DGPF Tagungsband 16 / 2007 – Dreiländertagung SGPBF, DGPF und OVG

Modeling fractional shrub/tree cover and multi-temporal changes using high-resolution digital surface models and CIR-aerial images

E. BALTSAVIAS*^,1^, H. EISENBEISS[1], D. AKCA[1], L.T.WASER[2], M. KÜCHLER[2], C. GINZLER[2], P.THEE[2]

Abstract:

The objective of this paper is to assess increase and decrease of forest area and estimate shrub encroachment between 1997 and 2002 in open mire land using CIR-aerial images, DSMs derived from it and LiDAR data. The present study was carried out in the framework of the Swiss Mire Protection Program, where changes of forest area are a key issue. The study area is located in the Pre-alpine zone of Central Switzerland. In a first step, high-quality DSMs were automatically generated from CIR- aerial images of 1997 and 2002. This DSM generation is based on high accuracy, intelligent matching methods developed at ETHZ which are able to produce very dense and detailed DSMs that allow a good 3D modeling of both deciduous and coniferous trees and shrubs, and multi-temporal analysis of their growth pattern. In a second step, tree layers from both years were then generated combining canopy height models derived from the DSMs and LiDAR DTM with a fuzzy classification of spectral information (NDVI) of CIR aerial images. In a third step, on the basis of these tree layers fractional tree/shrub covers were generated using explanatory variables derived from the DSMs and logistic regression models. Finally, bias was estimated by analyzing the distribution of the fractional model differences. The corrected models reveal a decrease of tree/shrub probability. This indicates a decrease of forest and other wooded areas between 1997 and 2002. On the other side, the models also indicate real shrub encroachment and tree growth in open mire land. The study stresses the importance of high-resolution and high-quality DSMs and highlights the potential of fractional covers for ecological modeling.

1 Introduction

This study focuses on assessing increase and decrease of tree / shrub area in a mire ecosystem between 1997 and 2002. The study was carried out in the framework of the Swiss Mire Protection Program which aims at conserving mire ecosystems of national importance and outstanding beauty in their present state. This implies no decrease of the mire area and no degradation of vegetation. A monitoring program based on a representative sample of 130 mires was set up in 1996 to examine the effectiveness of the conservation status (Küchler et al., 2004). Since changes of the extent of forests as well as shrub encroachment may alter a sensitive mire biotope, detection and evaluation of increase and decrease of the entire wooded area is indispensable and may help for preservation of these biotopes.

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[1] Institute of Geodesy and Photogrammetry, ETH Zurich, 8093 Zurich, Switzerland

[2] Swiss Federal Research Institute WSL, Department of Landscape Inventories, 8903 Birmensdorf, Switzerland

* Corresponding author.

Using traditional methods of field survey or aerial photograph interpretation to gain information on shrub encroachment and tree growth etc. is not feasible for larger monitoring programs regarding costs and time (St-Onge and Achaichia, 2001; Watt and Donoghue, 2005). Recent progress in three-dimensional remote sensing e.g. digital stereophotogrammetry, radar interferometry and LiDAR (Hyyppä et al., 2000) in combination with high resolution images may be helpful to estimate increase and decrease of forest area and occurrence of shrubs. Some studies suggest the use of canopy height models to detect changes in the forest stands (Schardt et al., 2002; Naesset and Gobakken, 2005) and to evaluate growth estimations (including extent of forest area and shrub encroachment). Canopy height models can be calculated by subtracting a digital terrain model (DTM) from a digital surface model (DSM). DSMs can be generated automatically by image matching methods, whereby most commercial packages use cross-correlation or matching of interest points. Meanwhile, several LiDAR systems enable the derivation of DSMs and DTMs (Hyyppä et al., 2000; Baltsavias, 1999). There is a growing need for sensitive tools to predict spatial and temporal patterns of plant species or communities (Kienast et al., 1996). Spatially explicit predictive modeling of vegetation is often used to construct current vegetation cover using information on the relations between current vegetation structure and various environmental attributes (Grünig et al., 2004). Some studies point out that modern regression approaches have proven particularly useful for modeling spatial distribution of plant species and communities (Guisan and Zimmermann, 2000; Scott et al., 2002). Since old CIR aerial images are often available and necessary variables of the DSM can be calculated, retrospective analysis of changes in forest area and shrub/tree encroachment in a mire biotope is feasible. Thus, airborne remote sensing data in combination with generalized linear models (GLM) could be useful for modeling these changes in mire ecosystems over time.

