# K&C Science Report – Phase 1
# Detection of deforestation in Swedish forest

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***Abstract*—An extensive dataset of ALOS PALSAR L-band Synthetic Aperture Radar (SAR) backscatter images is investigated for clear-cut detection in Swedish forest. SAR data were available for the counties of Västerbotten and Västra Götaland as well as for two local test sites (Remningstorp and Krycklan). A strong forest/non-forest contrast and temporal consistency were found for the Fine Beam Dual HV-polarized backscatter in summer/fall. Thus, a simple thresholding algorithm could be used for clear-cut detection. Using the ALOS PALSAR data and methods applied so far, most pixels in the clear-felled areas could be correctly classified as changed. For the county of Västerbotten in northern Sweden, up to about 50% of the pixels were correctly classified as changed for about 90% of the clear-felled areas using a 2 dB threshold. The results were less good for the county of Västra Götaland in southern Sweden, where only up to about 40% of the pixels could be correctly identified as changed for about 65% of the clear-felled areas. For the south county, also much over classification of non changed areas occurred. It would still be possible to use the ALOS PALSAR data in a sampling routine, where changed areas are checked against cutting permits and samples of the remaining detected changes should be checked *in situ* for determining type of change. In the extension phase of the project, an up scaling of the mapping of clear-cuts, and possibly also biomass, to all of Sweden is planned. There is also a need for further algorithm development.**

***Index Terms*—ALOS PALSAR, K&C Initiative, boreal forest, forest theme, deforestation, clear-cuts, Sweden.**

## I. Introduction

In Sweden, a nationwide coverage of satellite data is acquired annually by the government. The images are used by the Swedish Forest Agency for change detection in order to find clear-felled areas and subsequent verification of the cutting permits of about 70,000 clear-felled areas yearly. In combination with about 50,000 National Forest Inventory (NFI) field plots, the images are also used for producing nationwide forest maps, and for post stratification of forest variable estimates from the NFI plots. At present, optical satellite imagery are used. Sweden is, however, characterized by frequent cloud-cover and long periods of reduced solar illumination. In order to obtain the about 200 cloud-free SPOT scenes that are needed for a nation-wide coverage, about 6,000 programming attempts of the SPOT satellite are needed. In this respect it is of interest to investigate space borne Synthetic Aperture Radar (SAR) as a future complement for forest monitoring due to its independence of cloud cover and thus the possibility to obtain the needed imagery in a foreseeable way.

It is of particular interest to investigate the usefulness of L-band SAR sensors, for which the backscattered signal has shown a high sensitivity to forest structural properties, in particular for the cross-polarized return (see e.g. [1-8]). This has motivated further investigation of the usefulness of the Advanced Land Observing Satellite (ALOS) Phased Array L-band type Synthetic Aperture Radar (PALSAR) images for forest change detection and mapping. Logging activities and fire scars are characterized by noticeable decrease of the backscatter. The backscatter difference before and after the forest cover change has been devised to be a tool for mapping clear-cuts and deforestation in boreal [9-13] and tropical forest [14-17]. Several studies, however, highlighted the importance of the environmental conditions at the time of image acquisition, concluding that data acquired under dry conditions perform better than in case of wet conditions [14, 15, 18, 19]. The importance of a multi-polarization and multi-sensor approach for mapping of reforestation and disturbance has been reported by [11, 14, 20].

Although a few algorithms have been presented to detect deforestation, no large area applications of deforestation mapping using change detection with SAR data has been reported in literature yet. To fulfill the goals of the K&C Initiative project (see Section II), efforts had to be paid to the development of an algorithm for mapping deforestation at regional level. A further challenge was represented by the availability of temporally dense time series of data, which required a thorough investigation of ALOS PALSAR backscatter signatures in order to be able to develop a robust deforestation change detection algorithm [23].

## II. DESCRIPTION OF THE PROJECT

### A. *Relevance to the K&C drivers*

The prime scope of this K&C Initiative project was to develop, verify and demonstrate a methodology for detection and delineation of deforestation (primarily clear-cuts) in managed forest regions in Sweden using multi-temporal ALOS PALSAR data. Methods for detecting land use change are of prime interest for green house gas reporting. In the case of Sweden most changes in mature forest will be clear-cuts, which are re-planted after a few years. It is of interest to develop a system that can detect all clear-felled areas and sort out the large majority of legal fellings by comparisons with granted cutting permits. The remaining detected forest changes are likely to be illegal fellings, large damages or permanent land cover changes and should, thus, be visited in field.

### B. *Work approach*

To demonstrate the potential of ALOS PALSAR imagery to map deforestation, the counties of Västerbotten and Västra Götaland, in the north and in the south of Sweden, respectively, were selected (Fig. 1). These counties will be referred to as prototype areas, in agreement with the nomenclature adopted in the K&C Initiative (see also [21]). The two counties are covered predominantly by forests as shown in Table 1 and in Section II.C, Figs. 6 and 7). The county of Västerbotten consists of boreal forest, whereas the county of Västra Götaland is located within the hemi-boreal forest zone. The average annual timber production is substantially higher and the clear-felled areas are generally smaller but more frequent in Västra Götaland than in Västerbotten.

Detection of deforestation was based on multi-temporal datasets of ALOS PALSAR images acquired in different seasons and with different polarizations (as further described in Section II. C). The deforestation part of the work approach was arranged in four parts:

- Analysis of ALOS PALSAR backscatter signatures to understand which type of backscatter could be more suitable for detecting deforestation;
- Development of an algorithm for the detection of deforestation using time series of ALOS PALSAR data;
- Generation of deforestation maps using the developed algorithm;
- Accuracy assessment of the produced deforestation maps.

A detailed analysis of the temporal signatures at the two test sites of Remningstorp (Lat. 58°30' N, Long. 13°40' E) and Krycklan (Lat. 64°14' N, Long. 19°50' E) in the prototype areas (Fig. 1) has been recently reported in [23].

