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NINA Kortrapport 6

Sentinel4Nature: Estimating environmental gradients and properties using remote sensing

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Abstract

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The Sentinel4Nature project was launched in 2014 with the objective of exploring the potential of using remote sensing techniques to detect and model environmental gradients identified by the Nature in Norway (NiN) classification system. The following report describes the progress of the Sentinel4Nature project to date. Two environmental gradients were selected, namely 1) Reduced growing season due to prolonged snow-lie and 2) Tree canopy cover. The methodology for modelling these two gradients is discussed. The suitability of Sentinel imagery for the objectives of this project has also been explored.

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Appendix

1 Background

In spring 2014, the first in a series of satellites was launched by the European Space Agency (ESA), as part of today's most ambitious Earth Observation Program: Copernicus (European Space Agency 2010). These Sentinel missions will provide the public with free Earth Observation data with unchallenged spectral, temporal and spatial resolution for a wide range of purposes. They will undoubtedly offer new and unique possibilities for environmental assessments, monitoring and management.

At the same time, a new system for describing, mapping and analyzing Nature in Norway (NiN) has been developed (Halvorsen et al. 2015). One of the leading principles in NiN is to account for gradual transitions in nature and thus to focus on the underlying environmental gradients and properties (e.g. related to climate, soil, etc.) that govern the occurrence of species and associated nature types. Although NiN is a specific system for Norway and does not cover the whole range of environmental conditions in Europe, it can be seen as a comprehensive list of important environmental gradients and properties with a pan-European relevance, esp. in coastal (hard rock) and alpine environments. The specific recognition of gradual transitions in nature and a systematic use of spatial and temporal scales in NiN can be seen as a contrast to most of the other classification systems applied in European countries (see Ichter et al. (2014)).

The Sentinel4Nature project, financed by ESA`s PRODEX program, seeks to investigate the methodological potential of detecting and modelling the NiN environmental gradients using Sentinel imagery.

2 Aim and expected benefits of the project

The main objective of the Sentinel4Nature project is to develop and advance a novel approach to remote sensing, which focuses on monitoring basic environmental gradients and properties (covering physical, chemical and biological components as well as their interactions). It is based on the hypothesis that the upcoming Sentinel satellites, with their increased temporal, spatial and spectral resolution, and increased spatial coverage (compared to e.g. Landsat) will provide valuable information in this respect. Here the aim is to, a) identify the potential of Sentinel imagery for modelling and identifying environmental gradients, and b) explore how they could be applied in order to support various sectors in their need for area information. This includes integration with other relevant datasets such as e.g. Digital Elevation Models (DEM) using data fusion techniques to optimize the results (Salberg et al. 2013, Ichter et al. 2014).

The Sentinel4Nature project will explore the usefulness of remote sensing techniques to identify environmental gradients in the NiN classification system. The work is based on the hypothesis that monitoring of environmental gradients and their changes can provide environmental researchers, managers and policy makers with valuable information because:

- Monitoring environmental gradients can serve as an early warning system for changes in ecosystem processes and functioning and thereby improve targeted responses, because one can expect that characteristics of the underlying environmental gradients change before vegetation patterns change.
- Environmental gradients can be indicators for the quality of different nature types, which is why modeling them will provide additional information about e.g. mapped nature types of special interest.
- Information on environmental gradients has a broader scope of possible applications (e.g. pattern of snow cover in arctic or alpine areas is not only important for vegetation structure but also for the arctic or alpine fauna).
- Monitoring of environmental gradients will not only help policy and decision makers but also scientists in order to identify reasons or drivers of change.

Another hypothesis is that gradients can be monitored with a higher robustness because the focus is on single environmental characteristics and not on multiple vegetation classes / types and continuous data are generated instead of discrete classes.

For the reasons above, it can be expected that a gradient-based approach will be useful for indicator systems developed across European countries (OECD) (in Norway the Nature Index (NI)), which are meant as tools for guiding environmental policies. Here, the gradient-based approach may fit nicely into the Driving Force, Pressure, State, Impact, and Response concept (DPSIR). Because, this approach aims at identifying underlying characteristics or trends in nature (pressures and impacts) and thus may help to identify links between the latter and the current state of the environment.

Furthermore, the gradients listed in the NiN system overlap with the concept of Essential Biodiversity Variables (EBV), which the Group on Earth Observations Biodiversity Observation Network (GEO BON) to “become the window into the biodiversity observation systems upon which researchers, managers and decisions makers at different levels can better interact while they do their jobs” (Group on Earth Observations Biodiversity Observation Network 2016). Thus the project has the potential to provide linkages to the global activities of GEO BON.

Finally, the project will give environmental management institutions an assessment of the potential the Sentinel satellites will provide within remote sensing based nature management, both in terms of mapping and modeling, but also for detecting changes caused by e.g. climate or intervention. The project will also contribute to the use of satellite-based and cost-effective methods for collecting environmental information and support the analysis of nature types, and thereby contribute to the implementation of NiN in Norwegian management institutions. For nature management institutions, like the Norwegian Environment Agency, improved analysis of mountain areas will be vital for the management and surveillance of national parks.

The work will be carried out through case studies on select environmental gradients and properties with relevance for mountain and coastal ecosystems, which are ecosystems of special interest in many European countries.

