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# MAPPING OF WIND-THROWN FORESTS USING SATELLITE SAR IMAGES

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**ABSTRACT**

The study focuses on investigation and evaluation of wind-thrown forest mapping using satellite remotely sensed data from three synthetic aperture radar (SAR) sensors. The study is carried out at Remningstorp, a test site in the south of Sweden dominated by coniferous forest, where trees were manual felled to simulate wind-thrown forest. The satellite data consisted of time series of HH polarized SAR images acquired by the Advanced Land Observing Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR), Radarsat-2 (C-band) and TerraSAR-X (X-band). The results from visual interpretation of SAR images acquired before and after the simulated wind-throw together with corresponding ratio images show that ALOS PALSAR HH polarized intensity images are not able to detect wind-thrown forest, probably due to too coarse spatial resolution. In contrast, the wind-thrown forest is clearly visible in the Radarsat-2 and TerraSAR-X HH polarized images, implying that it may be possible to develop a new application using these SAR data for mapping of wind-thrown forests.

***Index Terms*****—**Synthetic aperture radar, forest, change detection, storm damage

## 1. INTRODUCTION

Mapping of wind-thrown forest using satellite data is an area of research important to explore further. This was demonstrated in 2005 and 2007, when devastating storms hit Sweden (among other countries) causing large damages to forested areas. In these two storms, it was estimated that about 70 million cubic meters (2005) and about 12 million cubic meters (2007) of timber fell down to a value of billions of Euro. At these occasions, a rapid mapping of wind-thrown forests is crucial in order to salvage timber values and prevent insect outbursts that could kill the remaining standing trees. After a severe storm it is also of high importance to get a fast overview to assess the roads that should be cleared from wind-thrown trees as well as to detect power lines that are broken. It is likely that storm events causing damages to forests will occur more often in the future due to global climate change; one reason being the warmer temperatures during winter time.

After the devastating storm in 2005, research activities for detection of wind-thrown forest were initiated and conducted in Sweden. Satellite images were provided from the International Charter for Space and Major Disasters that is an instrument for rapid provision of images in catastrophic events. A large number of different spaceborne remote sensing techniques were investigated including optical remote sensing. The success of the optical satellites was limited by the prevailing winter conditions (low sun-angle, extensive cloud cover and variable snow cover). The major benefits of using satellite SAR are the all weather day and night capability and the short revisit time, which make it feasible to provide timely maps. However, the radar analysis showed that with a limited number of backscatter intensity images from C-band SAR onboard Envisat and Radarsat-1 it was not possible to detect wind-thrown forests due to too high frequency and coarse resolution [1]. Conversely, a sign of storm damage was seen in the highest resolution Radarsat-1 images as changes in texture, primarily related to changes in shadowing from standing/fallen trees.

The lack of sensitivity in backscatter measurements with coarse resolution at shorter wavelengths is possible to explain theoretically as the felling of trees does not change significantly the total backscatter, since the needles and small branches are still present as a randomly oriented scattering volume. At coarse resolution, the speckle noise is also more extended compared with higher resolution SAR images, limiting the possibilities to detect wind-thrown forests. On the other hand, longer wavelengths are sensitive to larger structures like stems and large branches that would improve the possibilities to detect wind-thrown forest. In particular, the significantly improved spatial resolution of satellite SAR images is expected to improve the possibilities to detect wind-thrown forest. Thus, to further explore the use of radar remote sensing to detect wind-thrown forest it is of interest to analyze images from the new satellite SAR systems, i.e. the Advanced Land Observing Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR) because of the longer wavelength and Radarsat-2 and TerraSAR-X because of the high spatial resolution.

A preliminary investigation on the feasibility of mapping wind-thrown forest using ALOS PALSAR data was carried out as a controlled experiment, where trees were manual felled to simulated wind-thrown forest [2]. The experiment took place in 2006 at the test site Remningstorp located in the south of Sweden. The results showed that the backscatter intensity decreased about 1.6 dB for the ALOS PALSAR Fine Beam Single 34.3° (look angle) HH polarized images, when comparing the reference with the wind-thrown stands. This drop in backscatter is not considered enough in order to detect wind-thrown forests.

The objective of this new study is to investigate the possibilities to detect wind-thrown forests using HH polarized images from the ALOS PALSAR, Radarsat-2 and Terra-SAR-X sensors. The investigation is done by visual interpretation of images acquired before and after a simulation of wind-thrown forest together with corresponding ratio images for each image pair.

