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Detection of windthrown trees using airborne laser scanning

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ABSTRACT

In this study, a method has been developed for the detection of windthrown trees under a forest canopy, using the difference between two elevation models created from the same high density (65 points/m^2) airborne laser scanning data. The difference image showing objects near the ground was created by subtracting a standard digital elevation model (DEM) from a more detailed DEM created using an active surface algorithm. Template matching was used to automatically detect windthrown trees in the difference image. The 54 ha study area is located in hemi-boreal forest in southern Sweden (Lat. 58°29′ N, Long. 13°38′ E) and is dominated by Norway spruce (*Picea abies*) with 3.5% deciduous species (mostly birch) and 1.7% Scots pine (*Pinus sylvestris*). The result was evaluated using 651 field measured windthrown trees. At individual tree level, the detection rate was 38% with a commission error of 36%. Much higher detection rates were obtained for taller trees; 89% of the trees taller than 27 m were detected. For pine the individual tree detection rate was 82%, most likely due to the more easily visible stem and lack of branches. When aggregating the results to 40 m square grid cells, at least one tree was detected in 77% of the grid cells which according to the field measurements contained one or more windthrown trees.

1. Introduction

Dead wood in the form of logs from windthrown trees is a valuable resource for biodiversity in forest ecosystems (Bouget and Duelli, 2004; Jonsson et al., 2005). The large number of windthrown trees usually occurring after major storms might, however, sustain large populations of insects that could impose a danger to the remaining living forest (Martikainen et al., 1999). In Sweden's managed boreal and hemi-boreal coniferous forests large populations of the European spruce bark beetle (*Ips typographus*) are especially dangerous for the most common tree species, Norway Spruce (*Picea abies*). Therefore, forest managers would be aided by remote sensing methods which could find the location of recent windthrown trees.

For ecosystem management, as well as for carbon accounting, there is a need for efficient statistical methods for surveying the amount of logs with dead wood. Field based survey methods have been developed by, e.g., Warren and Olsen (1964), Ståhl (1997), Gove et al. (1999, 2005), Bebber and Thomas (2003), Jordan et al. (2004) and Ståhl et al. (2010). Such methods are expensive if not combined with other surveys like National Forest Inventories, e.g., Fridman and Walheim (2000), or used in multiphase sampling approaches together with remote sensing data. There is also a need for objective surveys on a regional scale to assess the amount of windthrown trees after major storms. For example, after the storm "Gudrun" that hit southern Sweden in January 2005, the number of windthrown trees was estimated using visual assessment from an aircraft flying along sampling strips.

Previous remote sensing studies of windthrown forest have shown that aerial photos or optical satellite images can be used for finding areas where many trees have fallen (Pasher and King, 2009; Wilson and Sader, 2002). However, it is difficult to find scattered windthrown trees located under a tree canopy from optical satellite data or aerial photos acquired from standard altitude (i.e., 4000–5000 m above ground). A drawback of using optical satellite images for this purpose is that thinning cuttings cause a similar increase in reflectance as partially windthrown areas, which reduces the usefulness of change detection (Olsson, 1994). Compared to optical satellite data, use of radar data can provide better separation, since windthrown trees tend to increase radar backscatter while removal of trees reduces the backscatter. However, the increase or decrease of backscatter for windthrown forest depends largely on the wavelength used. Promising results have been obtained using the long wavelength airborne radar system CARABAS-II (Fransson et al., 2002; Ulander et al., 2005). The results from CARABAS-II show that detection success depends mainly on the direction of illumination (flight direction), with illumination perpendicular to the windthrown trees giving the strongest backscatter.

Airborne laser scanning (ALS) is, similar to radar, an active remote sensing technology that penetrates the tree canopies and therefore has potential to find objects close to the ground.