The objective of the present study is to assess decrease and increase of forest tree / shrub area in a mire ecosystem between 1997 and 2002 using logistic regression models, aerial images and DSMs derived from it. A fractional cover approach seem to be more appropriate since the discrimination of tree covers (Mathys et al., 2006) into simple forest / non-forest categories results in a loss of information. The resulting shrub/tree cover maps contain the fraction of shrub/tree as a continuous variable and can be adapted easily and consistently to a range of protecting purposes as applied in the Swiss Mire Protection Program.

2 Materials and methods

2.1 Study area

Models have been developed and tested for the mire "Walchwil/Oberallmig" which is located on a small plateau in the East of Lake of Zug in the Pre-alpine zone of Central Switzerland (approx. 47°07' N and 8°32' E). The mire site covers an area of approx. 4.2 km^2, whereas the core of the mire has an area of approx. 2.61 km^2. The altitude varies from 900 m to 1000 m above sea level. The landscape is highly fragmented and characterized by pastures that are crossed by shrubs and bright broad-leafed woodland (see Fig. 1). The dominant vegetation types are moist and wet meadows and pastures, low sedge poor fen, bog forest and broad-leaved woodland and willow Carr. The most relevant changes (1997-2002) for the present study are namely storm losses caused by hurricane Lothar (1999), a permanent shrub encroachment in open mire land and selective logging activities and cutting of shrubs as a result of conservation efforts.

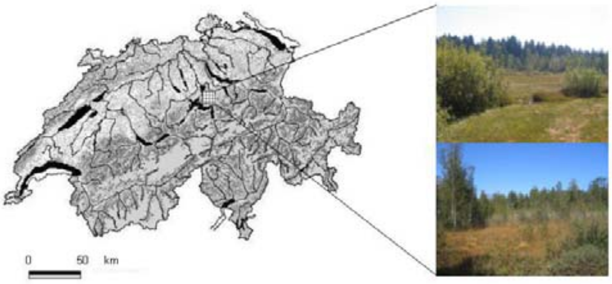

Figure 1. Left side: overview of the test site (Pixelmap © 2006 Swisstopo JD052552); right side: bog and fenland, coniferous and deciduous trees and shrubs.

2.2 Remotely sensed data

Three different sets of input data are used: 1. Image data: consist of 4 CIR aerial images (1 strip) of 1997 and 12 CIR aerial images (2 strips) of 2002, scale 1:10000 and 1:5700, respectively and orthoimages that were generated with a spatial resolution of 0.5 m. 2. Digital surface models: DSMs were generated automatically from the above images of the years 1997 and 2002, respectively with a spatial resolution of 0.5 m. 3. National LiDAR data of the Swiss Federal Office of Topography (SWISSTOPO) was acquired in 2001 with leaves-off. From the raw data, both a DTM and DSM are generated by SWISSTOPO (as raw irregularly distributed points and regular grid; the first dataset was used in this study). The LiDAR DTM had an average point density of 0.8 points / m^2 and height accuracy (1 sigma) of 0.5 m. The DTM was interpolated to a regular grid with 0.5 m grid spacing for reasons explained below.

2.3 Automatic generation of digital surface models

Since accurate surface information in forested and open mire land is very important for this modeling approach, high-resolution DSMs of 1997 and 2002 are indispensable. Thus, a matching method which is described in detail in (Zhang, 2005) was used. This method can simultaneously use any number of images (> 2), matches very densely various primitives (grid points, feature points with good texture and edges), uses geometrical constraints to restrict the search space, combines two matching algorithms (sum of modified cross-correlation, and least squares matching) to achieve speed but also higher accuracy if needed, combines the matching results of the three primitive types with another matching approach to ensure local consistency, and performs an automatic blunder detection. The matching method is implemented in the operational, quasi-complete photogrammetric processing package Sat-PP which supports satellite and aerial sensors with frame and linear array geometry. The result was a regular grid DSM with 0.5 m spacing which was interpolated from a matching point cloud of similar density (ca. 15 million match points per stereo-pair). Visual inspection revealed that vegetation surface was best modeled with the blue channel.