Table 1. Statistics on forest status and clear-cut activities for the prototype areas [22].

| | Västerbotten | Västra Götaland |
|---|---|---|
| Area of forest land | 3.2 $10^6$ ha | 1.3 $10^6$ ha |
| Proportion of forest land | 57.7% | 54.3% |
| Notified clear-cuts in 2007 | 5,033 | 6,025 |
| Area of notified clear-cuts in 2007 | 27,289 ha | 15,805 ha |


Figure 1. The K&C Initiative prototype areas in Sweden and local test sites.

In this K&C science report, we summarize the main findings, highlighting those that were relevant for the development of the change detection methodology.

- The HV-backscatter is more sensitive than the HH- and VV-backscatter to forest growth stage, i.e. stem volume or biomass (see e.g. Fig. 2).
- The HV-backscatter has a very high temporal consistency under unfrozen conditions (Fig. 3). No HV-backscatter data were acquired under frozen conditions.
- The HH-backscatter presents clear seasonal dependencies. The sensitivity to different growth stages is higher for unfrozen conditions. For unfrozen conditions the backscatter of dense mature forest is consistent, whereas it is affected by the wet or dry weather conditions in regrowing young forest (Fig. 4).
- The sensitivity of the backscatter to forest growth stage increases slightly between 21.5 and 41.5 degrees look angle, both at HH- and HV-polarization.
- The backscatter signatures do not change significantly between 20 m pixel size (ALOS PALSAR path data) and 50 m pixel size (K&C ALOS PALSAR strip data).

The strong sensitivity of the ALOS PALSAR HV-backscatter data acquired under unfrozen conditions to forest growth stage and the strong temporal consistency suggested that a simple change detection algorithm based only on HV-backscatter would be sufficient to detect deforestation. It is, however, foreseen in the extension phase to look at possible improvements, e.g. by also including HH-backscatter in the detection algorithm.

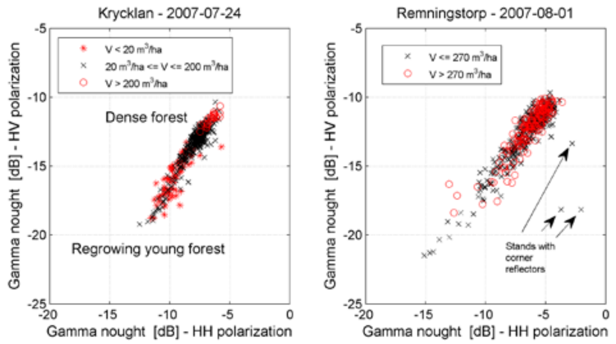


Figure 2. Scatterplot of HH- and HV-backscatter for the test sites of Krycklan and Remningstorp. The SAR images were acquired under unfrozen conditions. Acquisition mode: Fine Beam Dual at 34.3 degrees look angle [23].

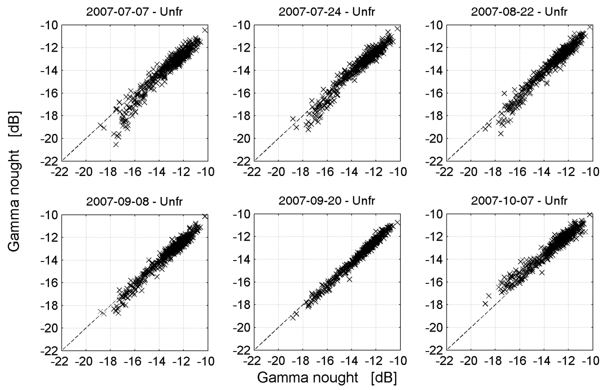


Figure 3. Scatterplot of HV-backscatter for the test site of Krycklan for six different dates with reference to a common date (2007-08-05). The SAR images were acquired under unfrozen conditions (Unfr). Acquisition mode: Fine Beam Dual at 34.3 degrees look angle [23].

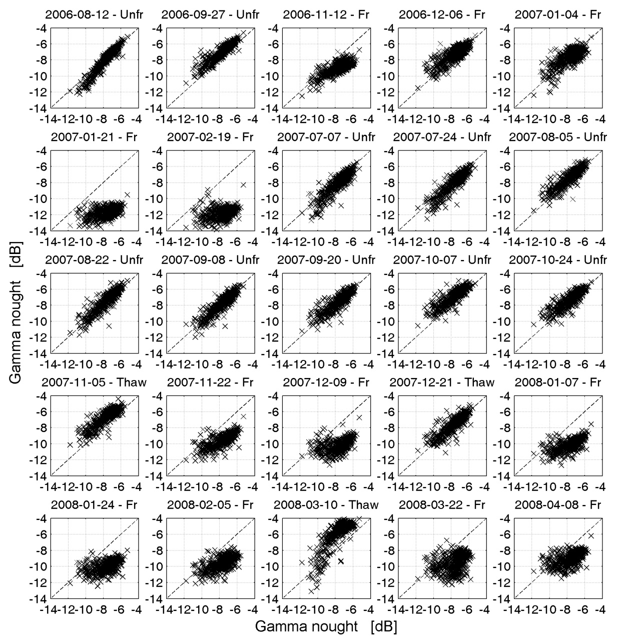


Figure 4. Scatterplot of HH-backscatter for the test site of Krycklan for 25 different images plotted along the y-axis with respect to a common date (2006-06-07) plotted along the x-axis. Acquisition mode: Fine Beam with 34.3 degrees look angle [23].

The change detection algorithm was developed based on the multi-temporal dataset of ALOS PALSAR HV-backscatter images available over the two prototype areas (see Section II. C). For each summer/fall during 2007 and 2008 several backscatter measurements were available for all points on the ground within the prototype areas. As a time series of backscatter measurements was available it was suggested to develop a slightly more complex algorithm than just adopting a simple two-date change detection algorithm.

