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FACULTY OF GEOGRAPHY AND EARTH SCIENCES

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FOREST MANAGMENT CONTROL POTENTIAL USING SENTINEL-1

BACHELOR THESIS REVIEW

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ANNOTATION

Research shows Sentinel-1 data potential for tree cutting detection. Despite that Sentinel-1 information is open source and provide six-day temporal resolution over Latvia data usage for forestry purpose in Latvia haven't been widely discussed. Data availability and quality is independent from weather and sensing time what could be considered as advantage for forest monitoring development. This study is based on 16 Sentinel-1 GRD images over time period from 30th December 2017 to 29th March 2018. Radar backscattering data was analysed using weather information to better understand signal dynamics before and after tree cutting operations in 18 clear-cut compartments and 18 reference polygons.

Results indicate that radar information is dependant from air temperature caused object dielectric property change, object shape and surface roughness. Radar image mean VH polarisation backscattering value and air temperature correlated with coefficient of 0,811, but VV polarisation is not appropriate for forest monitoring in Latvia. To increase cutting control accuracy radar information should be obtained in similar conditions to avoid situations when weather caused signal changes depress felling produced radar differences. Results are validated with forest compartment data from State Forest Service.

Study results revealed that tree cutting control accuracy for 18 felling polygons were 77,8 % but total monitoring accuracy for 36 compartments - 83,3%. Sentinel-1 data can be considered as a suitable information source for clear-cut detection or other forest monitoring issues in Latvia.

Key words: SAR, forestry, C band backscatter, Sentinel-1 clear-cut detection

INTRODUCTION

Sustainable and efficient resource management is important aspect to build a successful economy. Nowadays huge role in resource management plays new technology implementation and innovative approaches. One of them could be considered remote sensing and it's provided solutions that are often used in process optimization. Remote sensing has been developed very intensively and it is more approachable with improved spatial and temporal resolution. That allows to use that kind of information in sectors where it hasn't been used before. In this paper I focused on remote sensing technology usage for forest process monitoring. Forestry historically has been very important sector for Latvia's economy. That is why many companies are looking for solutions that could optimize their operations and make them more effective. Remote sensing has been used in forestry for decades but nevertheless there are data types and processing methods that haven't been widely used in forestry sector at least in Latvia's conditions. In this research author used European Space Agency's (ESA) Copernicus program's satellite Sentinel-1. Data is open-source and almost completely independent from weather and day-night conditions that can be considered as asset that give new possibilities for academic and applied field.

In this research synthetic aperture radar (SAR) Sentinel-1 backscatter intensity information will be used for clear-cut detection. Result are validated with actual forest compartment information from State Forest Service database.

Target: Determine Sentinel-1 data potential for clear-cut detection.

Objectives:

1. Chose the study area.
2. Create database with SAR data that overlays study site and consist of compartment's qualitative and quantitative parameters.
3. Accomplish data processing and calculate compartment's average backscatter changes during the control period.
4. Determine Sentinel-1 clear-cut detection and asses accuracy with reference data.
5. Conclude about data usage possibilities and make summary about factors that influence tree cutting detection.

MATERIALS AND METHODS

Study site selection was based on two criteria – large forested areas and Sentinel-1 data availability with temporal resolution of six days. Forest compartment search for clear-cut detection was made within 100x100 km expanded study site (15,5 % of Latvia area). There were selected 18 compartments that were cut during control period – from 30th December 2017. to 29th March. Taking into account logging polygon location actual study site was stated. In actual study site respectively to clear-cut comportment's area and forest type 18 reference compartments were selected. Reference polygons were intact during monitoring period and should give consistently higher radar backscattering values.