3 The suitability of remote sensing (Sentinel) for estimating environmental gradients and properties in NiN

A first step in the Sentinel4Nature project was to explore the suitability of remote sensing (esp. Sentinel) for identifying and modelling environmental gradients and properties in NiN.

In the system Nature in Norway (NiN) version 2.0, there are 60 local complex environmental variables (hereafter referred to as environmental gradients) listed which are known to influence species occurrence in nature. The main focus of the assessment of the suitability of remote sensing for estimating environmental gradients and properties in NiN is on these environmental gradients.

NiN also lists a significant number of environmental features which can be used to describe nature types (habitats) in more detail in the description system / sources of environmental variation. The most relevant of these features were also included in the assessment.

Criteria used during this assessment, which is based on expert judgement, are:

- the observable properties in the imagery (spectral response, image structures)
- suitable and available sensors
- the required spatial resolution
- the need for time series
- additional required data sources
- existing and related examples

The results of this assessment are provided in a spread sheet, which follows this document as an electronic attachment. The assessment of the suitability of remote sensing (in particular, Sentinel imagery) for estimating environmental gradients and properties in NiN will be continued throughout the life span of the project and updated and adjusted when new research becomes available. The table presented in the (electronic) appendix should therefore be considered as a first, preliminary version.

4 The selected case study sites and gradients

The following sections describe the methodology used to detect and model the two selected environmental gradients, as well as the case studies used and the data fusion techniques proposed for this ongoing study. It should be noted that as Sentinel imagery has only recently become available, other types of imagery have been used as a proof of concept.

The selection of relevant case study sites is closely linked to the selection of the environmental gradients to be studied in the project. Study sites have been chosen dependent on the selected case study gradients, which are "Reduced growing-season due to prolonged snow-lie (SV, NiN 2.0)" and "Tree canopy cover (TT, NiN 1.0)". The sites chosen to study those gradients will be presented first (chapter 4.1), while the gradients and approaches to estimate them using remote sensing will be described in chapter 4.2.

4.1 Case study sites

In order to study the detectability of the environmental gradients named above, the following case study sites were chosen (see figure 1):

- Oslofjord
- Lurøykalven
- Hjerkinn
- Sunndalen

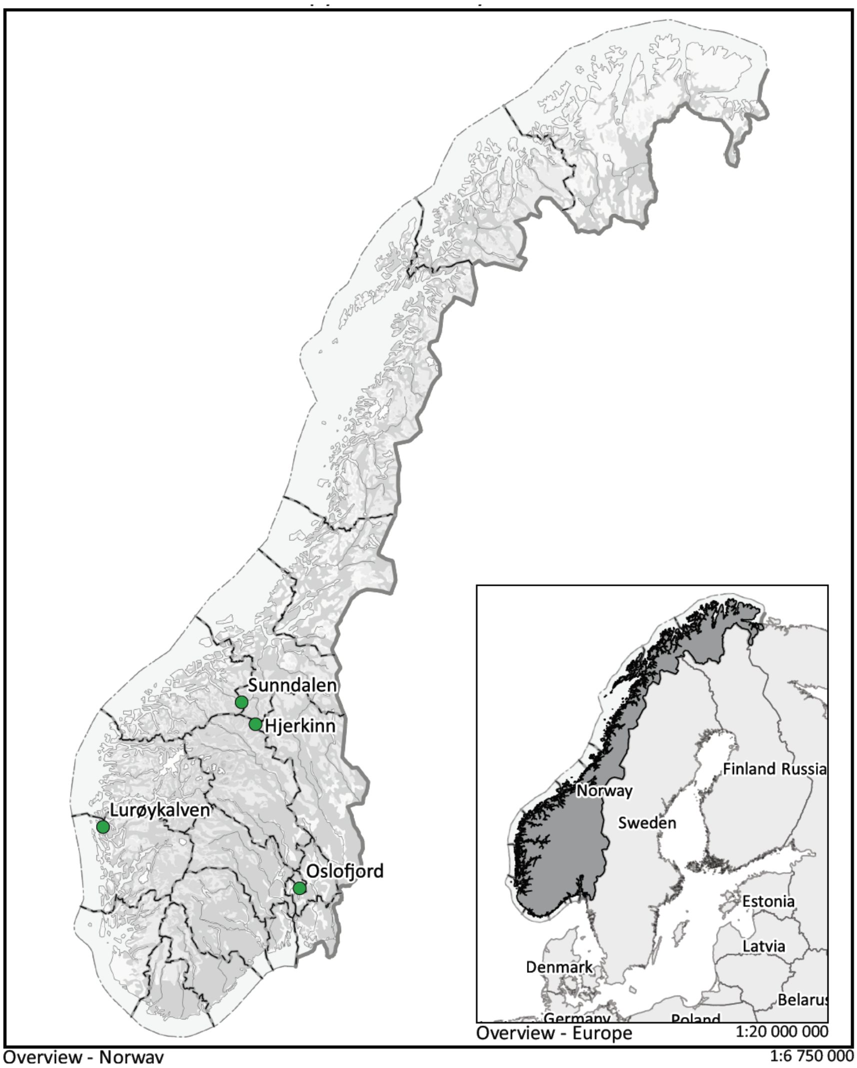

Figure 1: The tree canopy cover gradient was mapped in three of the four case studies.

