ON CLEAR-CUT MAPPING WITH TIME-SERIES OF SENTINEL-1 DATA IN BOREAL FOREST – EXTENDED ABSTRACT

Yrjö Rauste, Oleg Antropov, Teemu Mutanen, and Tuomas Hämé
VTT, P.O. Box 1000, 02044 VTT, Finland; yrjo.rauste@vtt.fi

ABSTRACT

Clear-cutting is the most drastic and wide-spread change that affects the hydrological and carbon-balance properties of forested land in the Boreal forest zone.

A time-series of 27 Sentinel-1 images was used to study the potential for mapping clear-cut areas. The time-series covered a full year (2014-10-04 ... 2015-09-29) in a 200-km-by-200-km study site in Finland. The Sentinel-1 images were acquired in Interferometric Wide-swath (IW), dual-polarized mode (VV+VH). All scenes were acquired in the same orbit configuration. Amplitude images (GRDH product) were used. The Sentinel-1 scenes were ortho-rectified with in-house software using a digital elevation model (DEM) produced by the Land Survey of Finland. The Sentinel-1 amplitude data were radiometrically corrected for topographic effects.

The temporal behaviour of C-band backscatter was studied for areas representing 1) areas clear-cut during the acquisition of the Sentinel-1 time-series, 2) areas remaining forest during the acquisition of the Sentinel-1 time-series, and 3) areas that had been clear-cut before the acquisition of the Sentinel-1 time-series.

The following observations were made:

1. The separation between clear-cut areas and forest was generally low;
2. Under certain acquisition conditions, clear-cut areas were well separable from forest;
3. The good scenes were acquired: 1) in winter during snow cover and temperature above zero degrees Celsius, and 2) in late summer towards the end of a warm and dry period;
4. The separation between clear-cut and forest was higher in the winter/snow/above-zero scenes than in the dry summer scenes.

Key words: radar; forestry; logging; Sentinel-1.

1. INTRODUCTION

Clear-cutting is the most drastic and wide-spread change that affects the hydrological and carbon-balance properties of forested land in the Boreal forest zone. Even though forest logging operations are usually well known in advance by forest authorities, independent means for mapping logging operations are continuously sought after. Although the forest owners have to report the planned logging operations to forest authorities, there is no certainty about the time and exact borders of the cutting or even whether the planned logging has been done at all. Therefore, independent means for mapping logging operations are continuously sought after.

Space-borne SAR sensors with their all-weather capabilities can produce a frequent, regular time-series of observations in cloud-plagued Boreal forest areas.

Space-borne L-band SAR data has been studied widely for mapping clear-cut areas in Boreal forest (see e.g. [1],[2],[3]). Even though L-band [4] and C-band [5] SAR data have been used for mapping selective logging in the tropics, C-band satellite SAR data has not been studied extensively until lately.

Sentinel-1 with its high-frequency data acquisition strategy is the newest addition to SAR tools for mapping forest changes. A year-long time-series of Sentinel-1 was studied for mapping clear-cut areas in a test site in southern Finnish Boreal forest.

2. MATERIALS AND METHODS

2.1. Study Site

The study site Hyytiälä of project NorthState was chosen. This site covers a 200 km by 200 km area in southern Finland, centered around the Hyytiälä research station (61.8° north, 24.3° east) of University of Helsinki. The study site includes forest, agricultural land, lakes, and population centres (Tampere, Jyväskylä, Lahti). The forests are dominated by Norway spruce (Picea abies Karst.), Scots pine (Pinus sylvestris), and birch (Betula pendula and Betula pubescens). The soils are mainly glacial drift, but sandy soils are also common as well as clay, especially in agricultural areas. Marshes and open
bogs are also common.

2.2. Sentinel-1 data

The Sentinel-1 time-series included 27 images acquired between 2014-10-04 and 2015-09-27 (table 1). Dates in this paper are given in the YYYY-MM-DD format, where YYYY = year, MM = month, and DD = day. The choice of this numeric format over more conventional text-based formats was made for reasons of simplicity. The meteorological data in table 1 are for the airport of Halli (EFHA), which is located in the site. The meteorological data were obtained from the Weather Underground service. Temperatures are in Celsius degrees. The column “0-Crossing” in table 1 indicates whether the temperature crossed 0 degrees Celsius during the acquisition day before the acquisition time of 15:55. All 27 ascending-orbit images were acquired at approximately 15:55 UTC. If the symbol in column “0-Crossing” in table 1 is in parenthesis, the temperature just reached zero without crossing it. The column “Last Rain” gives the time of the latest precipitation observation during the acquisition day before the acquisition time. Minus sign in column “Last Rain” means that there was no precipitation on the acquisition day before the acquisition time.