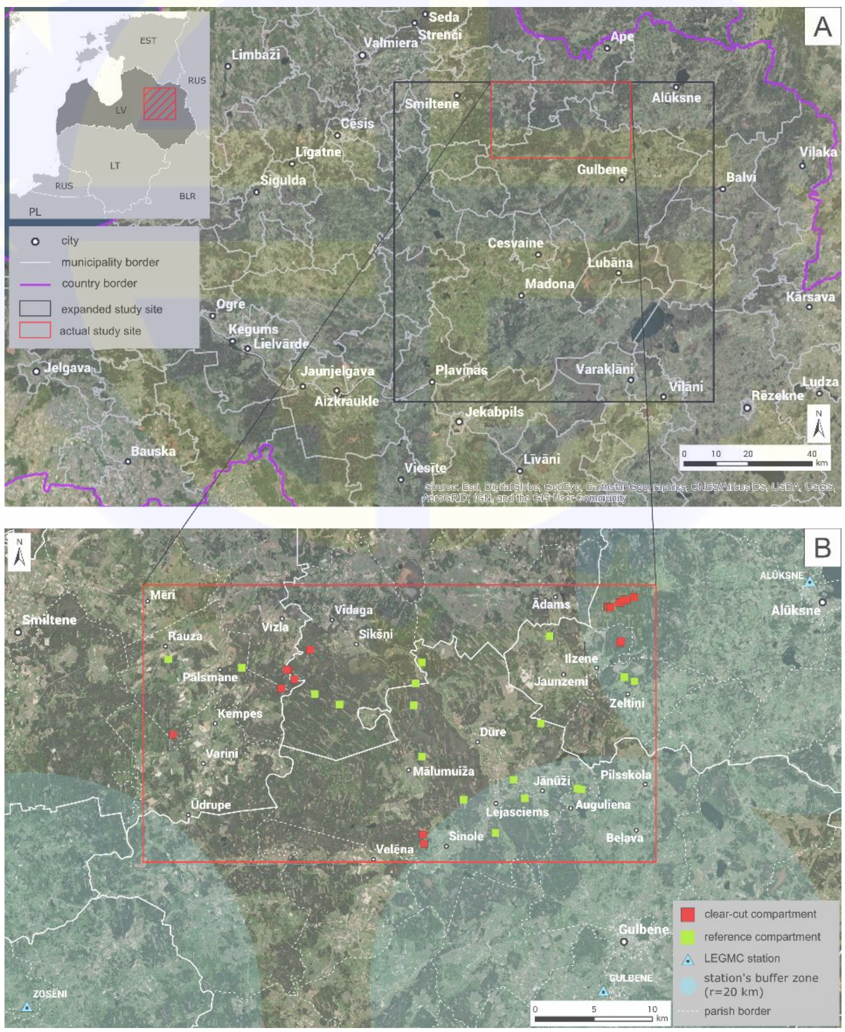

Fig. 1 (A) Expanded study site – area where forest clear-cut compartments were found in State Forest Service database. (B) Actual study site – area where clear-cut monitoring was accomplished.

LEGMC data

Radar signal backscattering type and properties are influenced by many factors. Weather doesn't make straight forward effect on Sentinel-1 signal, but weather change object physical properties that influence image radiometric values. Weather influence is important factor to make relevant image interpretation because that change dielectric properties of sensed objects. Weather information was provided by Latvian Environment, Geology and Meteorology Centre (LEGMC). Data acquired from tree closest meteorological stations – "Zosēni", "Gulbene", "Alūksne" – to make more objective information. Every satellite has information about precise image sensing time. Sentinel-1 images were taken from two orbits 80. and 160. and captured at 6:34 AM and 5:55 PM respectively. Temperature (°C) information was used as average from 6 and 7 AM and 5 PM. Precipitation (mm) information is calculated as sum of previous 24 h every hour precipitation.

State Forest Service data

Result accuracy and analyse was made with reference data from controlling institution. State Forest Service provided data from expanded study site with comportment's – location, geometry, area, compartment ID, forest land category type, forest type, forest thickness, forest stock, forest tree formula, recent forest operation type, recent forest operation time.

Clear-cut compartments for this study were selected if recent forest operation time year of 2018 and recent forest operation type – cutting using clear-cut method. Clear-cut is considered if within a year compartment's basal area has been reduced under critical basal are limit. In received data there is possibility to recognise which compartments have been cut until 3th April (day when State Forest Service prepared and updated data) because after clear-cut forest land category has been changed from "forest" to "clear-cut" and information about forest stock has been deleted.

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Sentinel-1 data

Research involved 16 Sentinel-1 images from from 30th December 2017. to 29th March with temporal resolution 5-7 days with a pixel size of 10x10 m. Control period was determined in winter months when air temperature is expected to be below zero and soil would be frozen. Frozen conditions allow better determine land cover and clear-cutting caused signal dynamics and give higher clear-cut detection accuracy (Dostálová et al. 2016). All satellite images are *Interferometric wide-swath* (IW) first level *Ground Range Detected* (GRD) pre-processing level data products. Each image contains VV and VH polarisation backscatter intensity. Before Sentinel-1 GRD data products have been uploaded in ESA data server it has been processed to fulfil first level processing requirements. For further Sentinel-1 data analysis have to make additional processing which is dependant from study objectives and data type. Data processing has to follow logical sequence. Sentinel-1 data was processed in SNAP software where processing can be automated with built-in function.

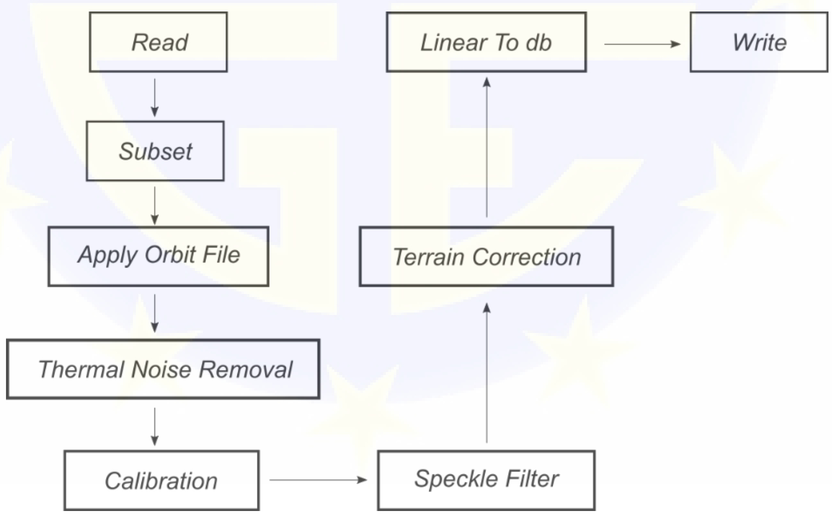

Fig. 2 Sentinel-1 data processing steps.