4.1.1 Oslofjord

The Oslofjord region is located in south-east Norway (59° 53'N 10° 42'E). This lowland area is characterized by a hilly terrain with an oceanic to continental climate. The landscape consists of a mixed habitat mosaic with a fjord, islands, forests and human infrastructure (see figure 2). The average annual temperature is reasonably stable and ranges from -0.6 to 3.4°C. Precipitation is fairly constant throughout the year. The city of Oslo surrounds the four islands included in the case study. The islands of Gressholmen and Rambergøya are moderately inhabited, while Ormøya and Malmøya have more human infrastructure.

Topics to be studied in the Oslofjord area are the gradient "Tree canopy cover" and the usefulness of data fusion and scale effects in the small scale vegetation sequences in Oslofjord (see figure 3).

Figure 2: Landscape at the Oslofjord (Photo: Anne Sverdrup-Thygeson)

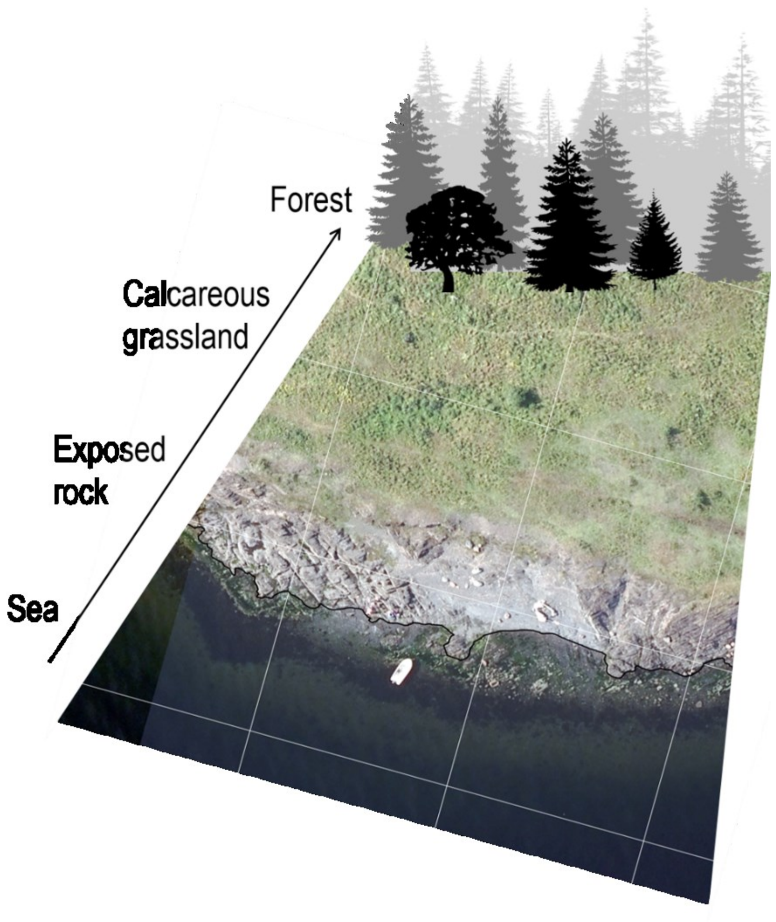

Figure 3: Example a vegetation sequence in the Oslo fjord case study, representing succession from unvegetated gravel, through sparsely vegetated calcareous grassland and further stages of succession to forest.

4.1.2 Lurøykalven

Located in western Norway, Lurøykalven is an island about 50km north-west of Bergen (60° 42'N 5° 4'E). The study site consists of coastal lowlands with a hilly terrain. The island has an oceanic climate and contains the prioritized nature type of coastal heathland. The average annual temperature ranges from 1.3 to 5.3°C with rainfall falling predominantly in autumn. Lurøykalven has very little human infrastructure (see figure 4).


Figure 4: Landscape at Lurøykalven (Photo: Vegar Bakkestuen)

Topics to be studied in Lurøykalven is the gradient “Tree canopy cover”. Furthermore the usefulness of data fusion and scale effects are important aspects in the small scale vegetation mosaic in Lurøykalven.

4.1.3 Hjerkinn

The study area Hjerkinn is located in the Norwegian mountain region Dovrefjell (62° 13'N, 9° 27'E), between 1000 to 1500m above sea level. It represents a mountain area in the central to eastern parts of Norway, with relatively continental climate. The study site includes boreal to mainly low alpine climate zones. The landscape has mountainous terrain, characterized by small scale patterns with shrub, lichen, mire or tree dominated habitats as well as gravel, bare rock and human infrastructure (see figure 5). NINA has a lot of ongoing research activities in that area - including long term monitoring (TOV) and restoration projects – making it a natural candidate.

Most of Hjerkinn`s area is located above the tree line. Figure 5 shows the typical landscape at the study site during melting season. The image was acquired on May 19, 2013, and it can be seen that the ridge vegetation was becoming visible, but there were still large areas covered with snow.