The multi-temporal approach was based on the temporal consistency of the backscatter difference for each combination of backscatter measurements for a given point. If the backscatter difference for all image pairs covering the felling date of a forest was consistently above a certain level (e.g. 2 or 3 dB), while the difference for image pairs acquired before and after the felling date was small, the pixel was classified as "change". Support to this approach is illustrated in Fig. 5 that shows the temporal signatures of the HV-backscatter for a set of polygons clear-felled between 2006 and 2008 within a 50×50 $km^2$ large area in Västerbotten. Red crosses refer to polygons clear-felled between the two image acquisition dates reported on the plot axes. Black crosses refer to polygons clear-felled before both image acquisition dates (lower backscatter) and green crosses refer to polygons reported as clear-felled in the reference dataset but not yet clear-felled at the time of both acquisitions (higher backscatter). Unchanged polygons between image acquisitions were mostly along the 1:1 line, confirming the temporal consistency of the HV-backscatter. A few of the unchanged polygons were off the 1:1 line probably because of errors in the reference dataset or because felling had started at the time of the second image date, but had not yet been completed or registered. Polygons clear-felled between image acquisitions present a clear drop in most cases larger than 2 dB. Very few of these cases show a small variation of the backscatter, which could be related to the small size of the polygon, thus altering the temporal signatures of the backscatter in case of change.

An issue that had to be taken into account when developing the change detection algorithm concerned intercepts and slopes in the trend of co-plotted backscatter measurements. These can be due to the effect of large area variations of the environmental conditions or non-perfect data calibration. Such deviations can disturb the analysis if not accounted for. For example, if the second image of a pair has a consistently higher backscatter compared to the first image (e.g. top-left scatterplot in Fig. 5), clear-cuts occurred between the two acquisitions might not be detected because the backscatter difference might be too small. This suggested that it makes more sense to use the variation of the backscatter with respect to a reference level rather than the simple backscatter difference between the image acquisitions. The reference level can be obtained by fitting a linear or non-linear regression model to the pairs of backscatter values as shown by the solid red line in the top-left scatterplot of Fig. 5 and measure the difference between the backscatter on the first date and the model-based value for the second date, i.e. the model residual.

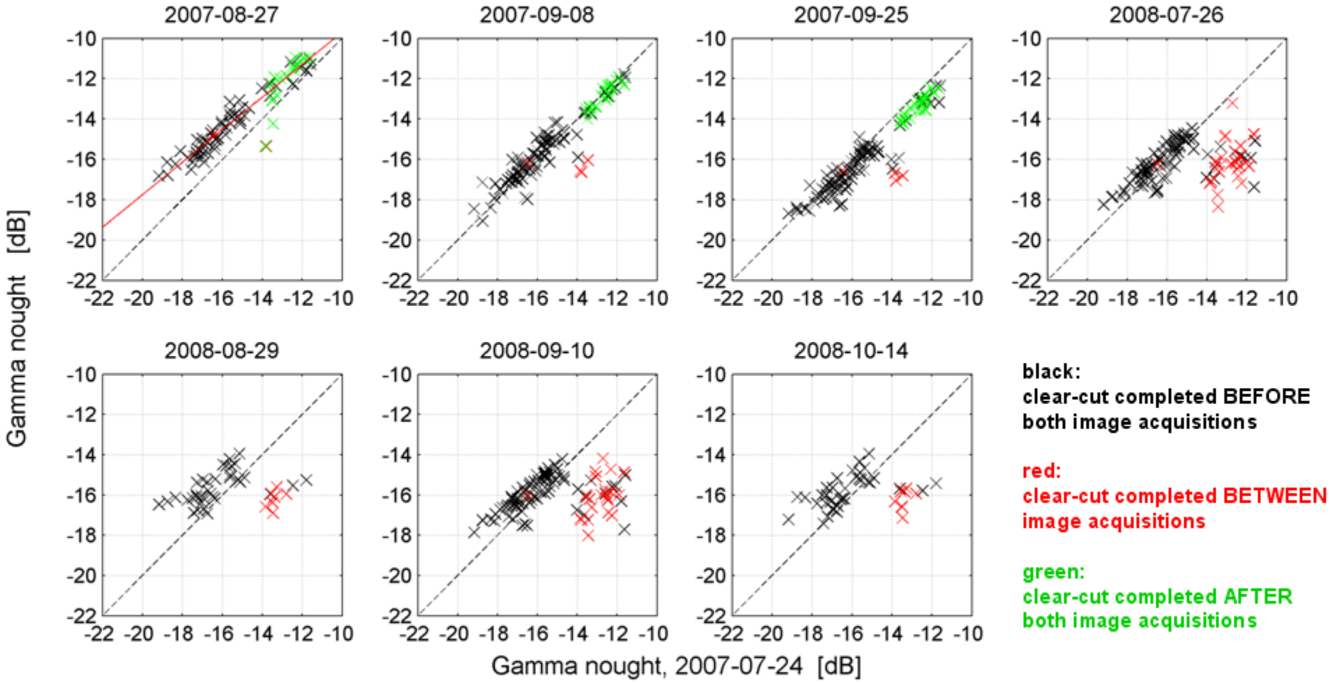


Figure 5. Scatterplots of HV-backscatter for clear-cuts in Västerbotten occurred between image acquisitions (red crosses) and outside the interval between the two image acquisitions (black and green crosses).

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Based on this rationale the multi-temporal clear-cut detection method was setup as follows:

- The prototype area was first divided into areas of smaller size. The size was a trade-off between having on one hand a large number of measurements for accurate estimation of the regression model coefficients that describe the backscatter trend of two acquisitions and avoiding on the other hand that large-scale spatial variations of the environmental conditions (e.g. thaw in one area and dry conditions in another) might distort this trend. Dividing the prototype areas into 50×50 $km^2$ large tiles seemed to be reasonable.
- Given a tile, for each combination of images the coefficients of the regression model relating the backscatter at the two dates were estimated. For each pair of images the regression coefficients were estimated using the measurements of all pixels labeled as forest in a forest/non-forest map available from the Swedish National Land Survey. A linear regression model seemed to be sufficient. The residuals were then computed. It was assumed that within the tile the number of pixels subject to change was negligible with respect to the total number of pixels labeled as forest so that no a priori information on the actual forest cover at the time of image acquisitions was required to determine the estimates of the regression coefficients.
- For each pixel the temporal evolution of the residuals was analyzed with respect to a threshold value according to the basic idea presented at the beginning of this Section.