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Sentinel-1 backscatter information from forest compartment

Before backscatter information obtaining have to prepare study compartment shapefiles. Shapefiles with reference and clear-cut polygons and additionally layers with polygon boarders. Sentinel-1 data acquisition was made in SNAP software where all prepared compartment shapefiles were used to export backscatter pixel values from all Sentinel-1 images. All pixel values were stored in database. Exported information contain pixel's coordinates, both polarisation values. Two additional fields were added to database – *AINA (IMAGE)* and *KLASE* (*CLASS*). These fields record pixel's belonging to radar image (time) and compartment's type (reference or clear-cut). Furthermore compartment boarder shapefiles were used to obtain radar pixel data that represents only polygon borders. This process was repeated for all images that were used in monitoring period and imported in backscattering database. Database was saved as .csv file and imported in RStudio software. Database were updated with field – *LOCATION* where each pixel's X and Y coordinates were merged. All database rows with duplicate *LOCATION* values were deleted because that could represent potentially misleading radar values. Border values may give confusing data from neighbouring compartments that make influence on compartment's average backscatter calculations. Database was divided by field IMAGE. After that raster files were generated and each compartment's average backscatter value was calculated in all radar images during clear-cut monitoring period.

Table 1 Sentinel-1 backscattering information database

	Pixel.X	Pixel.Y	Longitude	Latitude	Sigma0_VH_db	Sigma0_VV_db	KLASE	AINA	LOCATION
30064	3844.5	2612.5	26.46522	57.35583	-24.33808	-13.50137	2	8	26.4652169423 57.3558291807
30049	3844.5	2610.5	26.46523	57.35601	-24.22261	-13.60753	2	8	26.4652289817 57.3560086738
30057	3844.5	2611.5	26.46522	57.35592	-24.07958	-13.46537	2	8	26.465222962 57.3559189273
29034	5623.5	2060.5	26.76429	57.39922	-23.79538	-13.97624	1	8	26.7642881628 57.3992231496
30065	3845.5	2612.5	26.46538	57.35583	-23.59738	-13.34789	2	8	26.4653829927 57.3558259271
30050	3845.5	2610.5	26.46540	57.35601	-23.54882	-13.46522	2	8	26.4653950329 57.3560054202
30058	3845.5	2611.5	26.46539	57.35592	-23.44337	-13.26125	2	8	26.4653890127 57.3559156737
30040	3844.5	2609.5	26.46524	57.35610	-23.35824	-13.62811	2	8	26.4652350014 57.3560984204
27785	2958.5	2145.5	26.32073	57.40054	-23.19042	-12.20691	1	8	26.3207300729 57.4005417993
10509	3844.5	2610.5	26.46528	57.35614	-23.18729	-13.72289	2	3	26.4652806698 57.3561439847

RESULTS AND DISCUSSION

Weather influence on radar backscatter signal

Backscatter information is dependant from multiple factors and one of them is weather. Precipitation and temperature changes influence study object and surface moisture level. Dry and frozen conditions reduce moisture level and change dielectric properties. Before further radar signal analysis have to study weather information during the control period. Within this research period temperature amplitude was notable and radar image mean value changed by 5,7 db.

Similar sensing conditions give better chance to set up higher clear-cut detection accuracy and most of signal dynamics would be related to forestry operations not weather effect. Radar images that were acquired when temperature was above 0°C, don't make significant signal dynamics reducing forest condition detection effectiveness. Temperature difference between first and last image is 1,1°C and signal changes for VH and VV polarisation were 1,9 and 0,9 db respectively. Temperature increment correlate with Sentinel-1 backscatter values in both polarisations (Fig. 3). In winter months temperature increase often comes with precipitation increase.

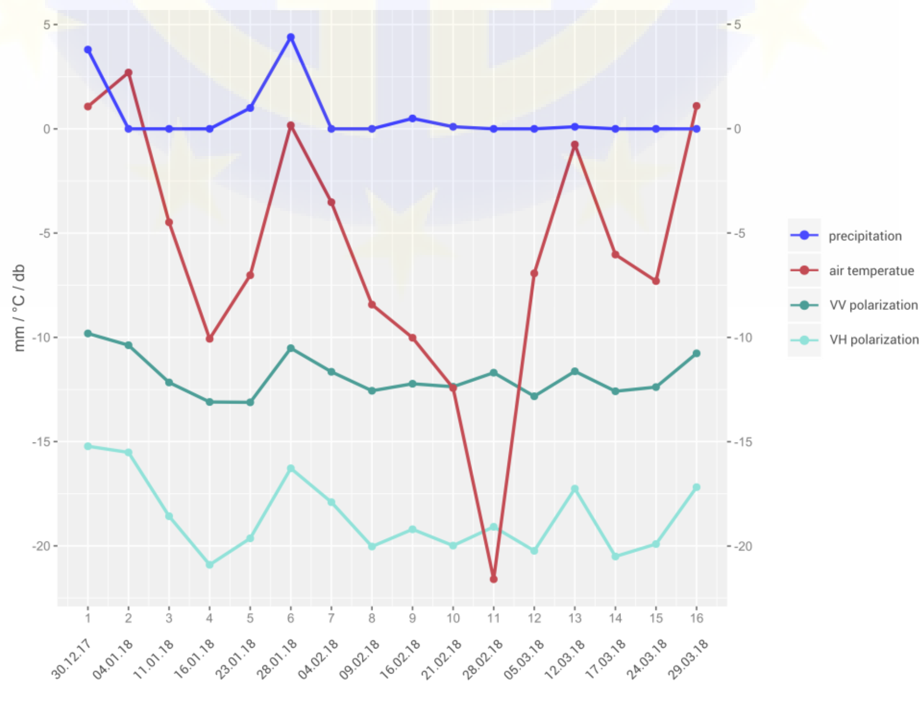

Fig. 3 Sentinel-1 data and weather dynamics in control period.