The most common low alpine nature types are represented in the test area, including heaths, meadows, snow-beds, marsh areas, and shrub vegetation. In this region the snow cover distribution is a key factor with respect to the distribution of vegetation types and species. On top of ridges, there is a strong wind during the whole year, little snow cover, and a high degree of desiccation. These areas are dominated by lichens, grass and dwarf shrubs that are able to live under such conditions. In the lee sides, which are more protected from wind, and has access to moisture during the whole year, the vegetation is lush with a higher biomass production, more species of herbs, mosses, and grass, and normally some dwarf shrubs species and shrub vegetation.

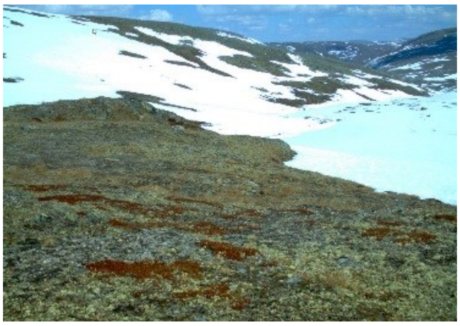
Figure 5: Landscape at Hjerkinn (Photo: Lars Erikstad)

Topics to be studied in Hjerkinn are the gradients “Tree canopy cover” and “Reduced growing-season due to prolonged snow-lie”. Furthermore the usefulness of data fusion and scale effects are important aspects in the small scale vegetation mosaic in Hjerkinn.

4.1.4 Sunndalen

The study area Sunndalen is, like Hjerkinn, a mountain area in the Dovrefjell region (62° 34'N 9° 2'E). It covers boreal to alpine climate zones, but the terrain is steeper with deep valleys. Being in central Norway, the climate is relatively continental. A reason for choosing Sunndalen as a case study was to establish a link to the project ECOFUNC, funded by the Norwegian research council, where the products from the Sentinel4Nature project will be evaluated with respect to their benefits for understanding mountain ecosystems and their changes.

Topics to be studied in Sunndalen are the gradients “Tree canopy cover” and “Reduced growing-season due to prolonged snow-lie”. Furthermore, the usefulness of data fusion is an important aspects in Sunndalen as well.

4.2 Selected gradients from NiN

4.2.1 Reduced growing-season due to prolonged snow-lie (SV, NiN 2.0)

In arctic and alpine areas, an important factor for the occurrence of plant species is the long duration of snow cover. The length of the snow cover season determines the length of the growth season and thereby the time the species have to conduct its cycle of life. Here, snow-beds represent the most extreme cases, which are only snow-free for a few weeks during the summer months. In snow-beds, very few species are found. The environmental gradient reduced growing season due to snow-lie is one of the most important factors for variation in species composition in snow-beds.

At some locations in mountain areas, it is the stability of the snow cover and not the length of the snow cover season that determines the collection of species. Areas without a stable snow cover are highly exposed to strong wind and frost during the winter. In order to live at such places, the species need to be able to cope with tough conditions without any protecting snow cover. The environmental gradient of snow cover stability is directly related to the thickness of the snow cover, which again is based on the amount of precipitation and the strength of the wind.

The snow cover stability and reduced growing season due to snow-lie are two very important environmental gradients for the nature types *upland and tundra* and *snow-bed*. Since these environmental gradients are strongly related to the snow cover, satellite-based sensors may be used to monitor them. Satellite sensors have been widely used to map the snow covered areas and cryosphere (see e.g. (Scherer et al. 2005, Maher et al. 2012, Crawford et al. 2013, Metsamaki et al. 2014). Contrary to the Landsat based schemes proposed by Crawford et al. (2013) and Maher et al. (2012), the aim in the Sentinel4Nature project is to derive satellite-based maps that describe the spatial distribution of the dates for melted snow cover, with corresponding uncertainties. Maps based on the dates for melted snow cover may also contribute to increased knowledge about the local vegetation and consequence of climate changes.

Estimation of the temporal-spatial snow cover distribution using satellite images
Snow-covered areas are often easy to identify in optical satellite images. However, there are many factors that may influence the performance of an automatic system for monitoring the spatial snow cover distribution. These include:

- *Spatial resolution*: For low and medium resolution images, it is often a snow cover fraction that is estimated, since the area of the pixel unit is not completely snow covered (Metsamaki et al. 2014).
- *Band configuration*: Some sensors have thermal bands or bands that are sensitive to cirrus clouds (e.g. Landsat-8 and Sentinel-2). Use of data from these bands will often improve the performance with respect to distinguishing snow from clouds (Zhu and Woodcock 2012).
- *Temporal resolution*: In order to estimate the environmental gradients snow cover stability and reduced growing season due to snow-lie or the date for melted snow cover, satellite data with high temporal resolution is needed. The estimation of snow cover stability may be particularly challenging since this requires monitoring of the snow cover during the full winter season when there is limited daylight. For areas in the far north, this is more or less impossible using optical satellite data.
- *Land cover*: Some vegetation types (e.g. ridge vegetation) have a very high albedo, and may therefore be confused with snow.

Some ancillary information may be used to improve the performance:

- *Other sensors*: SAR is suitable for identifying wet snow (Nagler and Rott 2000), and Sentinel-1 may therefore be used in the melting season to locate snow patches. A major benefit with SAR is that it penetrates clouds.
- *Precise elevation model*: Altitude indices like topographic position index (TPI), insolation, slope, or aspect may be used to improve the identification of snow-beds.
- *History*: If previous snow cover distribution maps are available, these may be used as prior information on where snow-beds and areas with less snow cover stability are located.