To test the sensitivity of the classification to the threshold, three threshold values were used: 2 dB, 2.5 dB and 3 dB. The maps of detected deforestation were finally mosaiced together and majority filtering was applied. The filter was designed to remove isolated pixels up to groups of three neighboring pixels. This implies that detected deforestation smaller than 1 ha has been neglected.

*C. Satellite and ground data*

For this K&C project, image strips have been provided by JAXA in form of multi-look amplitude images in slant range geometry with approximately 50 m pixel size [24]. Absolute calibration of the data was performed by using the updated calibration coefficients published in [25]. For each of the years 2007 and 2008, one cycle of images acquired in FBS34 mode during winter and two cycles of images acquired in FBD34 mode during summer/fall have been delivered. In total, data from six ALOS repeat-pass cycles have been obtained. For each season a complete coverage of the prototype areas was obtained. Because of the strong multi-looking applied, no action was taken to further reduce speckle effects. All image strips have been geocoded to 50 m pixel size in order to adhere to the original size of the data. To increase the geolocation accuracy co-registration of neighboring strips was applied after geocoding. Final co-registration errors were less than the pixel size. Topographic normalization of the backscatter for local incidence angle and pixel area was applied. For details on the processing it is referred to [23]. Figs. 6 and 7 show two mosaics in form of RGB color composites obtained from K&C ALOS PALSAR strip data. The red areas, overlaid on the mosaic, correspond to detected changes between summer 2007 and fall 2008. Red corresponds to the HH-backscatter, green to the HV-backscatter and blue to their ratio. Forests appear in green. Bare surfaces, agricultural fields and marshes appear in purple. Rivers, lakes and the sea appear in blue. Urban settlements appear in yellow/pink.

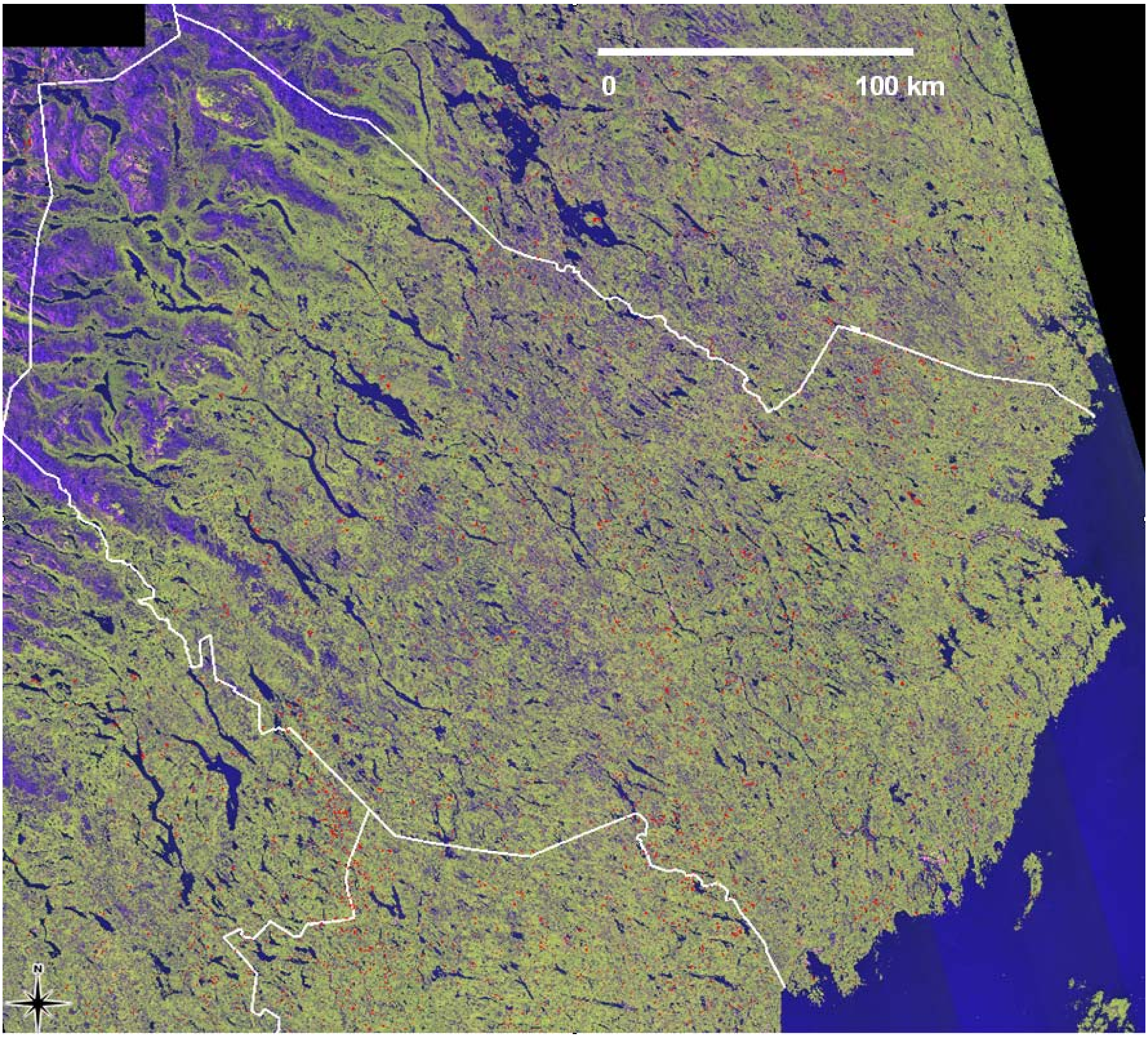



Figure 6. False color composite of ALOS PALSAR HH-backscatter (red), HV-backscatter (green) and backscatter ratio HH/HV (blue) for the county of Västerbotten. Time frame of ALOS PALSAR dataset: July 2007 - October 2008. The areas detected as deforestation during the time frame of the ALOS PALSAR dataset are overlaid in red. ALOS PALSAR images © JAXA/METI.