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This relatively short control period doesn't allow to make relevant assumptions about radar backscatter and precipitation correlation. Connection between temperature and radar signal is notable because study object properties changes and microwave scattering mechanism is dependant from temperature. Correlation coefficients increase if data from 28th February is removed from dataset.

VH coefficient increase to 0,811 but VV to 0,768. Data from February 28th prove that radar signal is not directly dependant from air temperature, but it's caused ground and vegetation freeze (Fig. 4).

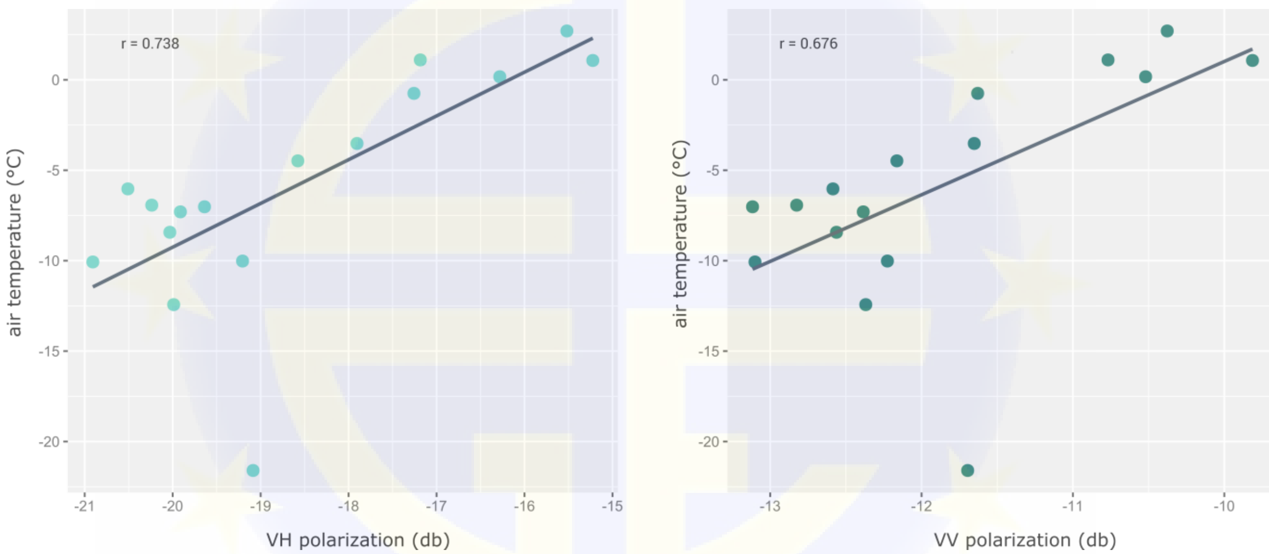

Fig. 4 Sentinel-1 backscattering and air temperature correlation.

Pixel obtaining methodology

Radar image pixels were obtained with two shapefiles – compartment's boarder line and full compartment polygon. Then using their coordinates border-eroded rasters were generated. Author assumed that border pixel values may contain information that would make biased calculations (Fig. 5). Relevance of this methodology is dependant from data spatial resolution and compartment size and shape. In this research pixel size was 10x10 m and average forest compartment size was 1,3 ha. Methodology was tested using 29th March radar backscatter raster that was processed with and without border values. This image was selected because until this date all forest clear-cuts have

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to be logged and the difference between clear-cut polygon and neighbouring forest compartment should be the most significant.