2.4 Co-registration

The matching DSMs of 1997 and 2002, and the LiDAR DTM were co-registered, using a point cloud co-registration procedure described in (Gruen and Akca, 2005). This co-registration uses a 7-parameter 3D similarity transformation to remove systematic differences (bias) between two datasets, e.g. due to different image orientation. For the estimation of these parameters, we used control surfaces, i.e. DSM parts that did not change in the two datasets, i.e. bare ground, and also removed large differences due to matching errors with a robust filtering. After co-registration, different products could be generated and conclusions drawn. The difference 2002-1997 matching DSM gives the changes between the two epochs, especially regarding vegetation. After co-registration, the Z-component of the Euclidian distances (sigma a posteriori) was 3.4 m, showing a clear reduction of trees and other wooded plants from 1997 to 2002. The difference matching DSMs minus LiDAR DTM gives the normalized DSMs (nDSM), i.e. the 3D objects in the scene and especially the canopy height models (Fig. 2).

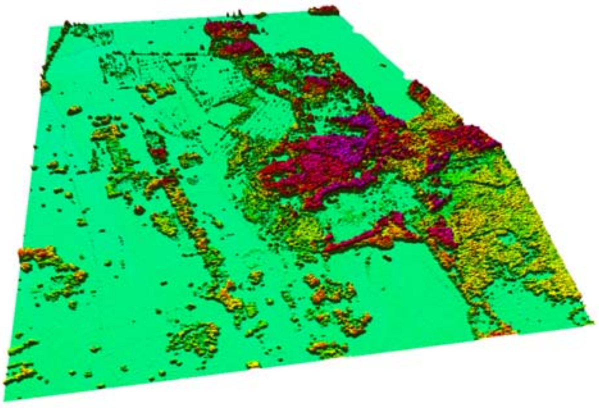

Figure 2. The 2002 matching DSM minus the LiDAR DTM, showing 3D objects on the terrain, especially trees and shrubs (canopy height model). Non-vegetation objects like buildings could be detected and eliminated by using NDVI and green index thresholds (see section 2.5).

2.5 Tree layers

In this study, two tree layers serve as basis (response variable) for the fractional modeling approach. Preliminary tree covers were calculated using the canopy height models of both epochs. In a first step, woody areas were extracted according to the 3m height definition of a tree in the National Forest Inventory.

In a second step, non-tree objects (buildings, rocks etc.) of the canopy covers were removed by using spectral information of the CIR orthoimages (normalized difference vegetation index and a green index). Non-tree objects have low NDVI and green index values. In former tests, non-tree objects were removed using a multi-resolution segmentation of the canopy cover and CIR-orthoimages and a fuzzy classification using eCognition which revealed similar results but was more time-consuming. The resulting tree layers of 1997 and 2002 (*tree_layer97* and *tree_layer02*) are a product of canopy model pixels with height values more than 3m and high NDVI and green index values.

2.6 Fractional tree/shrub covers

Logistic regression is often used to predict probabilities for presence/absence of a specific vegetation type at each point (Toner and Keddy, 1997). Shrub/tree occurrence maps can be constructed by analysis of these probabilities' actual occurrence. The logistic regression model is a special case of the generalized linear model (GLM) and is adapted for modeling such data (McCullagh and Nelder, 1983). The result is a fractional tree/shrub cover, i.e. a probability for each pixel to belong to the class "tree/shrub". The training data for the model were selected in a way to enable estimation of bias: only pixels were used which belong to the same class in both surveys, i.e. that were either corresponding forest pixels or open land pixels in the 1997 and 2002 tree layers. The explanatory variables consist of five commonly used topographic parameters derived from normalized DSMs (slope, aspect, curvature, and local neighboring functions), see Table 1. Most of these parameters have successfully been applied for ecological modeling purposes in mires (Küchler et al., 2004) or in biodiversity studies (Walser et al., 2007). Two fractional tree/shrub covers of 1997 and 2002 respectively were produced using the tree layers described in section 2.5.

Table 1. Overview of the five explanatory variables (derived from the nDSMs) as used to generate the fractional shrub/tree covers.

Name	**Derivation**
curvature	curvature of the surface at each cell center (3x3 window)
plan	curvature of the surface perpendicular to the slope direction, referred to as the planform curvature (3x3 window)
prof	rate of change of slope for each cell, curvature of the surface in the direction of slope (3x3 window)
slope	rate of maximum change in z value from each cell
top	assessment of topographic position (4 classes: ridge, slope, toe slope and bottom), the resulting grid displays the most extreme deviations from a homogenous surface

2.7 Bias estimation

Coppin et al. (2004) and Lu et al. (2004) present various change detection algorithms and techniques in ecosystem monitoring. E.g. ideally one would like to use imagery from the same sensor to keep the sensor characteristics as consistent as possible. It should be noted that even using imagery from the same sensor is no guarantee that the sensor characteristics will be equal.