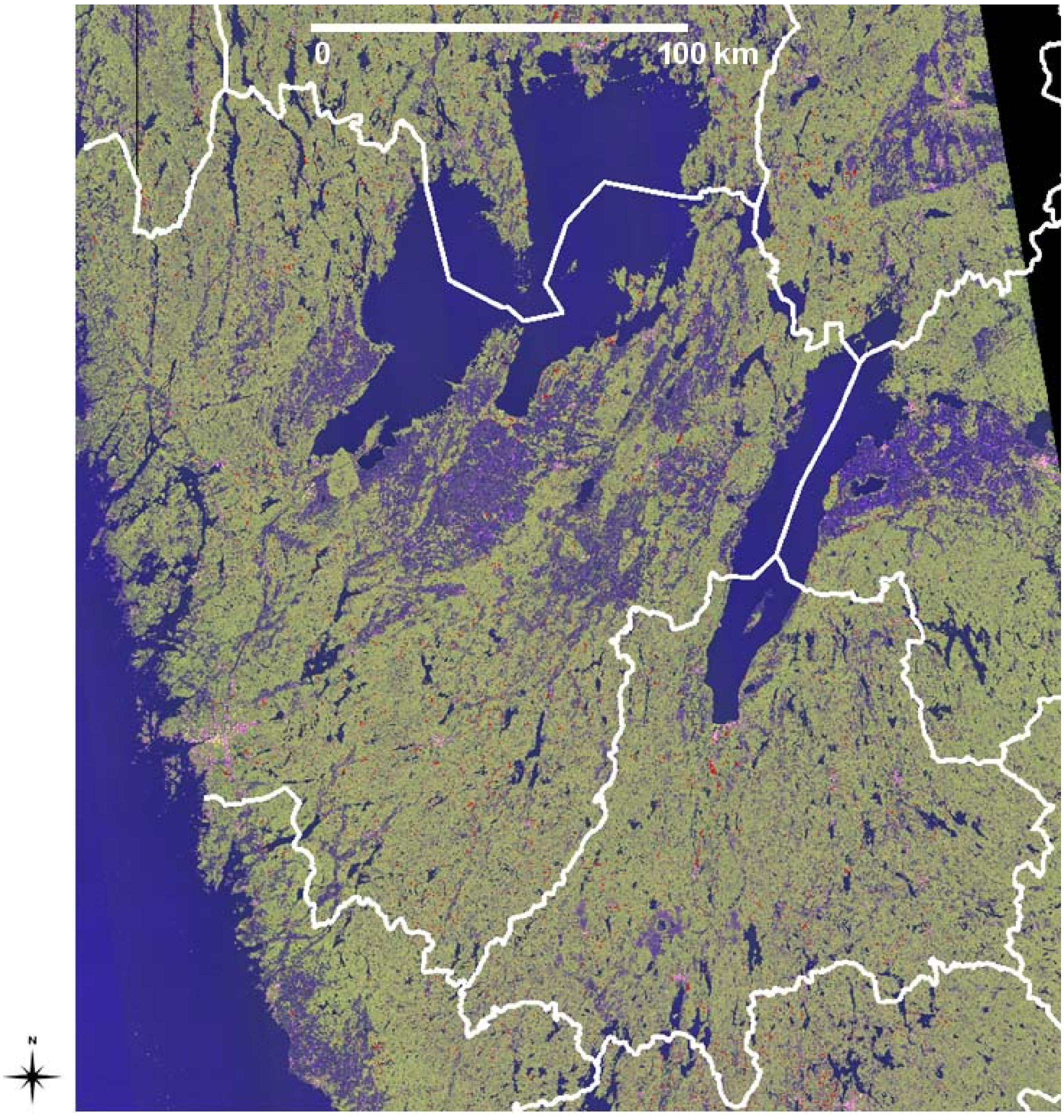
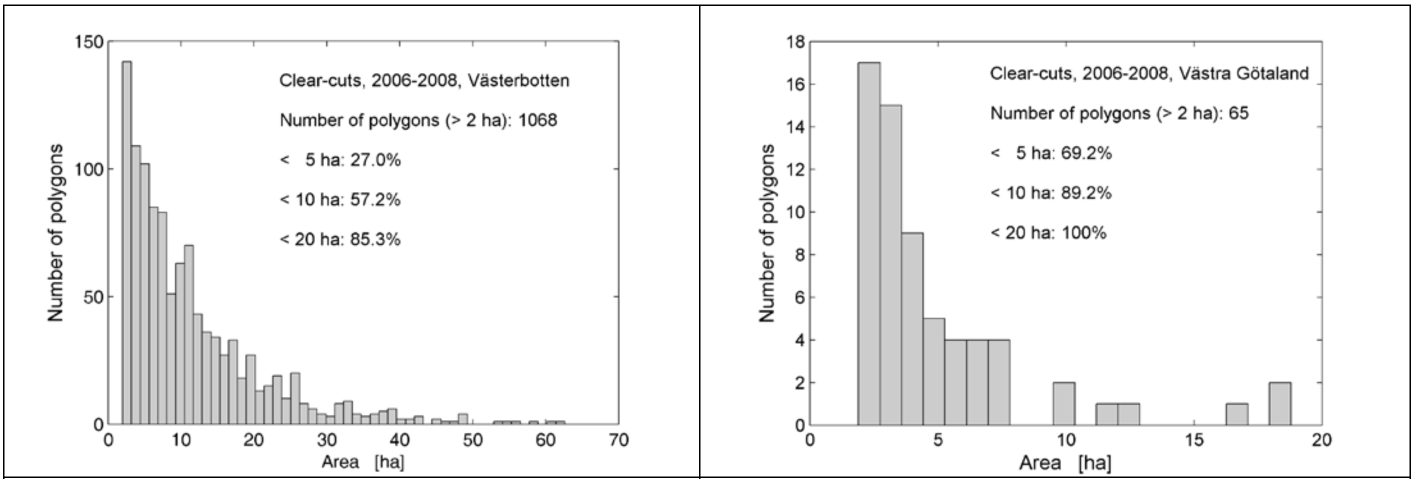



Figure 7. False color composite of ALOS PALSAR HH-backscatter (red), HV-backscatter (green) and backscatter ratio HH/HV (blue) for the county of Västra Götaland. The false color composite includes the entire county of Västra Götaland (west) as well as the county of Jönköping (south-east). Time frame of ALOS PALSAR dataset: July 2007 - October 2008. The areas detected as deforestation during the time frame of the ALOS PALSAR dataset are overlaid in red. ALOS PALSAR images © JAXA/METI.