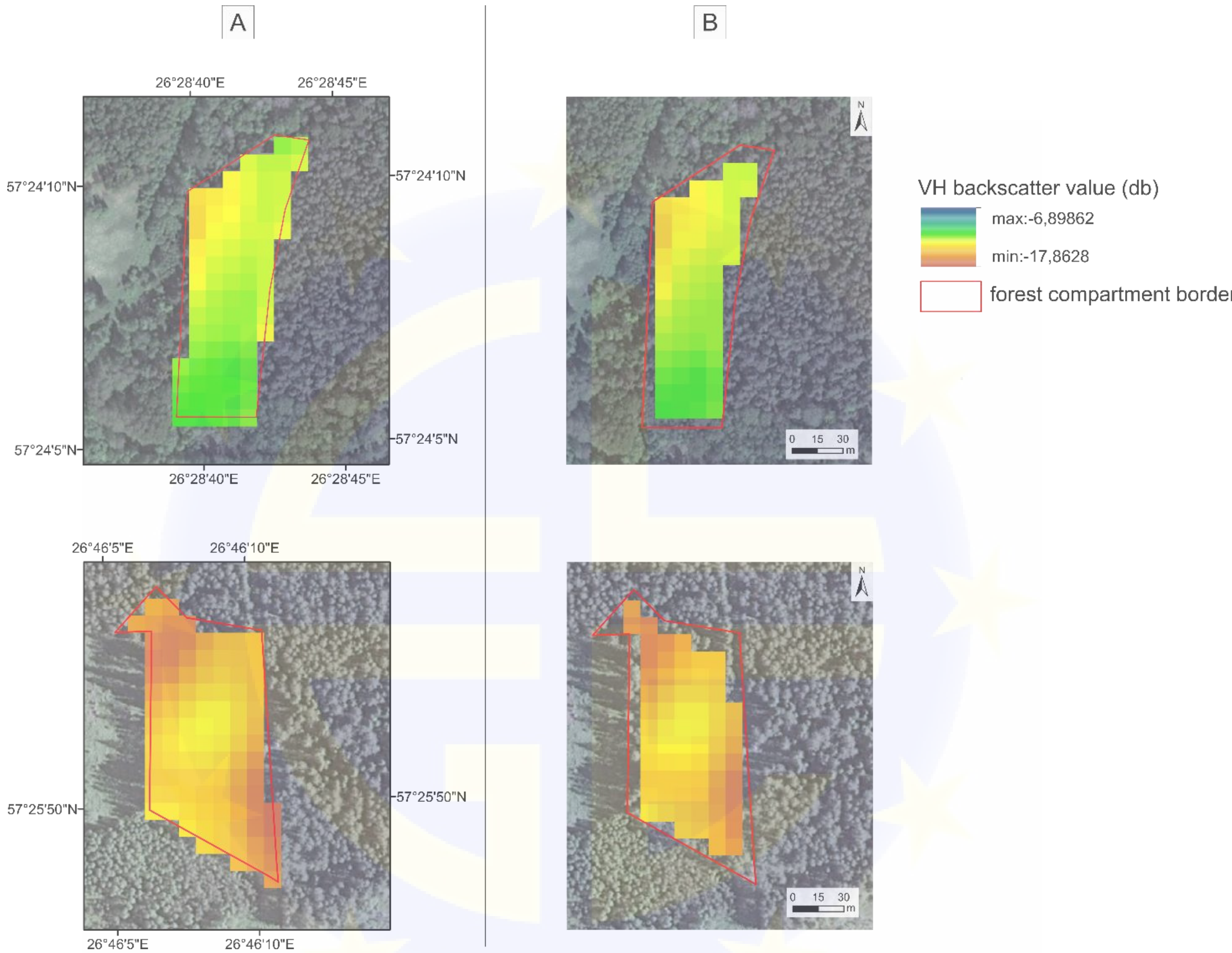

Fig. 5 (A) Sentinel-1 backscattering raster with border pixel, (B) Sentinel-1 backscattering raster without border pixel.

There were no relations between forest stand size and mean backscattering value difference for border and non-border rasters. Boarder pixel made uncertain mean value changes because pixel manipulation caused value increase and decrease at the same time (Fig. 6).

In this study pixel eroded raster methodology does not make significant influence but author assumed that this approach is more appropriate, and it was used in further calculations.

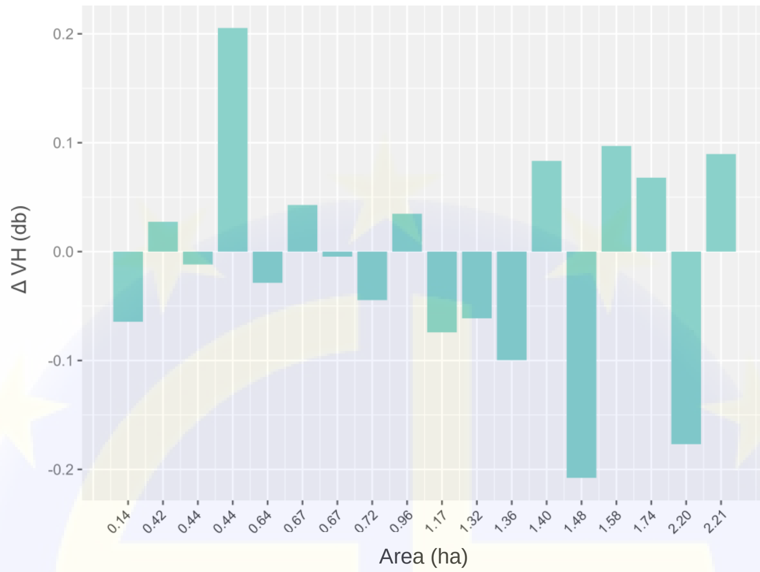

Fig. 6 Difference between eroded and uneroded rasters which were processed from 29th March mean clear-cut compartment backscatter values.

Research shows that polygons which are smaller than 0,2 ha are not suitable to delete border pixel because that reduce total number of pixels which make unstable and potentially misleading results. Small size and elongated shape compartments can consist of different number of pixels between radar images because despite sensor use precise orbit trajectory it's signal can slightly shift. That is enough to reduce pixel number and influence compartment's mean backscatter value calculations.

Radar signal changes before and after clear-cut

Sentinel-1 data backscattering give understanding about irradiated object shape and moisture properties which are reflected in radar image radiometric values. This information can be used for forest structure and forest area change detection. Radar data was acquired from 18 forest compartments where clear-cutting was made in period from 30th December 2017 to 29th March 2018 and 18 intact forest polygons. Data shows that Sentinel-1 backscatter values were changed during monitoring period and that was caused by forest felling (Fig. 7).

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Radar signal which was acquired from intact polygons maintain relatively high pixel values, but backscatter values from clear-cut compartments have decreased. Reference compartment data from control period start and end are more concentrated and point deviation interval is smaller than points from clear-cut areas. In the beginning of control period it is visible that reference polygon VH polarisation data has point density peak at ~ -14,8 db, but 29th March radar data peak has decreased by 2 db (Fig 7A).