### Table 1. SAR and meteorological data of the study site.

<table>
<thead>
<tr>
<th>No</th>
<th>Date</th>
<th>Temp.</th>
<th>0-crossing</th>
<th>Last Rain</th>
<th>Wind (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2014-10-04</td>
<td>10</td>
<td>-</td>
<td>06:00</td>
<td>7.2</td>
</tr>
<tr>
<td>2</td>
<td>2014-11-09</td>
<td>4</td>
<td>+</td>
<td>08:20</td>
<td>10.8</td>
</tr>
<tr>
<td>3</td>
<td>2014-11-21</td>
<td>-3</td>
<td>-</td>
<td>12:00</td>
<td>7.2</td>
</tr>
<tr>
<td>4</td>
<td>2014-12-03</td>
<td>2</td>
<td>(-)</td>
<td>03:00</td>
<td>18.0</td>
</tr>
<tr>
<td>5</td>
<td>2014-12-15</td>
<td>1</td>
<td>+</td>
<td>16:00</td>
<td>18.0</td>
</tr>
<tr>
<td>6</td>
<td>2014-12-27</td>
<td>-7</td>
<td>-</td>
<td>08:50</td>
<td>9.3</td>
</tr>
<tr>
<td>7</td>
<td>2015-01-08</td>
<td>-4</td>
<td>(+)</td>
<td>16:00</td>
<td>10.8</td>
</tr>
<tr>
<td>8</td>
<td>2015-02-13</td>
<td>-4</td>
<td>-</td>
<td>16:00</td>
<td>10.8</td>
</tr>
<tr>
<td>9</td>
<td>2015-02-25</td>
<td>2</td>
<td>+</td>
<td>02:20</td>
<td>10.8</td>
</tr>
<tr>
<td>10</td>
<td>2015-03-09</td>
<td>6</td>
<td>-</td>
<td>01:00</td>
<td>36.0</td>
</tr>
<tr>
<td>11</td>
<td>2015-03-21</td>
<td>-2</td>
<td>-</td>
<td>-</td>
<td>25.9</td>
</tr>
<tr>
<td>12</td>
<td>2015-04-02</td>
<td>2</td>
<td>(-)</td>
<td>09:21</td>
<td>14.4</td>
</tr>
<tr>
<td>13</td>
<td>2015-04-14</td>
<td>3</td>
<td>(+)</td>
<td>16:00</td>
<td>14.4</td>
</tr>
<tr>
<td>14</td>
<td>2015-04-26</td>
<td>4</td>
<td>-</td>
<td>16:00</td>
<td>14.4</td>
</tr>
<tr>
<td>15</td>
<td>2015-05-08</td>
<td>13</td>
<td>-</td>
<td>15:00</td>
<td>18.0</td>
</tr>
<tr>
<td>16</td>
<td>2015-05-20</td>
<td>15</td>
<td>-</td>
<td>08:00</td>
<td>14.4</td>
</tr>
<tr>
<td>17</td>
<td>2015-06-01</td>
<td>15</td>
<td>-</td>
<td>16:00</td>
<td>37.0</td>
</tr>
<tr>
<td>18</td>
<td>2015-06-13</td>
<td>22</td>
<td>-</td>
<td>-</td>
<td>21.6</td>
</tr>
<tr>
<td>19</td>
<td>2015-06-25</td>
<td>14</td>
<td>-</td>
<td>16:00</td>
<td>46.3</td>
</tr>
<tr>
<td>20</td>
<td>2015-07-07</td>
<td>13</td>
<td>-</td>
<td>16:00</td>
<td>7.2</td>
</tr>
<tr>
<td>21</td>
<td>2015-07-19</td>
<td>14</td>
<td>-</td>
<td>16:00</td>
<td>21.6</td>
</tr>
<tr>
<td>22</td>
<td>2015-07-31</td>
<td>16</td>
<td>-</td>
<td>-</td>
<td>14.4</td>
</tr>
<tr>
<td>23</td>
<td>2015-08-12</td>
<td>20</td>
<td>-</td>
<td>-</td>
<td>10.8</td>
</tr>
<tr>
<td>24</td>
<td>2015-08-24</td>
<td>24</td>
<td>-</td>
<td>-</td>
<td>7.2</td>
</tr>
<tr>
<td>25</td>
<td>2015-09-05</td>
<td>14</td>
<td>-</td>
<td>14:20</td>
<td>7.2</td>
</tr>
<tr>
<td>26</td>
<td>2015-09-17</td>
<td>15</td>
<td>-</td>
<td>11:20</td>
<td>10.8</td>
</tr>
<tr>
<td>27</td>
<td>2015-09-29</td>
<td>12</td>
<td>-</td>
<td>-</td>
<td>7.2</td>
</tr>
</tbody>
</table>