To avoid that changes occurring in other land covers such as cropland would be confused with the detection of deforestation, a forest/non-forest map provided by the Swedish National Land Survey was used to mask out non-forested areas. Temporal signatures of the backscatter for agricultural fields and clear-cut areas are in fact similar, i.e. sudden decrease of backscatter at harvest.

For the establishment of the algorithm and the validation of the detected changes a GIS layer of forest polygons subject to felling between 2006 and 2008 was available from the Swedish forest company Sveaskog. All polygons were larger than 2 ha. For each polygon the date of completion of the clear-felling was reported. The dataset included 1068 polygons for the county of Västerbotten, but only 65 polygons for the county of Västra Götaland. Of these 341 (Västerbotten) and 29 (Västra Götaland) polygons were clear-felled during the period of the HV-backscatter data acquisition, i.e. July 2007 to October 2008. These sets were considered for the accuracy assessment. The remaining clear-fellings took place before July 2007.

Fig. 8 shows the size distribution of the clear-cuts for the validation data available from the two counties. Clear-cuts in the Västerbotten county are on average larger, several exceeding 20 ha. In the Västra Götaland county the clear-cuts are smaller, none of them available in the reference dataset being larger than 20 ha. This aspect might be of importance considering that the pixel size of the ALOS PALSAR K&C strip data is 50 m, i.e. 1 ha corresponds to 4 pixels. In the following, it is primarily referred to the results obtained in the county of Västerbotten because of the larger number of reference polygons as well as the larger distribution of polygon sizes.




(a) (b)

Figure 8. Distribution of the size of the clear-cuts in the GIS database used for validating the developed methodology for detection of deforestation in the two prototype areas, (a) Västerbotten, (b) Västra Götaland.

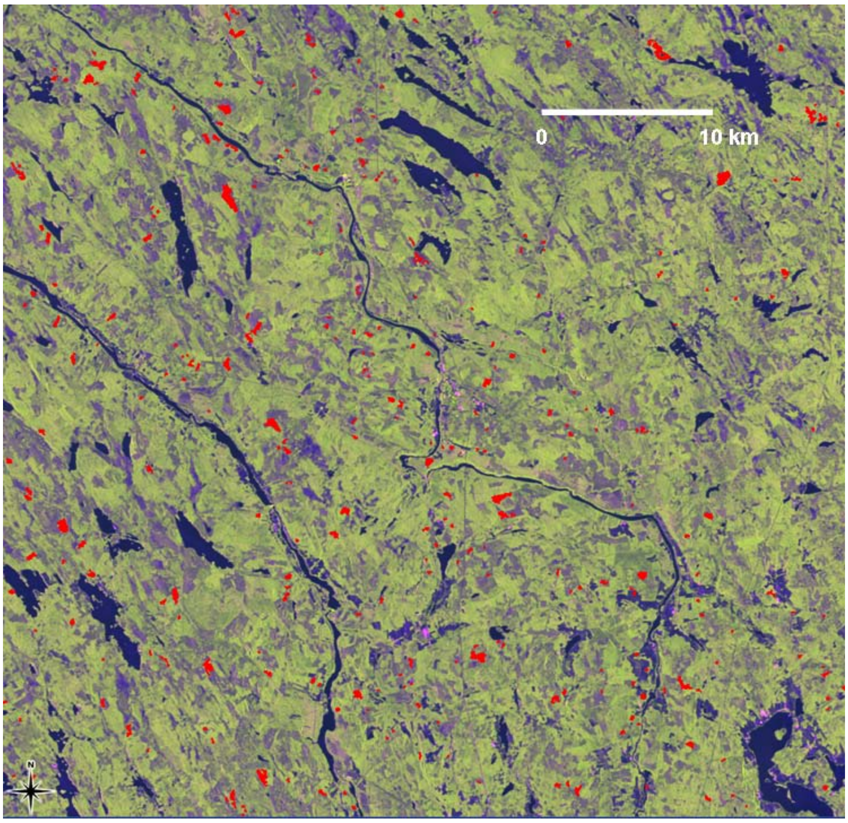



Figure 9. Subset of the image shown in Fig. 6 centered at the test site of Krycklan (Lat. 64°14' N, Long. 19°50' E), Västerbotten. ALOS PALSAR images © JAXA/METI.

## III. Results and Summary

The output of the change detection algorithm applied in this study consisted of maps of detected changes, i.e. detected deforestation, in the forested areas of the prototype areas, i.e. the Västerbotten county and the Västra Götaland county. The extent of the ALOS PALSAR strips also allowed mapping the Jönköping county, located south-east of the Västra Götaland county. The accuracy assessment, however, has been carried out for the prototype areas. The maps overlaid on the false color composite of ALOS PALSAR HH- and HV-backscatter imagery are illustrated in Figs. 6 and 7. For each pixel detected as change, the dates of the two images comprising the detected change were also reported. Fig. 9 shows a zoom of the image shown in Fig. 6 around the test site of Krycklan.

The scope of the accuracy assessment of the deforestation maps was twofold

*1)* For a given detection threshold verify whether a clear-cut had been detected and determine a measure of the agreement in terms of correctly detected pixels. In this way, information was obtained on the capability of the 50 m resolution ALOS PALSAR K&C strip data to detect as well as to delineate clear-cuts.

*2)* Verify the sensitivity to the different detection thresholds. In this way, information was obtained on the robustness of the change detection algorithm and whether improvements to the simple approach are required.