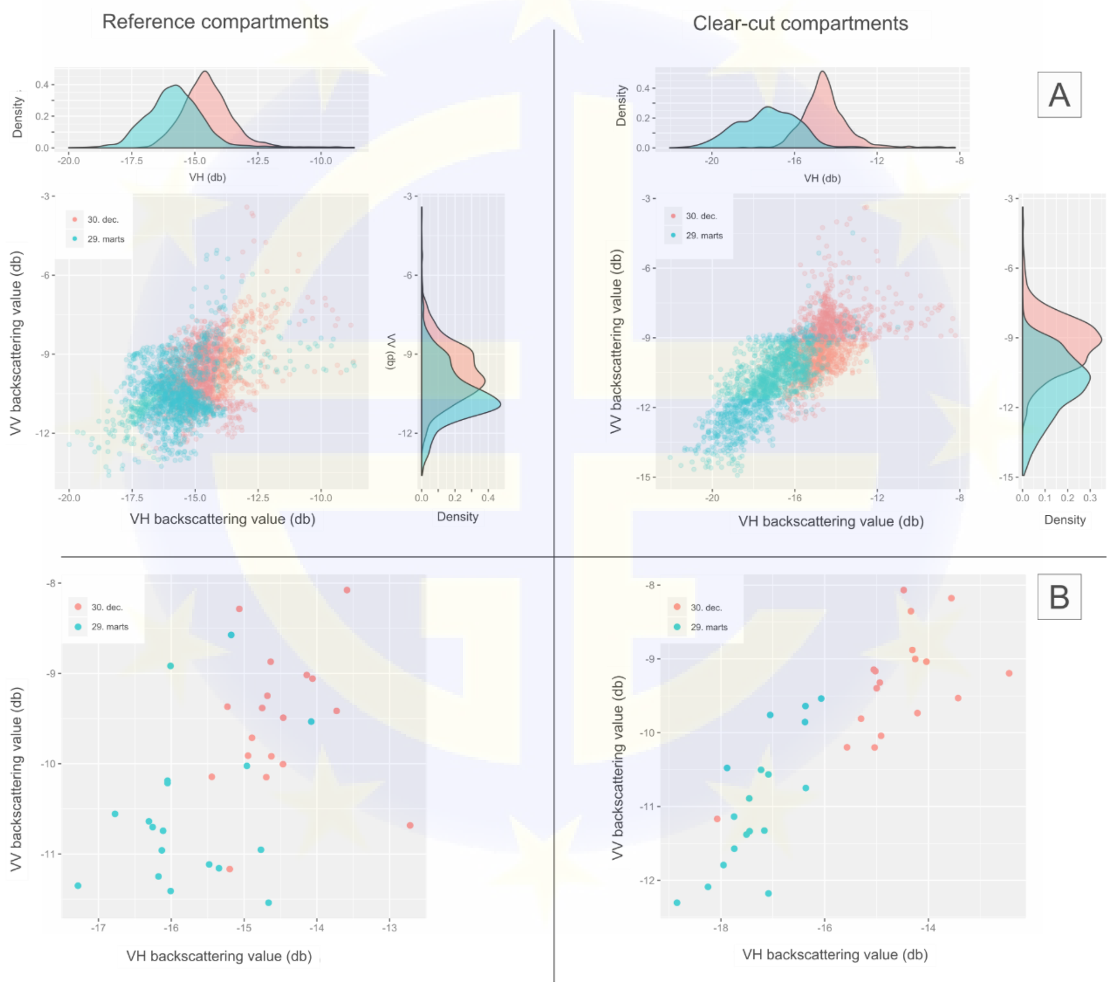

Fig. 7 (A) All Sentinel-1 backscattering pixel values. (B) Compartment mean Sentinel-1 backscattering values

That happened because factors that influence backscattering values were changed by the time and that is visible in mean radar scene backscattering value decrease as well (Fig. 7B). Data from clear-cut compartments in 30th December VH polarisation remind to normal distribution curve. VH data density peak for reference and clear-cut polygons in 30th December doesn't change for more

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than 1 db. That means information acquired from similar territories and mentioned differences could arise because most of clear-cut compartments concentrated in actual study site NE and NW part where backscattering values probably influenced by different snow depth or soil moisture conditions (Fig. 1B). Reference compartments are distributed more evenly throughout actual study site. There was no information about clear-cut compartment volume and thickness parameters that could help interpret radar signal. These parameters were deleted from State Forest Service database when clear-cut was registered.

Data distribution and scattering was changed when pixel information from clear-cut polygons was acquired in 29th March. This was monitoring end date and due to this day, all clear-cuts are completed. Radar signal values which was obtained from clear-cut sites has decreased but scattering interval was larger (Fig. 7).

Backscattering changes were visible in compartment's mean values, where intact and clear-cut compartments after forestry operations can be divided easily and that indicates about Sentinel-1 data potential in cutting event detection. One of 30th December clear-cut polygons is outlier because its radar value has low backscattering signal which would be relevant to deforested territory, but in 30th December it should be unharmed. This compartment's area is 0,14 ha and most likely mean backscattering value was impacted by object or sensor properties which does not make such influence in bigger polygons. It has been stated that Sentienl-1 data effectiveness for forestry operation control reduces significantly when polygons are smaller than 0,5 ha (Olesk et al. 2015).

Sentinel-1 VV polarization backscattering data similarly to VH polarization information and make correlation with air temperature, but it does not characterise stand structure and can't detect forest spatial changes which are very important components in this research. Data which was acquired after felling activity does not make significant changes compared to reference compartments. Signal can't respond to forest dynamics and therefore VV information was ignored in further research (Santoro et al. 2012).

After 36 forest compartment analysis it was cleared that clear-cut polygons after felling made 2,63 db mean backscattering value drop, but reference compartment average decrease was 1,19 db. In 77,8 % of cases clear-cut polygons had at least 2 db decline (Fig. 8).