The Sentinel-1 images were acquired in Interferometric Wide-swath (IW), dual-polarized mode (VV+VH). All scenes were acquired in the same orbit configuration. Amplitude images (GRDH product) were used. The Sentinel-1 scenes were ortho-rectified with in-house software using a digital elevation model (DEM) produced by the Land Survey of Finland. A pre-averaging of 2 lines by 2 columns was applied before the ortho-rectification. Bi-linear interpolation (in power domain) was applied as the resampling method. The pixel spacing of the ortho-rectified Sentinel-1 data was 20 m. The Sentinel-1 amplitude data were radiometrically corrected for topographic effects, by normalizing with the projected pixel area. The resulting amplitude data are proportional to backscattering coefficient $\gamma$.

2.3. Reference Data on Clear-Cut Areas

Clear-cut areas were mapped with visual interpretation of two Landsat-8 images, acquired on 2014-07-23 and 2015-08-20. Both images were almost cloud free. A natural colour composite was made of each Landsat-8 image and imported to a GIS system (QGIS). Clear-cut areas of more than 1.5 hectare were delineated, and stored as polygons in a shape file. In addition to recent clear-cut areas, areas were delineated for reference:

- three stands of older clear-cuts (before 2014-07-23),
- two stands of stable forest, and
- two agricultural areas.

The shape file of clear-cut areas was converted to a raster file and eroded by one pixel (20 m). An average of Sentinel-1 data was computed for each patch in power domain.

3. RESULTS AND DISCUSSION

3.1. Backscatter profiles

The C-band backscatter profile for five representative clear-cut areas are shown in figures 1 and 2 for VV and VH, respectively. Similar diagrams were generated also for all clear-cut areas over 8 ha (12 such areas), but the diagrams of the selected 5 stands are shown here for clarity. The curve marked “Agr” is the average of two large agricultural fields. The curve “Old” is the average of three clear-cut areas logged before the first Landsat-8 scene (2014-07-23). The curve marked “ForAvg” is the average backscatter amplitude computed (in power domain) over all forest pixels in the earlier land cover map.

In most of the images before February 2015, there is no clear separation between forest and open areas. In the images of 2015-02-25 and 2015-03-09 (both acquired in temperatures above zero with some precipitation during the day but no precipitation during image acquisition, snow on the ground), there is a strong contrast between open areas and forests. For instance, in the 2015-02-25 image the contrast between the old clear-cut and average forest is 3.9 dB in VV and 4.4 dB in VH. In the images
Figure 1. VV backscatter profiles for 5 new clear cut areas (S34...S72), old clear-cut areas (Old), agriculture (Agr), and forest (ForAvg).

Figure 2. VH backscatter profiles for 5 new clear cut areas, old clear-cut areas, agriculture, and forest.
of 2015-02-25 and 2015-03-09, some of the new clear-cut areas belong to the forest group or the group of open areas. These selected clear-cut sites are further elaborated in section 3.2.

One possible explanation for the high contrast between open and forested areas in the Sentinel-1 images of 2015-02-25 and 2015-03-09 can be seen in figure 3 (from [6]).

After these two good images, there is again a period with no clear separation between open and forested areas. In the summer months (June, July, and August), there are four images with no rain during the acquisition day (2015-06-13, 2015-07-31, 2015-08-12, and 2015-08-24). In these images, there is again some separation between forested areas and clear-cut areas. Agricultural areas also tend to have lower backscatter level than forested areas, but some fields also have a high backscatter in some scenes, most likely due to ploughing or other agricultural treatments. In VV band, the contrast between open and forested areas is smaller in these dry summer images than in the good winter images. In VH band, the contrast is about the same in both cases.