Therefore, a possible bias may result from different data quality of the CIR aerial images from the two survey times, e.g. different spatial resolution, different image scanning facilities, varying radiation, different acquisition data (different status of phenology of trees and shrubs) etc. In the context of predictive modeling, bias denotes a systematic error in predicted values which might be misinterpreted as a change. A method of estimating bias arising from different data quality in two surveys is presented in Küchler et al. (in press).

In the present study, bias was estimated by the following procedure: The probabilities of each pixel of the corresponding smoothed fractional cover (i.e. *model_uncorr*) were added together and the sums stratified into 20 classes. The lowest class (0.0 - 0.1) of model sums corresponds to “non-tree/shrub” whereas the highest class (1.9 - 2.0) corresponds to “tree/forest”. Intermediate classes represent either partly forested areas or areas that have been deforested or areas where shrub encroachment occurred (Fig. 3). To estimate bias, the smoothed fractional covers (2002 - 1997) were subtracted. Then, distributions of the resulting differences were analyzed separately within each of the 20 classes. As a result, discrete bias estimations for each class were obtained (Fig. 3). To have a continuous bias estimation, the discrete values were smoothed by Loess regression with span 0.3.

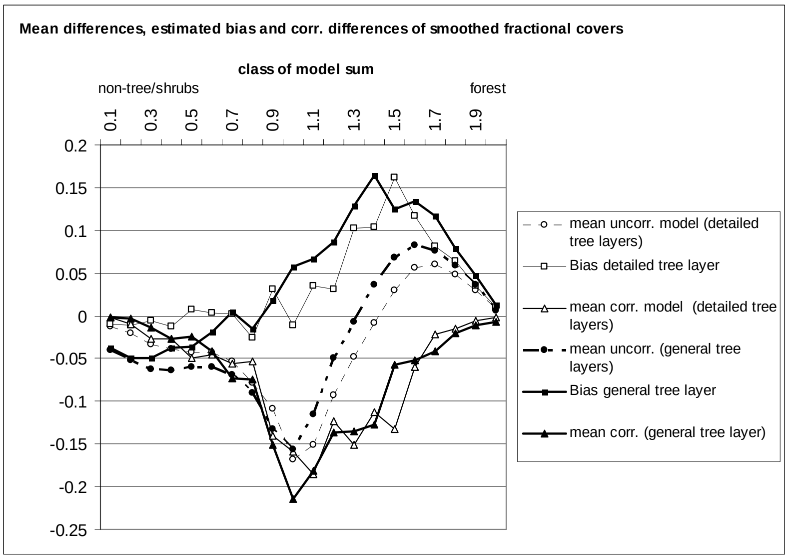

Figure 3. Mean differences, bias (estimated by modus) and corrected differences of smoothed fractional tree/shrub covers for 20 classes of model sums. Lowest class (0.0 - 0.1) of model sums corresponds to “non-tree/shrub”, whereas the highest class (1.9 – 2.0) corresponds to “forest”. Intermediate classes represent either partly forested area or areas that have been deforested or areas where shrub encroachment occurred.

2.8 Ground truth

For validation purposes ground truth data was produced using four types of samples (4 x 40) that were digitized from the stereo aerial images: 1. Tree/shrub-less areas in both years 1997 and 2002 (equal vegetation), 2. Tree/shrub areas in both years 1997 and 2002 (equal vegetation), 3. Tree/shrub-less areas of 2002 that belonged to tree/shrubs in 1997 (vegetation decrease), 4. Tree/shrub-less areas in 1997 that are covered with trees/shrubs in 2002 (vegetation increase).