Fig. 10 gives an example of the performance of the change detection algorithm based on a time series of ALOS PALSAR HV-backscatter data for the county of Västerbotten. On the x-axis the percentage of pixels detected as deforestation (i.e. correctly classified) is reported for each of the reference polygons. On the y-axis the size of the polygons is reported. For Fig. 10 the detection result was based on the 2.5 dB threshold. The scatterplot shows that a large number of polygons were not only detected but also rather well delineated. Polygons showing less than 50% of correctly classified pixels are less compared to those including more than 50% of correctly classified pixels. When relating the percentage of correctly classified pixels to the size of the polygons no significant trend was seen, i.e. the classification accuracy did not improve when considering only larger polygons.

Fig. 10 also shows a certain number of polygons with zero percentage of pixels classified as deforestation. These 25 polygons were reported as clear-felled during the acquisition period of the HV-backscatter data, but were not detected by the change detection algorithm. A closer look at these polygons revealed that most of them were between 2 and 3 ha large, so that edge effects might have distorted the backscatter difference. Part of the largest polygons were actually detected with the 2.0 dB threshold, thus confirming the indication reported in Fig. 5 that not all clear-cuts present a strong variation of the HV-backscatter. This issue needs to be looked at in more detail in future work dealing with the improvement of the detection algorithm. Finally, for two polygons the felling date was reported to be two days after the date of the first ALOS PALSAR backscatter dataset. It is likely that the forest in the polygon had already been clear-felled at the time of the first image acquisition.

As outcome of these observations it might be stated that:

- The GIS database of clear-cut polygons (in Västerbotten) is reliable as validation dataset;
- The impact of the spatial resolution of the ALOS PALSAR backscatter dataset on the detection accuracy is not marginal for clear-cuts smaller than 5 ha;
- The detection accuracy seems to be reasonable even if the algorithm is simple and uses a global threshold.

Further investigation on the detection accuracy is reported in Table 2, which gives a more general overview on the classification accuracy, also in terms of detection errors.

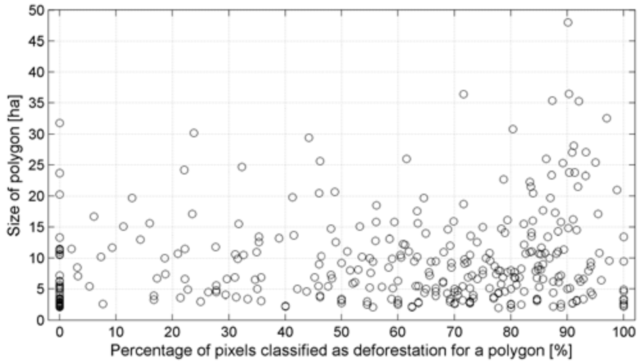



Figure 10. Polygon-wise percentage of correctly detected pixels in relation to area of the polygon. Prototype area: Västerbotten. Number of polygons: 341.

In Table 2, the total percentage of correctly detected pixels refers to the number of pixels detected as clear-cut and being actually reported as clear-felling within the temporal interval of ALOS PALSAR data for the specific pixel. The total error percentage is expressing the number of pixels classified as clear-cut for polygons that were clear-felled before the start of the time series of ALOS PALSAR data for the specific pixel. Table 2 shows that for increasing classification threshold the classification accuracy decreases from 78.2% to 57.4%, while the classification error also decreases from 9.7% to 3.0%. The detection of deforestation seems therefore to perform better when using lower threshold values, even though the detection errors increase with decreasing threshold value. Possible causes for the limited accuracy are

- Spatial resolution of the ALOS PALSAR dataset;
- Edge effects (edge erosion on the reference dataset was not performed);
- The simplicity of the change detection algorithm.

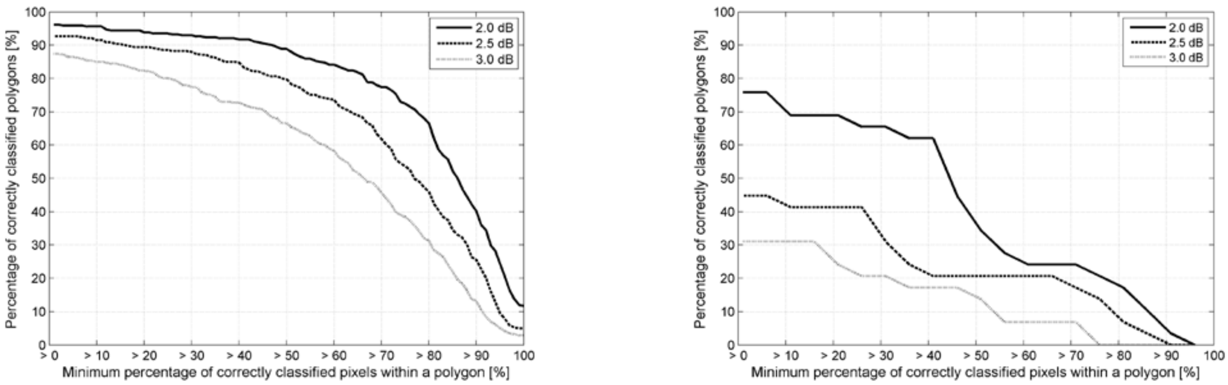
To assess the importance of each of these factors, the following studies could be considered in the K&C Initiative extension phase:

- Apply the change detection algorithm to ALOS PALSAR path data at 20 m spatial resolution (or similar);
- Apply edge erosion to the reference dataset and possibly exclude those polygons that do not cluster;
- Improve the change detection algorithm. In its current version the algorithm makes use of a global threshold for the entire prototype area. It is likely that the detection accuracy might increase if the algorithm is made adaptive to the local properties of the backscatter following spatial variations of the environmental conditions.