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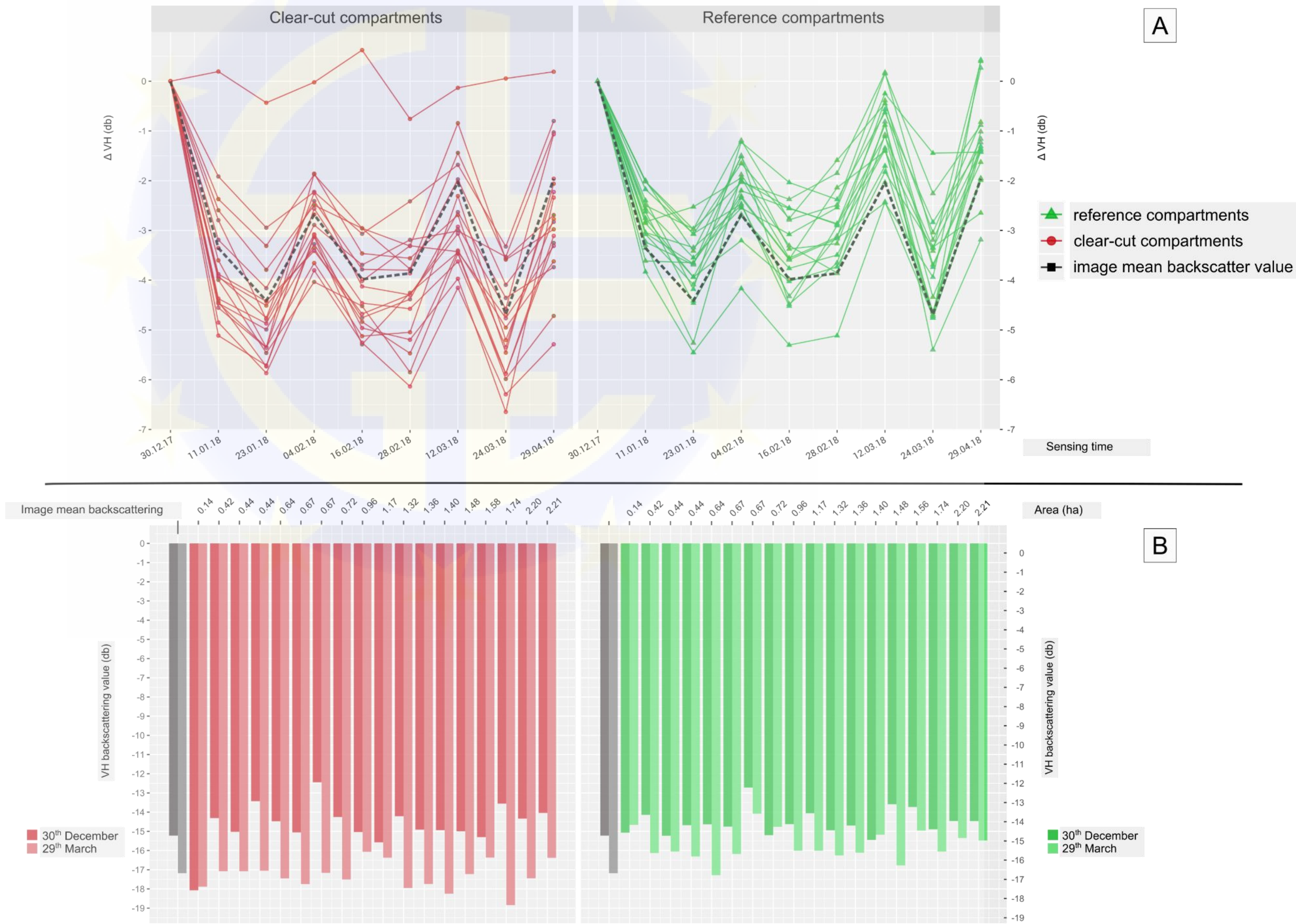

Fig. 8 (A) Compartment mean Sentinel-1 backscattering values relative difference within monitoring period. (B) Compartment mean Sentinel-1 backscattering value comparison between first and last date of control period.

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Clear-cut compartment mean value relative difference in the end of monitoring period 14 of 18 cases made bigger signal difference than image mean backscattering value, but reference compartment situation was opposite. Reference compartment data shows that 16 of 18 polygons 88,9 % of cases signal decrease in the end of control period was smaller than 2 db, but two compartments had bigger drop and signal changes were relevant to clear-cut polygons. Total clear-cut detection accuracy in this research – 83,3 %. Significant image mean backscattering value changes between sensing dates and lack of information about felling speed exclude sensible speculations about accurate compartment felling periods.

Accuracy assessment using image mean backscattering information is not very effective because radar mean backscattering value is dependant from captured territory land usage class ratio. More relevant assessment procedure would be if forest compartment mean radar data would be compared with mean backscattering value from actual study site not all image area. Four clear-cut compartments had backscattering value decline smaller than 1,2 db in these cases have to admit that it is impossible to detect clear-cutting activity. That can happen due to small size or oblong polygon shape. Compartment density and volume data could be essential to better analyse this situation because less dense compartments can be affected by meteorological conditions much easier. In sparse forests bigger radar backscattering portion comes from ground surface thereby making impact to mean compartment's value. Sparse forests make constant 2 – 3 db smaller backscattering values than dense stands because of different scattering mechanisms - dense forest backscattering information comes from surface scattering, but sparse ones have volume scattering (Santoro et al. 2012). These backscattering types can make misleading impressions about forest conditions and cutting operations (Santoro et.al. 2006).