3 Results

Fig. 4 a-d visualizes the difference between the tree layers and fractional covers of both years in a typical part of the mire where small shrubs and single trees are well present. The tree area extracted by both data sets is 0.901km^2 (*tree_layer97*) and 0.832km^2 (*tree_layer02*), respectively.
Visual image inspection revealed that several shrubs and small single trees are still not extracted in the remaining open mire land. Therefore, two fractional tree/shrub covers of 1997 and 2002

were produced using the tree layers described in section 2.5 as training data sets. A tree/shrub cover stratum of e.g. 0.1 - 1 (10-100%) means, that all pixels with a probability higher than 10% are assigned to shrub/tree etc. Fig. 4c-d) shows the five predicted tree/shrub cover strata for a typical part of the mire. Tree/shrub area that is previously missed by the tree layers is extracted as well – dependent on the threshold of probability. The area of extracted trees/shrubs increases with lower probability thresholds. At the same time, errors increase too. E.g. visual stereo image analysis revealed that a cover stratum of 10-100% also considers other vegetation than shrubs such as tall grass or herbs. In contrary, considering only a cover stratum of 0.5 – 1.0 (50-100%) leads to a significant underestimation of shrubs and trees in the open mire land.

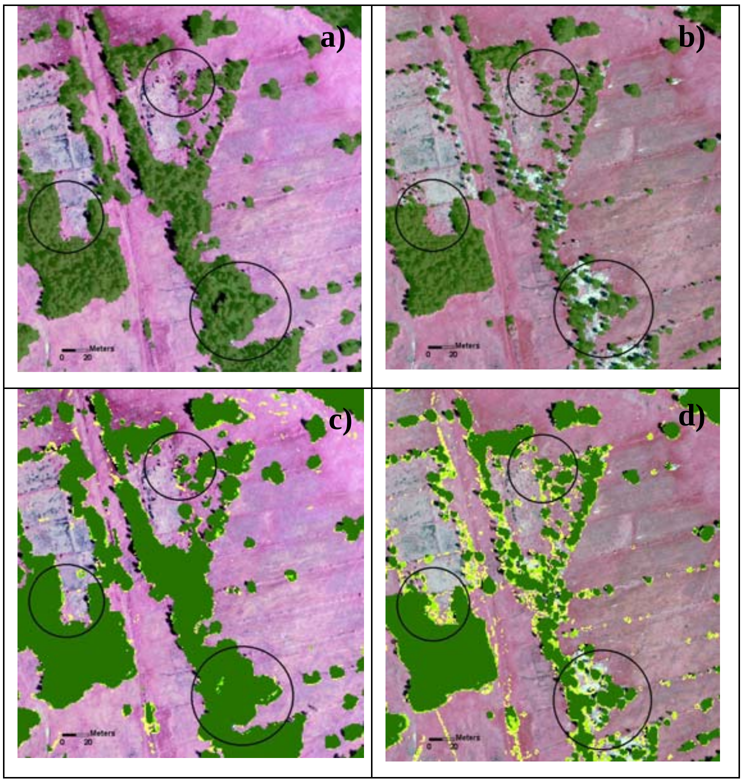

Figure 4. a) CIR orthoimages with tree layers of 1997 and b) of 2002, c) and d) corresponding fractional tree/shrub covers. The two smaller circles mark tree growth and shrub encroachment. The large circle marks areas with decreased tree/shrub cover due to selective logging activities.

Decrease and increase of forest area and other wooded area (1997-2002) is given in Table 2. The tree layer97_02 reveals a decrease of tree/shrub pixel portion of -0.059 between 1997 and 2002. Overall, the fractional cover approach revealed a decrease of tree/shrub probability between 1997 and 2002 of -0.029 for the uncorrected model (including bias) and -0.037 for the corrected model.
Table 3 summarizes the changes of tree/shrub pixel portion between 1997 and 2002 on the digitized sample areas between the tree layers and the changes of tree/shrub probability of the corrected fractional covers. Both the tree layers and fractional tree/shrub covers reveal no decrease/increase between 1997 and 2002 on the digitized samples where no change occurred. Tree layer and corrected model show a substantial decrease of tree/shrub probability in delineated areas where tree/shrub area declined between 1997 and 2002. Good information on deforestation

is also given by tree_layer97_02. However, shrub encroachment and growth of small trees in open mire land is not or only slightly detected when using the tree layer (+0.081). In contrary, the corrected model (+0.178) shows a shrub encroachment (general increase of tree/shrub probability in areas that were delineated as increase).

Table 2. Variations of change estimations for tree/shrub probability (1997-2002) as obtained by different methods.