Modelling of the probability for snow cover

Landsat data has a time resolution of 16 days, and due to cloud conditions this is often not sufficient for estimating the date for melted snow cover for a given year. In such cases, it is necessary to aggregate data from multiple years. Thus, the challenge is then to take the temporal variation across various melting seasons into account. To handle various melting seasons, the probability for snow cover at a given location (pixel) is modelled using a binomial distribution, where the probability for snow at a given time instant is estimated by means of a generalized linear model (GLM). The proposed methodology consists of the following steps:

1. *TOA reflectance*: Convert the Landsat images to top-of-the atmosphere (TOA) reflectance images using additional parameters found in the corresponding metadata (e.g. Solar Elevation Angle).
2. *Cloud and cloud shadow detection*: Clouds are detected by classifying each Landsat pixel into the following classes: Cloud, snow, green vegetation, brown land cover, and water (Salberg 2011). Cloud shadows and terrain shadows often cause problems when analysing optical data. By using information about the sun elevation angle and terrain topography, cloud shadows and terrain shadows may be estimated (Salberg 2011). For the current model of the probability for snow cover, cloud shadows are not detected.
3. *Applying a water mask*: The Landsat data is masked using a water mask from AR50 (Solbjørg Flo Heggem and Bjørnerød 2007).
4. *Snow detection:* For pixels that are not masked as clouds or water, the normalized difference snow index (NDSI)

$$NDSI = \frac{B_2 - B_5}{B_2 + B_5}$$

   is computed. Here B_k denotes Landsat band k of the TOA reflectance image. Pixels with $NDSI > 0.7$ is masked as snow covered (Zhu and Woodcock 2012).
5. Estimation of the probability for snow: For a given pixel there is a set of snow cover observations $y_1, y_2, \ldots, y_N$, where y_k is equal to 1 if the corresponding pixels in image k is snow covered, and 0 otherwise. There is also a set of corresponding time instants $t_1, t_2, \ldots, t_N$ that contain the Julian days the corresponding Landsat images were acquired. It is assumed that the time instants are ordered, such that $t_{k+1} \geq t_k$. Please note that since the images may come from different years such that y_{k+1} may be equal to 1 even if y_k is equal to 0. Since the focus is on mountain vegetation, January 1st was a priori defined to be snow covered for all pixels.
   For every pixel the probability for snow cover is estimated using a GLM with binomial distribution and logit link function. The probability for snow for time instant k is

$$p_k = \text{logit}^{-1}(\eta_k) = \frac{\exp(\eta_k)}{1 + \exp(\eta_k)},$$

   where

$$\eta_k = a_0 + a_1 t_k.$$

   The parameters a_0 and a_1 are estimated from the snow cover observations $y_1, y_2, \ldots, y_N$ and corresponding time instants $t_1, t_2, \ldots, t_N$ using an iterative re-weighted linear regression algorithm (McCullagh 1984).
   Note that the binomial distribution also applies if multiple observations fall on the same Julian day (from different years). In this case, the number of trials n_i is changed to the number of observations and y_i to the sum of snow covered observations on that day.

To handle the data separation problem, a Bayesian GLM approach was used where the parameters a_0 and a_1 are modelled as Cauchy distributed variables with mean values equal to 0 and -5.0, respectively, and scale parameters equal to 10.0 and 4.0 (Gelman et al. 2008).

6. *Estimation of the date for melted snow cover*: The date for melted snow cover is estimated as the time instant where the probability of snow is less than a given threshold. Here this threshold was set to p_{th} = 25%. The date for melted snow cover may then be estimated as

$$t_{melt} = \frac{\left(\log\left(\frac{p_{th}}{1-p_{th}}\right) - \widehat{a}_0\right)}{\widehat{a}_1}.$$

7. *Estimation of uncertainty*: Since the GLM is based on an iterative re-weighted linear regression, one may estimate the uncertainty to $\hat{a}_0$ and $\hat{a}_1$. A 90% confidence interval to t_{melt} may then be written as

$$t^u_{melt} = \frac{\left(\log\left(\frac{p_{th}}{1-p_{th}}\right) - \widehat{a}_0 + 1.645\sigma\right)}{\widehat{a}_1}$$
$$t^l_{melt} = \frac{\left(\log\left(\frac{p_{th}}{1-p_{th}}\right) - \widehat{a}_0 - 1.645\sigma\right)}{\widehat{a}_1},$$

where

$$\sigma^2 = \mathrm{var}(\widehat{a}_0) + \mathrm{var}(\widehat{a}_1)t^2_{melt} + \mathrm{cov}(\widehat{a}_0, \widehat{a}_1)t_{melt}.$$

The uncertainty of the date for melted snow cover is then defined to be: $(t^u_{melt} - t^l_{melt})/2$.

Preliminary results

The GLM-based estimation methodology for estimating the dates for melted snow cover is demonstrated by analysing Landsat 8 data collected at the Hjerkinn study site in Norway. The dates for snow melt and corresponding uncertainty were estimated from all Landsat 8 images at path/row 199/017 during the periods 2013-04-14 to 2013-08-20, 2014-01-11 to 2014-08-07, and 2015-01-14 to 2015-08-10.

