1
1292.6317412  1703.76325335 0.0  3.0 7.0   100.0        1
1625.54617472 1368.11694482 0.0  4.0 6.0   100.3        1
3239.82849913 1390.97403968 0.0  7.4 6.0   100.3        1
1570.09788497 2790.06537829 0.0  3.0 11.0  100.0        1
```

8. Ortho-rectify imagery group: i.ortho.rectify

This step is to be run in the *source location*.

Step 8 is used to perform the actual image ortho-rectification after all the transformation parameters have been computed. Ortho-rectified raster files will be created in the target location for each selected imagery group file. You may select either the current window in the target location or the minimal bounding window for the ortho-rectified image.
As a result, the ortho-rectified raster map is available for visualization and further image analysis.

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