## 2. MATERIAL AND METHODS

A controlled experiment was carried out in the beginning of September 2009 at the Swedish test site Remningstorp (Lat. 58°30’ N, Long. 13°40 E). The simulation of wind-thrown forest was done by manual felling of trees and instead of stripping and removing the trees (as is done in clear-felling), the trees were left for a few orbit repeat cycles to ensure image acquisitions after the “storm”. In total, four coniferous stands with a size of about 1.2 ha were used to simulate wind-thrown forest (Figs. 1 and 2). The trees were felled in two directions to simulate two possible main wind directions during a storm. For two of the stands, the trees were felled in 35° and for the other in 80° with the heading measured clockwise from north (0°). In total, over 3000 cubic metre of timber were felled. The felled trees were then harvested and removed from the forest in November 2009.

For the duration of the experiment, ALOS PALSAR data were acquired according to JAXA’s global observation strategy for ALOS, i.e. Fine Beam Dual mode at 34.3° look angle in ascending pass. Radarsat-2 and TerraSAR-X were programmed to acquire data at different look angles and in both ascending and descending passes to study differences in the shadowing effects. This study includes visual interpretation of SAR HH polarized images in ascending passes.

## 3. RESULTS

In Figs. 3-5, SAR images acquired before and after the simulated wind-throw are shown together with the corresponding ratio images for ALOS PALSAR, Radarsat-2, and TerraSAR-X. From visual interpretation, the results clearly show that SAR images from the two latter sensors are superior to PALSAR in order to detect wind-thrown forest.

Fig. 1. A mosaic of digital aerial photographs captured by a UAV covering three of the simulated wind-thrown forest stands, each with a size of about 110 × 110 $m^2$.

Fig. 2. Photograph taken from the ground over one of the simulated wind-thrown stands.

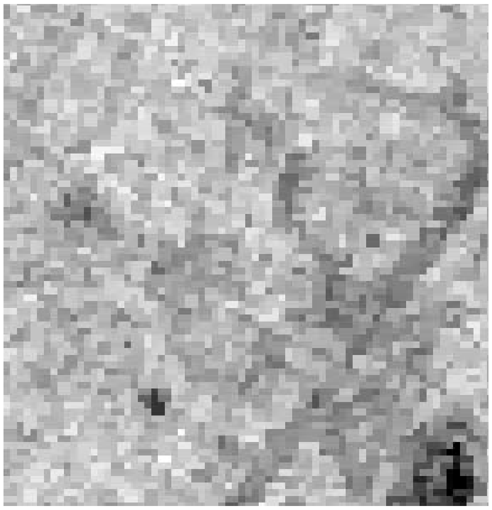

Fig. 3a. ALOS PALSAR FBD HH polarized image (look angle 34.3°) acquired on 2009-07-08 before the simulated wind-throw.

Fig. 4a. Radarsat-2 UltraFine HH polarized image (look angle ~ 41°) acquired on 2009-08-23 before the simulated wind-throw.

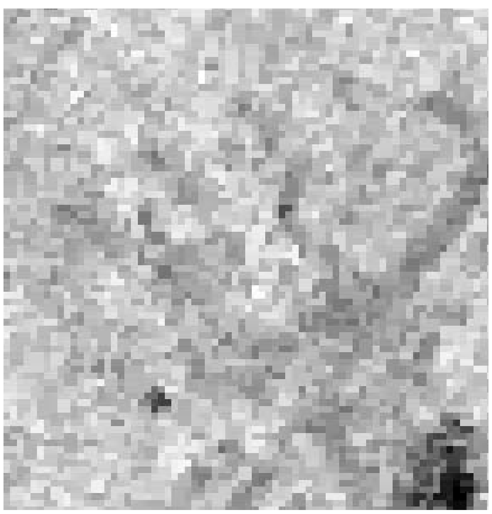

Fig. 3b. ALOS PALSAR FBD HH polarized image (look angle 34.3°) acquired on 2009-10-08 after the simulated wind-throw.

Fig. 4b. Radarsat-2 UltraFine HH polarized image (look angle ~ 41°) acquired on 2009-10-10 after the simulated wind-throw.