3.2. Sentinel-1 Images around Selected Clear-Cut Sites

Sites 34, 36, and 37 are shown in 4. The site numbering follows the order of the delineation of the clear-cut sites. The VV band of Sentinel-1 is shown in red and blue and the VH band in green. The colour rendition of Sentinel-1 images in figures 4 and 5 were set per image. The clipping limits (a.k.a. black point and white point) were computed as the 2-percent point and the 98-percent point over areas that were classified as forest in an earlier land cover classification. In this land cover classification, mean and temporal variability of the first 12 scenes of table 1 were used.

The site 34 (on the left in figure 4) was most likely impacted in February and March 2015 because it appears as a bright reddish area - like many forested areas - in both of these images. The sites 36 and 37 (on the right in figure 4) on the other hand appear as dark areas in the Sentinel-1 images of 2015-02-25 and 2015-03-09. Therefore, we can assume that these sites were likely logged between 2014-07-23 (the first Landsat-8 image used in delineating the reference data) and 2015-02-25.

Sites 72 and 41 are shown in 5. Site 41 (upper right in figure 5) was already logged on 2015-02-25. The delineation of site 72 (lower left corner of figure 5) was not perfect. The Landsat-8 image of 2015-08-20 reveals some remaining forest patches inside the site. This site probably consists of two stands. The northern stand was logged before 2015-02-25 and the southern after 2015-03-09.

3.3. Algorithm for Reliable Clear-Cut Mapping with Sentinel-1 Time-Series Data

Based on the observations from the backscatter profile data of Sentinel-1, a reliable clear-cut mapping algorithm can be outlined:

1. collect all Sentinel-1 scenes acquired in the chosen orbit configuration in dual-polarized interferometric Wide-swath mode,
2. for each winter scene, compute the contrast between agricultural and forested areas,
3. if the contrast in a winter scene is higher than a predefined threshold add the new scene to the feature set of further analysis,
4. select the best summer scene based on meteorological data: the scene with the longest period without rain before the image acquisition,
5. make a clustering of the selected images and label the clusters based on reference data from the ground or from interpretation of cloud-free optical images acquired in summer time.

In step 2, the contrast between clear-cut areas and forest could be used. As identification of agricultural areas is easier than identification of clear-cut areas, agricultural areas were chosen to make the algorithm more adaptable to new areas in the Boreal forest zone. The selection of summer scenes might also be possible with some indicators of contrast or dynamic range. As agricultural treatments like ploughing can vary the backscatter of agricultural areas a lot, the agriculture-forest contrast is not suitable for this task.

4. CONCLUSIONS AND OUTLOOK

It may be that clear-cut mapping requires images from two winters. Even in this case, the proposed clear-cut mapping enhances the potential of EO data in clear-cut mapping because Sentinel-1 data can be used for mapping clear-cut areas form one winter to another while optical data are used to map clear-cut areas from a summer
to another summer. Combining these two clear-cut mapping results achieves twice as high mapping frequency as with one data source alone.

In some winters, the good conditions for clear-cut mapping may remain missing if the image acquisition days do not coincide with the days with the required meteorological and snow conditions. This risk can be mitigated by using more than one stack over the monitoring area, for instance one stack of ascending-orbit images and another of descending-orbit images. The analysis of these stacks should be kept separate to avoid artefacts arising from comparison of pixels acquired with different geometries.

The algorithm outlined in section 3.3 has the drawback that it can detect clear-cut cases only between good scenes. In the case of the backscatter profiles of figures 1 and 2, the first clear-cut detection would be between the February-March 2015 and August 2015. An alternative approach could make a forest cover map e.g. using temporal mean and variation data as was done for the earlier land cover map, but excluding the good winter images. Then in areas classified as forest, the good winter images could be used to detect clear-cut areas: all areas where the backscatter amplitude is lower than the forest average minus a detection threshold.

A more thorough testing of the proposed clear-cut detection algorithm is planned for February-March 2016, when new good Sentinel-1 images are available.

ACKNOWLEDGEMENTS

This work was carried out in EU/FP-7 project NorthState (grant 606962).

REFERENCES

Figure 5. Clear-cut sites 72 (lower left) and 41 (upper right) in Sentinel-1 and Landsat (2015) data. Colours in Sentinel-1: R = VV, G = VH, B = VV. Colours in Landsat-8: R = band 4, G = band 3, B = band 2.