To provide indications on the capability of the change detection algorithm applied to ALOS PALSAR HV-backscatter data (acquired under unfrozen conditions), Fig. 11 shows the percentage of polygons for which the percentage of pixels classified as deforestation is above a certain threshold. When this requirement is satisfied, the polygon is referred to as "correctly classified". One plot is reported for each prototype area and in each plot the trend is reported for the three different thresholds applied to the detection of deforestation.

Table 2. Global figures of detection accuracy for the three different classification thresholds. Prototype area: Västerbotten.

| Classification threshold | Percentage of correctly detected pixels (reference dataset: 341 polygons) | Percentage of erroneously detected pixels (reference dataset: 727 polygons) |
|---|---|---|
| 2.0 dB | 78.2% | 9.7% |
| 2.5 dB | 68.4% | 5.0% |
| 3.0 dB | 57.4% | 3.0% |




(a) (b)

Figure 11. Percentage of correctly classified clear-cuts as a function of the minimum percentage of pixels correctly classified within the polygon for the prototype areas (a) Västerbotten, (b) Västra Götaland.

Fig. 11 a shows that in the Västerbotten county for 2.0 and 2.5 dB threshold and up to about 50% correctly classified polygons, the classification accuracy is about 90%. If a polygon is defined as correctly classified when more than half of the pixels within the polygon are correctly detected, then the classification accuracy decreases remarkably. For 3 dB threshold the decrease is steady and in general the detection accuracy is lower compared to the smaller thresholds of 2.0 and 2.5 dB. The accuracy assessment in the Västra Götaland county showed a similar trend, although the overall accuracy was lower compared to the Västerbotten county. Nevertheless, it must be reminded that the number of polygons in Västra Götaland was small (only 29), i.e. the significance of the results appears to be rather limited. Combining these observations with those reported in the two previous paragraphs, it is concluded that

- With the HV-backscatter from ALOS PALSAR K&C strip data it is possible to roughly delineate forest cover changes but not to fully match the extent of the deforestation;
- The accuracy of the detection depends on the classification threshold;
- Higher accuracy seems achievable with a threshold between 2.0 and 2.5 dB.

To gain further insight on which detection threshold is more suitable to use in order to achieve a more accurate detection of deforestation, Fig. 12 reports the total area classified as change in relation to the detection threshold used for classification. Fig. 12 shows that for both prototype areas the total area detected as change decreases significantly, in particular when going from 2.0 to 2.5 dB. Considering that the figure of notified areas of felling in each county as reported in the Statistical Yearbook of Forestry 2008, published by the Swedish Forest Agency [22], is 273 $km^2$ for Västerbotten and 158 $km^2$ for Västra Götaland, it is obvious that the estimates corresponding to the 2.0 dB level are extremely biased.

The algorithm detected far more areas of change than in reality, which could be related to speckle noise or not fully compensated effects of the environmental conditions on the backscatter. Another issue that might explain the large discrepancy is the accuracy of the forest/non-forest map used as basis for selecting the areas on which the algorithm should be applied. Several small parcels were detected as forest cover change in areas of patched land-cover, as well as along the border between forest and fields or roads or urban settlements. These results indicate that a more in depth study on the reasons of the mismatches should be considered in the extension phase.

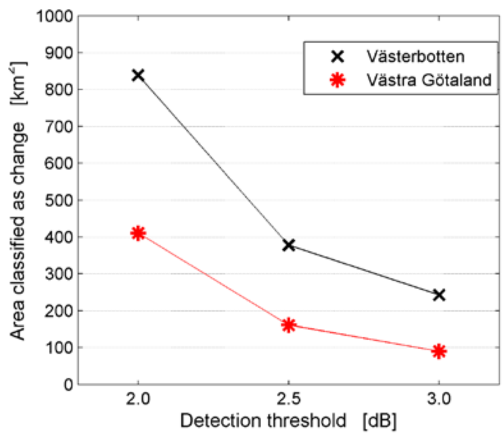



Figure 12. Total area classified as change, i.e. clear-felled areas (deforestation), for the three different detection thresholds used.

For the simple algorithm developed during the first phase of this K&C Initiative project, it seems that a classification based on a global threshold close to 2.5 dB is sufficient for obtaining a first-order, but nonetheless reasonable estimate of the total area subject to change during the acquisition period of the ALOS PALSAR data used in this study. Assuming that an extrapolation from the values reported above (which are valid for a period of 12 months) over the 15 months for which ALOS PALSAR data were available can be considered as a good approximation of clear-felled areas that deforestation occurred during this time frame, we obtain 360 $km^2$ and 200 $km^2$ in Västerbotten and Västra Götaland, respectively. Considering the result based on a threshold value of 2.5 dB, the total area of detected changes from the ALOS PALSAR HV-backscatter data is 378 $km^2$ and 161 $km^2$ respectively, which corresponds to a +5% difference for the Västerbotten county and a -20% difference in the Västra Götaland county.

Future studies should investigate whether the smaller size of the clear-cuts in the Västra Götaland county can explain the larger discrepancy and whether the method for change detection needs to be improved following the indications mentioned so far (e.g. inclusion of the HH-backscatter in the change detection algorithm, adaptation of the threshold to the local conditions).

In summary, it was found that K&C ALOS PALSAR HV-backscatter strip data acquired during unfrozen environmental conditions was a stable data source for change detection of clear-cuts. It was also shown that large area change detection of clear-cuts could be performed using these data. For the prototype area of Västerbotten in northern Sweden, up to about 50% of the pixels were correctly classified as changed for about 90% of the clear-felled areas using a simple thresholding algorithm with a threshold value of about 2 dB. The results were only partly satisfying for the prototype area of Västra Götaland in the southern Sweden. Here, up to about 40% of the pixels could be correctly identified as changed for about 65% of the clear-felled areas. This might be due to the limited reference dataset of clear-felled polygons, smaller stand size and maybe also the wetter soil conditions and the more abundant ground vegetation in these areas. In the extension phase of the K&C Initiative project, an up scaling of the mapping of clear-cuts, and possibly also biomass, to all of Sweden is planned. This phase will also involve further algorithm development. The possibility to timely find changed areas is of great interest for providing a sampling frame for *in situ* verifications of land cover changes.

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