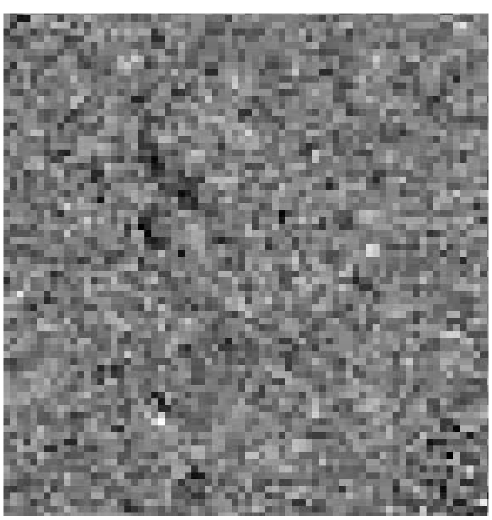

Fig. 3c. Ratio of ALOS PALSAR FBD HH polarized images (look angle 34.3°) acquired on 2009-10-08 and 2009-07-08.

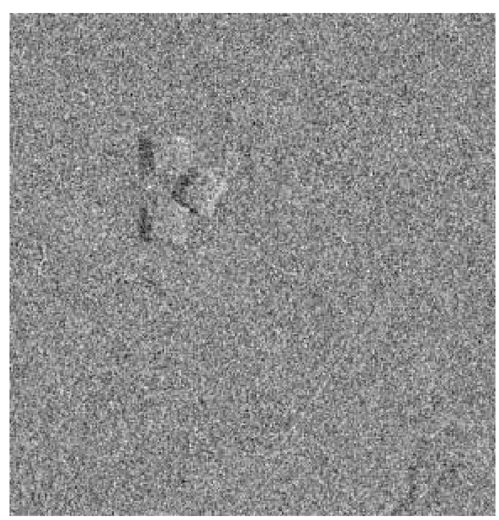

Fig. 4c. Ratio of Radarsat-2 UltraFine HH polarized images (look angle ~ 41°) acquired on 2009-10-10 and 2009-08-23.

Fig. 5a. TerraSAR-X HH polarized image (look angle ~ 38°) acquired on 2009-09-04 before the simulated wind-throw.

Fig. 5b. TerraSAR-X HH polarized image (look angle ~ 38°) acquired on 2009-10-07 after the simulated wind-throw.

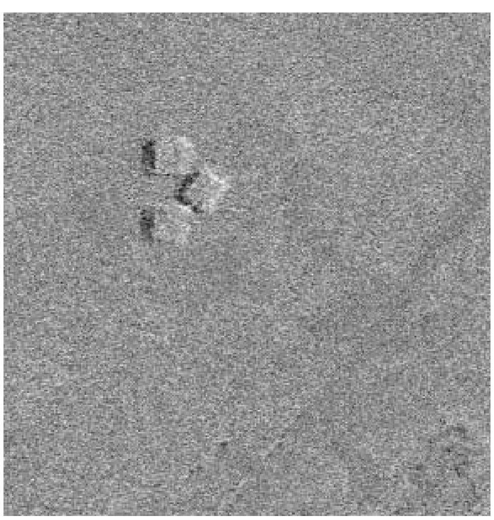

Fig. 5c. Ratio of TerraSAR-X HH polarized images (look angle ~ 38°) acquired on 2009-10-07 and 2009-09-04.

## 4. CONCLUSION

From visual interpretation of the spaceborne SAR images included in this study, wind-thrown forest stands are clearly visible in the Radarsat-2 and TerraSAR-X HH polarized intensity images acquired in ascending passes (Figs. 4-5). The results also confirm that it is not likely to detect wind-thrown forest in ALOS PALSAR images with corresponding polarization and orbital path (Fig. 3). The encouraging results from Radarsat-2 and TerraSAR-X can mainly be attributed to the higher spatial resolution (pixel size 10 m and 5 m, respectively) in comparison with ALOS PALSAR (pixel size 20 m). As expected the shadowing at the border between standing and wind-thrown trees is the most important effect in order to detect wind-thrown forest.

Further research will include a larger dataset of SAR images to investigate the effect of environmental conditions, look angles, orbital path and tree felling directions (35° and 80°). The investigations will include texture analysis and backscatter measurements.

The ultimate goal is to develop a new application for mapping of wind-thrown forest using high-resolution SAR data, where previous satellite sensors (e.g. Envisat, Radarsat-1) have been unable to deliver the information required in a timely fashion. In this study, the result from visual interpretation of SAR images acquired by Radarsat-2 and TerraSAR-X implies that it may be possible to develop a new application for mapping of wind-thrown forests.

## 5. ACKNOWLEDGMENT

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