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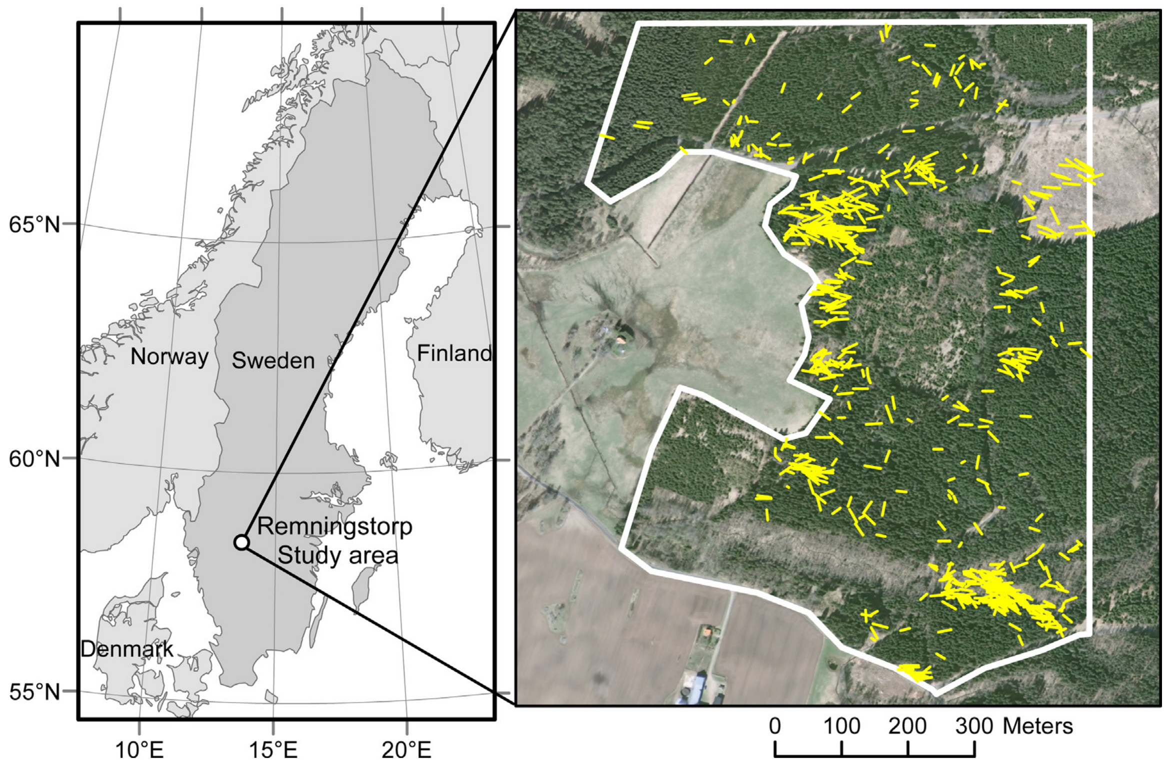

Fig. 1. The location of the study area in southern Sweden (left) and an orthophoto over the study area (right). The white border is the extent of the inventoried area (54 ha) and the yellow lines are digitized windthrown trees with actual location, length and direction as recorded in the field survey. © Lantmäteriet, i2012/901.

Successful results in detecting near-ground objects have been demonstrated for identification of small trees below the tallest canopy layer (Lindberg et al., 2013b), as well as detection of military targets partly occluded by forest (Grönwall et al., 2011).

Promising results have also been obtained in a few studies for area-level estimations of windthrown trees using ALS data. Pesonen et al. (2008) estimated downed and standing dead wood volumes at area-level using regression models of height and intensity metrics from ALS data calibrated with field measurements from 33 sample plots. They achieved a relative root mean squared error (RMSE) of 51.6% for downed dead wood volume. Vehmas et al. (2011) detected canopy gaps using ALS data and classified them into five canopy gap classes, including a class of downed dead wood. Vastaranta et al. (2012) detected snow-damaged trees in southern Finland using the difference in ALS measured canopy heights. The overall detection rate was 66% which represented 81% of the total stem volume of snow damaged trees. At plot level, the omission error was 19–75% and the commission error 0–21%. Honkavaara et al. (2013) detected gaps after a winter storm in Finland using the difference between the digital surface model (DSM) from ALS and the DSM from matching of aerial photos. Areas with significant damage (more than 10 fallen trees per hectare) were found with 100% accuracy. Areas with less than 10 fallen trees per hectare were confused with unchanged areas and were detected with an accuracy of 46%.

With higher density ALS data, it is possible to detect downed trees at individual tree level. Yu et al. (2004) automatically detected harvested trees using two ALS acquisitions with a point density of approximately 10 points/m^2. Sixty-one of the 83 field checked harvested trees were correctly identified with automatic detection. It was mainly the smaller harvested trees that were not detected. Blanchard et al. (2011) used object-based image analysis to detect downed logs in gridded ALS data (point density 10.5 points/m^2). Mücke et al. (2013) identified downed trees using small footprint full-waveform ALS data (point density 29.4 points/m^2). Mücke et al. used a stepwise detection process based on variables such as normalized heights and echo widths to generate a map of downed trees. Lindberg et al. (2013a) worked in the same study area as the present study, but used a line template matching method applied directly to the ALS point cloud (point density 69 points/m^2) to detect windthrown trees.

Active surfaces have previously been used to generate digital elevation model (DEMs) of the ground (Elmqvist, 2002, 2000; Elmqvist et al., 2001), as well as the top of the tree canopies (Holmgren and Persson, 2004; Persson et al., 2002). One of its advantages is the possibility of adjusting the elasticity and attraction of the surface. In the present study, an active surface with high flexibility was used to adapt to objects close to the ground. A second, "smoother" ground DEM was used to calculate distance to the ground in order to enable delineation of objects near ground level.

The objectives of this study were to develop and evaluate a method for discriminating windthrown trees in a difference elevation model created by subtracting an active surface DEM and a ground DEM. The results were evaluated at individual tree level and for 40 m × 40 m grid cells using a complete field survey of windthrown trees in the study area.

2. Methods

2.1. Study area

The study area (centered at Lat. 58°29′ N, Long. 13°38′ E) is a forest estate located in Remningstorp in southern Sweden (Fig. 1). Most windthrown trees in the study area were the result of a storm on January 14, 2007. The 54 ha large study area is flat with elevations ranging from 110 m to 132 m a.s.l. The managed forest consists mainly of Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*), and some deciduous tree species are also present, such as birch (*Betula pubescens*). The dominant soil type is till (i.e., a mixture