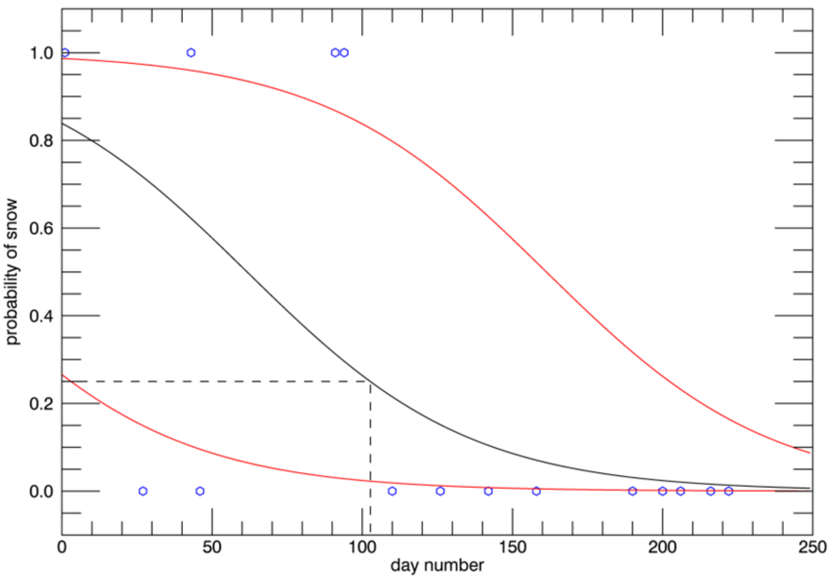

Figure 6: The estimated date for melted snow cover is day 103 (dashed line). The uncertainty is about ±100 (90%).

Figure 6 illustrates the snow observations (blue circles) and estimated probability (using the GLM-based methodology) for snow (black line), with corresponding 90% uncertainty confidence interval (red lines) for four different locations (pixels). The black dashed lines show the estimated date for

melted snow cover (using a 25% probability threshold). For many locations in the study area, a similar uncertainty was observed. These high uncertainties were related to the very few observations (maximum 35) used to estimate the probability curves.
Using the proposed GLM-based methodology, a continuous map was generated with Landsat resolution (30m), of the estimated dates for melted snow cover with a corresponding uncertainty map (Figure 7). The spatial variation of the estimated dates for melted snow cover was huge for the study area. The estimated uncertainties were also large and also varied substantially across the area. The use of improved cloud and cloud shadow detection in order to reduce the number of misclassified pixels was investigated. Here, the cloud detection method proposed by Zhu and Woodcock (2012) was tested, but this tended to classify small snow patches as clouds and was therefore not applicable for this purpose.

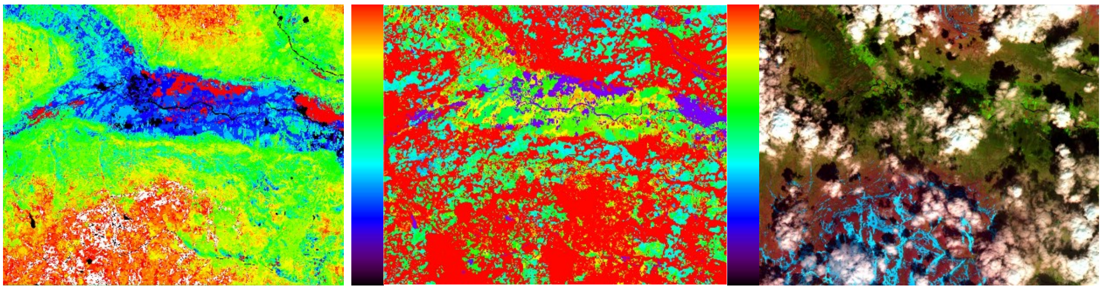

Figure 7: The estimated dates for melted snow cover (left) and corresponding uncertainties estimates (middle) for the study area. The colour scale for the image of the estimated dates for melted snow cover corresponds to day number, from day 1 (black) to day 220 (red). White represents permanent snow cover. For the estimated uncertainties image the colour scale denotes the degree of uncertainty (90% confidence interval, from 0 (black) to 100 days (red). The image on the right is a corresponding Landsat 8 image from 2015-07-25.

Future plans

From 2016, Sentinel-2 data will also be considered for modelling reduced growing season due to prolonged snow-lie. With Sentinel-2, more frequent acquisitions and higher spatial resolution will be obtained. However, one challenge with Sentinel-2 is the lack of thermal bands that are useful to discriminate snow from clouds.

Other important plans for the next period are to implement data fusion (see section 4.3) in the model that estimates date for melted snow cover, by means of integrating terrain information and terrain indices (including TPI and solar radiation) as well as radar data. In addition, it is planned to improve and validate the model using temperature logger data as well as fixed angle images from wildlife camera traps.