Differences 2002 - 1997	**Description**	**Mean change of tree/shrub pixel portion**
tree_layer97_02	tree layers 2002 - 1997	-0.059
		Mean difference of tree probability
Model_uncorr (not bias corrected)	based on tree layers	-0.029
Model_corr (bias corrected)	based on tree layers	-0.037

Table 3. Mean differences in tree/shrub probability (2002-1997) on the digitized sample areas.

Differences 2002-1997	**digitized as**	**Mean change of tree/shrub pixel portion**
tree_layer97_02	decrease	-0.602
	equal	-0.000
	increase	+0.081
		Mean difference of tree/shrub probability
Model_corr.	decrease	-0.518
	equal	-0.000
	increase	+0.178

4 Discussion and conclusions

Combining remote sensing data with regression analysis and fractional cover approaches as it is performed in many studies for land cover mapping (Mathys et al., 2006) is also shown to be appropriate for fractional tree/shrub cover mapping and assessing changes of forest area in a mire biotope. The usage of standard explanatory variables as already applied in other studies (Küchler et al., 2004) derived from the normalized DSM proved to be a good approach for fractional modeling. With a fractional cover approach, also subtle changes of forest and other wooded areas can be detected before reaching a discrete threshold value. Furthermore, shrub/tree classifications based on the continuous data can be adjusted retrospectively. This may be an advantage also for mire habitat management. However, different quality of the scanned CIR aerial images and the normalized DSMs from the two surveys 1997 and 2002 caused systematic errors in the predicted values of the models which could be misinterpreted as a change of forest area. In fact, bias proved to occur at a scale which would, without correction, make impossible for example a reproducible statement whether the removal of trees and shrubs or the encroachment by growing bushes was predominant in the survey time. Estimation and correction for bias is essential, if any change has to be assessed by statistical modeling.

Overall, the present study reveals a decrease of forest and other wooded areas since 1997 although shrub encroachment occurred in some parts of open mire land. This general decrease has two reasons: 1) most forest clearings in this region were caused by hurricane Lothar in 1999 and 2) selective logging of groups of trees, single trees, shrubs in open mire land in the framework of the regeneration program. These differences of the corrected fractional tree/shrub covers give us reliable indication of the magnitude of changes of tree area between 1997 and 2002. Information on shrub encroachment is essential for assessing possible impact on the mire environment. Future work will also pursue the retrieval of the type of trees/shrubs by using spectral information of ADS40 data or Ultracam data.

However, both the accuracy of the tree layers and the fractional tree/shrub covers strongly depend on the accuracy of the DSM data. Thus, DSMs derived from newly developed, high-quality matching methods are indispensable. The usage of a dense and accurate DSM and DTM are absolute prerequisites in order to be able to derive accurate topographic parameters which in turn are used to derive the tree layers and the fractional tree/shrub covers. The fact that these topographic parameters alone almost suffice for the generation of the tree layers and the tree/shrub covers underlines the importance of DSM and DTM quality. The existing Swiss national LiDAR data have low point density and due to partial canopy penetration or LiDAR flights with leaves off they are not appropriate for accurate shrubs/tree detection and vegetation canopy modeling (Baltsavias et al., 2006). The present study showed that derivation of DSMs by high-quality matching, compared to LiDAR, has an additional advantage: images of 1997 and 2002 were used to derive multi-temporal DSMs, tree layers and tree/shrub covers, thus permitting a better analysis of changes of tree/shrub area. Use of modern digital photogrammetric sensors, would lead to avoidance of scanner and film problems, better radiometric quality, and use of the NIR for classification, all factors that would result in a more accurate mapping and change detection of trees and shrubs. Further future investigations will include the direct use of multi-temporal matching DSMs and LiDAR DTMs for co-registration, therefore reducing bias errors, and estimation of tree layers and fractional covers using directly these datasets and their differences, possibly in a combination with multi-spectral classification.

To summarize, high-resolution 3D information as obtained by means of DSMs is indispensable for modeling changes in forest and other wooded areas. Modeling retrospective changes of these areas is feasible, since old aerial images are often available and necessary variables of the normalized DSM can be calculated.

Acknowledgements

The study was carried out in the frame of the Swiss mire monitoring program initiated in 1996 at the Swiss Federal Research Institute WSL and funded by the Swiss Agency for the Environment, Forest and Landscape (BAFU) and WSL. We acknowledge the support of Ruedi Boesch for providing the LiDAR data and Peter Longatti for linguistic improvements (both WSL) and Devrim Akca (ETH Zurich) for the co-registration of the DSMs.

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