It is possible that in some of research polygons felling operations were started before 30th December of 2017 despite cutting rights were given only in year of 2018. This situation is possible because information about cutting activities comes from controlling authority and not forest owner. Last radar image was acquired in 29th March, but State Forest Service prepared actual compartment information in 3rd April. That means there were 3-4 days when cutting could continue. In this case Sentinel-1 data would be acquired from clear-cut polygons where cutting is incomplete. Unfortunately, nor Landsat 8 nor Sentinel-2 sensors were not capable to take cloud free images which could be used to clarify compartments logging status in 1st January and 3rd April of 2018.

In this research it is impossible to consider how tree debris affect radar signal dynamics in clear-cut after felling operations. In cases when data acquired recently after cutting activity forest ground is still covered with rich residual layer. It is likely to get untypically small backscattering value. Branches can change surface moisture conditions, surface roughness, scattering mechanism.

Result analyse could be more extensive if State Forest Service database would consist of compartment forestry operation history. Maybe some of compartments had commercial or pre-commercial thinning in recent years. This information could be useful to better understand signal changes or properties after felling operation. Previous cuttings would make relatively uncharacteristic backscattering value at the start of monitoring period and would reduce clear-cut detection effectiveness.

Further research could be about clear-cut caused signal changes in relations to different dominant tree species – deciduous, coniferous. More reliable signal and air temperature correlation could get if study compartments would be closer to meteorological stations.

Sentinel GRD images could be stacked together in certain time period. This would reduce temporal resolution, but perhaps mean compartment's backscattering value would be more stable and reliable for further analysis and more accurate assumptions.

For complete Sentinel-1 data potential assessment Sentinel-1 SLC microwave phase data should be used that are useful for forest condition monitoring (Rauste et.al. 2017). To increase forest clear-cut monitoring accuracy, it is necessary to choose radar scenes where image or study site mean backscattering values in the start and in the end of control period does not change for more than 0,5 db. That would allow more clearly discuss about those signal changes that were caused by tree cutting not meteorological conditions. Interesting information could be produced if monitoring period would start and end when air temperature would be below zero and soil would be completely frozen. It has been studied that these are the best conditions for C band radar data to distinguish land cover and give most promising information about forest stand structure and conditions.

This research does not consider study site snow properties during monitoring period. It has been declared that snow in C band radar data can change forest backscattering values by 3-4 db (Pulliainen et al. 1994). Another aspect that can be studied is Sentinel-1 VH data dynamics after partial tree cutting operations and see radar response after this forestry activity.

CONCLUSIONS

1. Sentinel-1 backscattering information is dependant from different factors, but significant influence comes from meteorological condition caused object dielectric property changes which can depress tree cutting generated backscattering dynamics thereby decreasing clear-cut monitoring accuracy.
2. If forest compartment is smaller than 2.21 ha there is no need to create Sentinel-1 backscattering border eroded compartment rasters because they don't make relevant accuracy increase.
3. For clear-cut detection in Latvia it is not suitable to use Sentinel-1 VV polarisation data because tree cutting does not produce sufficient backscattering changes.
4. Backscattering values in 18 clear-cut compartments before and after felling operations dropped by average 2,63 db, but 77,8% of cases had decrease at least 2 db. Two reference sites at the end of monitoring period had backscatter value that is more relevant to clear cut site. Nonetheless research total accuracy 83,3%. Information can be useful for forest clear-cut detection in Latvia.
5. Sentinel-1 has broader tree cutting detection potential than it has been discussed in this paper because there is no information how monitoring accuracy would change if: radar phase data would be used, partial cutting would be used instead of clear-cutting, radar images acquired in different weather conditions, compartments divided and analysed by their qualitative and quantitative properties.
6. Research validation was based on controlling authority data about recent forest compartment activity with one year temporal resolution. This was setback for more detailed forest monitoring.

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REFERENCE

Dostálová, A., Hollaus, M., Milenković, M., Wagner, W. 2016. FOREST AREA DERIVATION FROM SENTINEL-1 DATA. *ISPRS Annals of the Photogrammetry. Remote Sensing and Spatial Information Sciences*. 7, 227-233.

Olesk, A., Voormansik, K., Põhjala, M., Noorma, M. 2015. Forest change detection from Sentinel-1 and ALOS-2 satellite images. *IEEE 5th Asia-Pacific Conference on Synthetic Aperture Radar(APSAR)*. 522-527.

Rauste, Y.A., Antropov, O., Häme, T. 2017. *Advantages in the Science and Applications of SAR Interferomtriy and Sentinel-1 InSAR.* VTT technical Research Centre of Finland. Sk. 08.05.18. Available http://fringe.esa.int/files/presentation268.pdf

Pulliainen, J.T., Heiska, K., Hyyppa, J., Hallikainen, M.T. 1994. Backscattering Properties of Boreal Forests at the C- and X-Bands. *IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING*. 32, (5), 1041-1050.

Santoro, M., Pantze, A., S.Fransson, J.E., Dahlgren, J., Persson, A. 2012. Nation-Wide Clear-Cut Mapping in Sweden Using ALOS PALSAR Strip Images. *Remote Sensing* 4, 1693-1715.

Santoro, M., Eriksson, L., Askne, J., Schmullius, C. 2006. Assessment of stand-wise stem volume retrieval in boreal forest from JERS-1 L-band SAR backscatter. *International Journal of Remote Sensing*. 27, (16), 3425–3454.

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