For the gradient “Reduced growing-season due to prolonged snow-lie,” the usage of wildlife camera traps for generating training data has been tested in the field. 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. Therefore, an approach for assigning suitable ground control points to pictures made by the wildlife camera trap was developed. These ground control points are sampled once in order to calibrate and enhance the accuracy of the imagery. The relatively simple solution was to place several coloured-marked sheets of water resistant paper in the viewshed of the camera and to measure their position by GPS (see figure 8). In addition, the position of distinct landscape structures which were relatively easy to identify in the images (e.g. single boulders) were measured in the field using the GPS.

Figure 8: Orthorectification of oblique, tilted digital images. Left: the proof of concept by Neteler et al. (2005) Right: wildlife camera image with colour marked GCPs.

In the summer of 2015, a first series of test images was obtained using the wildlife camera trap approach. Currently the orthorectification of the produced images is in progress, where issues with camera angles and exposure parameters in the orthorectification algorithms are under investigation. The idea of using “fixed angle” wildlife camera traps is to get daily oblique images from the study site, selected to match the temporal resolution of the Sentinel satellites. The high frequency of revisit is a particular challenge for collecting real time ground truth or validation data. The aim is to have an operational solution for the melting period in spring 2016.

As a second option the possibility to use temperature logger data as training / validation data for modelling the gradient(s) related to snow cover duration was investigated. From other projects conducted in NINA, temperature logger data was obtained and a distinct “snow on / snow off pattern” could be identified in the daily temperature data. Figure 9 shows that temperature variation is clearly reduced under snow cover compared to snow free days.

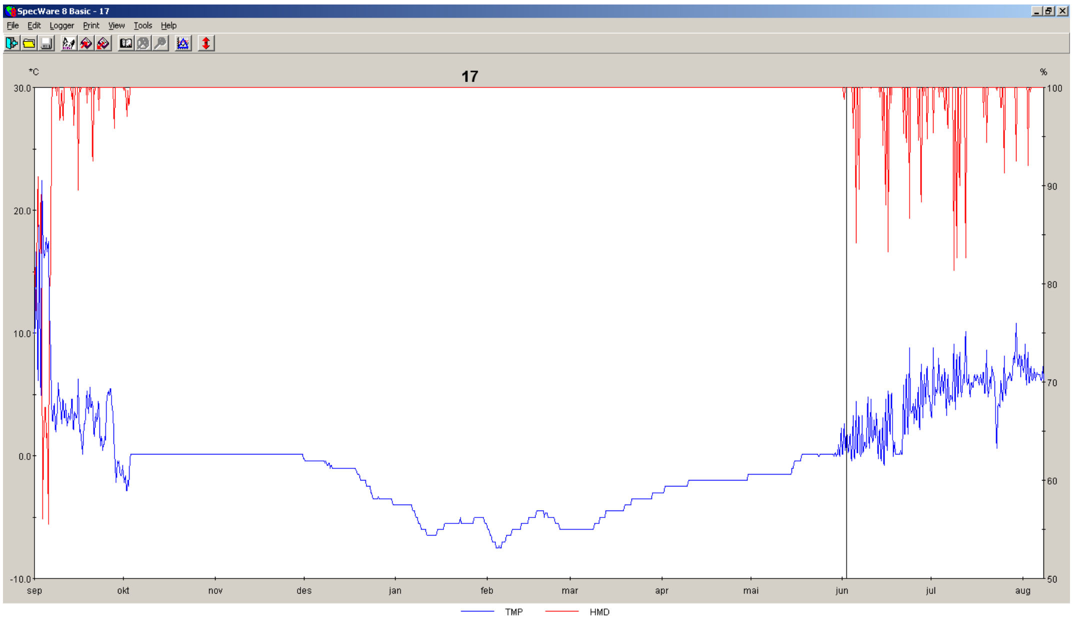

Figure 9: Data from temperature logger (in this case WatchDog B101 8K Temp Logger from Spectrum Technologies Inc.; http://www.specmeters.com/weather-monitoring/data-loggers/b-series-loggers/b-series/) can be used to identify snow cover and snow melt. The red line represents moisture, while the blue line is the temperature. The point where moisture and temperature begin to fluctuate indicates when the snow begins to melt.

4.2.2 Tree canopy cover (TT, NiN 1.0)

The density of tree canopy cover is one of the most important factors for species which can be found underneath the tree crowns. It affects the occurrence of species and species compositions in several ways: Canopy cover reduces the availability of light and precipitation that reaches the species under the trees. In addition, with an increased canopy cover, the amount of dead organic matter that is falling onto the soil increases. Tree canopy cover is furthermore related to several other gradients in NiN like: Drought exposure (UE), Severity of drought (UF), or Wind deflation (VI) from NiN 2.0, as well as Deforestation (BA), Forest regrowth (GG), or reduction of tree cover density (TR).

Beyond its relevance as a habitat for certain species, tree canopy cover is of vital interest for management in many other regards, including economic activities (forestry), CO_2-accounting, natural hazards, as well as landscape and nature conservation (e.g. in terms of maintaining open cultural landscapes). Furthermore, tree canopy cover is an important variable for characterizing the forest-tundra-ecotone and, as such, is of special interest for research on effects of climate change. Forest encroachment has the potential to significantly change ecosystem structure and functions in Norwegian mountain areas, but the speed and pattern of forest encroachment is disputed.

Thus, tree canopy cover has been of high interest for remote sensing projects earlier. However, both classical classification approaches (like NORUT`s vegetation map (Johansen 2009)) and more gradient-like approaches (like in Hansen et al. (2013)) struggle especially with “mixed signal”-pixels at the land water interface. Figure 10 shows lakes in an alpine area in Norway where pixels along the shore lines were associated with tree canopy cover.

For tackling the tree canopy cover gradient, recent, very high resolution orthophotos were used to (manually) digitize tree canopy cover below the resolution of satellite pixels (see figure 10). From these data the percentage of canopy cover has been calculated per pixel, following the raster (resolution and alignment of the pixels) of the satellite imagery (in this case from Landsat 8 scenes to start with). This results in a continuous value which is supposed to represent the tree canopy cover gradient. Such data have been produced for all 4 case study sites.

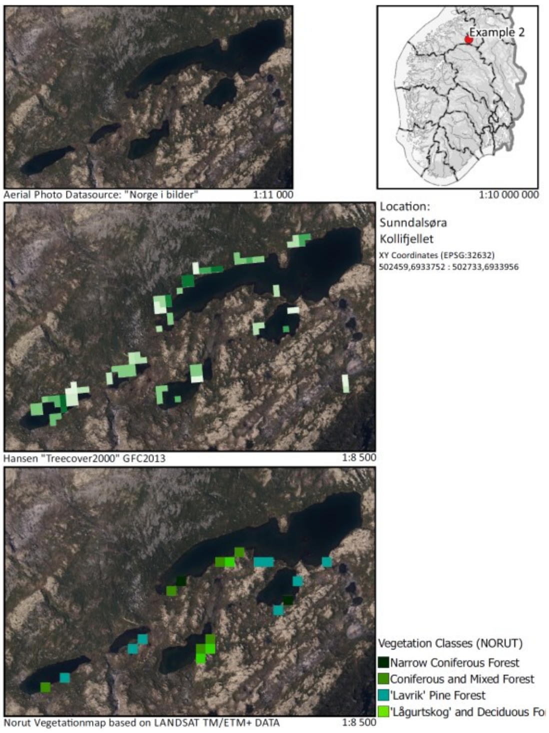

Figure 10: Errors in forest detection in existing remote sensing products along the land / water interface.

Future plans

Future plans for the work on the Tree Canopy Cover gradient are to statistically investigate the effect of spatial, spectral and temporal resolution on the abilities to identify residuals at the land water interface. Furthermore, the interaction between the Tree Canopy Cover and the results of the model for the “Reduced growing-season due to prolonged snow-lie” will be explored in more detail (see section 4.2.1).

4.3 Data fusion for improved estimation of environmental gradients from remote sensing data

A key component of the Sentinel4Nature project is to connect Sentinel data with other geospatial datasets such as aerial images, terrain models and indices derived from them as well as thematic maps by means of data fusion (Salberg et al. 2013, Ichter et al. 2014). This requires adjusting differently gridded data against each other.

The Sentinel4Nature project sets out to evaluate four different approaches to data fusion:

1) Aggregation: combining high resolution data (such as orthophotos or terrain models derived from LiDAR) with coarser satellite data.
2) Sharpening: combining lower resolution with higher resolution data by means of resampling to reduced pixel size
3) Merging: a combination of the two approaches above which meets at an intermediate resolution
4) Object-oriented data fusion: Another approach to data fusion is to merge characteristics of data with different resolution in image objects which were derived by segmentation of high resolution raster data.

A special focus is put on the object-oriented data fusion technique. The hypothesis is that the use of spatial structures (“image objects”) acquired from a segmentation of relevant (higher resolution) data layers will lead to a more realistic geographical representation of environmental patterns. The use of such segments as well as grids with different resolution allows for several aggregation techniques, e.g. based on variance or average or similar statistics, which may be utilized for improved analysis (Blaschke 2010).

In order to identify suitable data fusion strategies, some technical and methodological aspects are relevant, such as the trade-off between spatial and spectral resolutions (He et al. 2011), the amount of data to process, the availability and more or less unbiased coverage (regarding space, time and content) of especially the high resolution data. In addition, also characteristics of the spatial pattern to be observed (e.g. size and shape of terrain structures which govern the small scale snow pattern) are important in this regards.

Table 1: Data fusion of satellite imagery and other relevant data types enhances the mapping and monitoring of environmental gradients in the case study sites.

Site	Terrain model	Terrain indices	Landsat	RapidEye	Ortho-photos	MODIS VI	Sentinel-1	Radarsat-2
Oslo Fjord	DEM 10m, LiDAR DEM (0.5m)	Yes	2013/2014	Partly covered	2013	Yes	2015	No
Hjerkinn	DEM 10m, LiDAR DEM (0.2m)	Yes	2013/2014	Partly covered	2012	Yes	2015	2011/2012
Sunndalen	DEM 10m	Yes	2013/2014	Partly covered	2008	Yes	2015	2015
Lurøykal-ven	DEM 10m	Yes	2013/2014	Not covered	2010	Yes	2015	2015

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Appendix

The electronic appendix, covering "The suitability of remote sensing (Sentinel) for estimating environmental gradients and properties in NiN" as referred to in chapter 3 can be accessed here: http://hdl.handle.net/11250/2388193

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