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ANALYSIS OF PERMANENT SCATTERERS PROPERTIES BY LAND COVER TYPE IN IDA-VIRUMAA

(PÜSIVATE PEEGELDAJATE OMADUSTE ANALÜÜS MAAKATTETÜÜBI JÄRGI IDA-VIRUMAAL)

Bachelor thesis (12 EAP)

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List of abbreviations:

SAR – Synthetic Aperture Radar

InSAR – interferometric Synthetic Aperture Radar

DInSAR - differential Interferometric Synthetic Aperture Radar

PSInSAR - persistent scatterer Interferometric Synthetic Aperture Radar

ERS - European Remote Sensing satellite

DORIS - Delft object-oriented radar interferometric software

StaMPS - Stanford Method for Persistent Scatterers

SNAPHU - Statistical-Cost, Network-Flow Algorithm for Phase Unwrapping

QGIS - Quantum Geographic Information System

CLC2000 - Corine Land Cover 2000

1. Introduction

First radars were used during World War II with the purpose to track aircrafts and ships through heavy weather and darkness. For range determination time delay had to be measured and direction of a target was determinated via antenna directivity. Then it was discovered that the Doppler shifts could be processed to obtain fine resolution in radar's velocity direction. Thus in 1951 it was found that two-dimensional pictures of the Earth's surface could be made using radar. The method was termed Synthetic Aperture Radar (SAR) [1].

Nowadays, the number of practical applications of radars is quite big. For example, ground movement measurement. And measurement with radars in compare with measurements on the ground has many advantages: when costs are low, it is possible to collect data of much bigger territory; also data is collected during short period of time because of what enviromental conditions are almost the same for all studied area; the quality of the data is spatially and temporally uniform [2].

Measurement of crustal deformation provides us with a lot of important information. For instance, we can investigate consequences of earthquakes, study the movement of tectonic plates, divine landslides, measure deformation of buildings. Also, measurement of deformation contributed to our understanding volcanism [20].

This work is based on PSInSAR (*persistent scatterer Interferometric* SAR) method. Using this technique it is possible to very precisely measure the ground's deformation using SAR images and by identifying so called permanent scatterers. Permanent scatterer is a radar target, within a resolution cell, that displays stable amplitude and phase properties, throughout the images in a data stack [19]. The objective of this work is to identify permanent scatterers on SAR images and analyze their properties. Further using PS it will be possible to precisely measure ground deformation which due to shale mining in some places can be quite noticeable.

Firstly, for achieving the objective suitable SAR images for processing should be selected. Then, by using StaMPS program pixels with permanent scatterers will be detemined. After that, depending on type of land cover they will be divided into groups. This will be done by using Quantum Geographic Information System (QGIS) program and *Corine Land Cover 2000* (CLC2000) data. And the aim of this is to compare and analyze properties of permanent scatterers on different land covers. In this work analyze was carried out by Microsoft Excel and OriginLab programs.

2. Overview of the field

2.1 Synthetic aperture radar

SAR is radar, which especial feature is that it uses relative motion between satellite and studied area. And when ordinary radar resolution is usually limited to the size of antenna, SAR using relative motion can achieve effect of the bigger antenna what makes possible to get much bigger resolution. SAR is using microwaves so the electromagnetic beam which radar sends can pass through clouds and precipitation with little or no deterioration. Also the radar energy scatters off materials differently from optical energy providing a complementary and sometimes better discrimination of surface features than optical sensors. In addition, SAR carries its own illumination what makes possible to work equally well in darkness [1]. Other important point is that, in addition to amplitude measurement, SAR also measures the phases of the incoming signal what is very important information.

On the two-dimensional SAR image two directions are distinguished: azimuth and ground range directions. Azimuth direction is parallel to the satellite's flight direction and range direction is perpendicular to it, see Fig.1 [3].

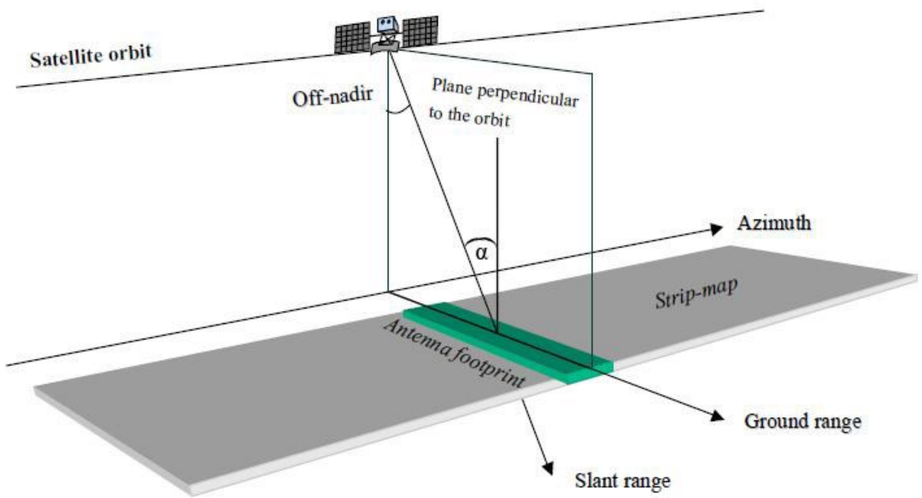

Figure 1. A SAR system from a satellite [3].

SAR image has some peculiarities. For example, speckle. The visual effect of speckle is a sort of 'salt and pepper' screen and it is a direct consequence of the superposition of the signals. Signals are reflected by many small scatteters and due to scatterer specific phase jump in scattering process and different distances traveled by beams they have visually random phase. The option how to solve this problem is to take more pictures of the same area and average them. This can greatly reduce speckle. Others problems are coming from the slope of the surfaces. For example, if slope angle of surface is bigger than off-nadir angle then scatterers are imaged in reverse order and superimposed on the contribution coming from other areas. This effect is called layover, see Fig.2. On the other hand, when terrain is parallel to the line of sight or this angle is even smaller, we can't have any information about this area because it is in shadow, see Fig.2. To solve this problem, two pictures can be taken, one from ascending pass, other from descending passes [3].

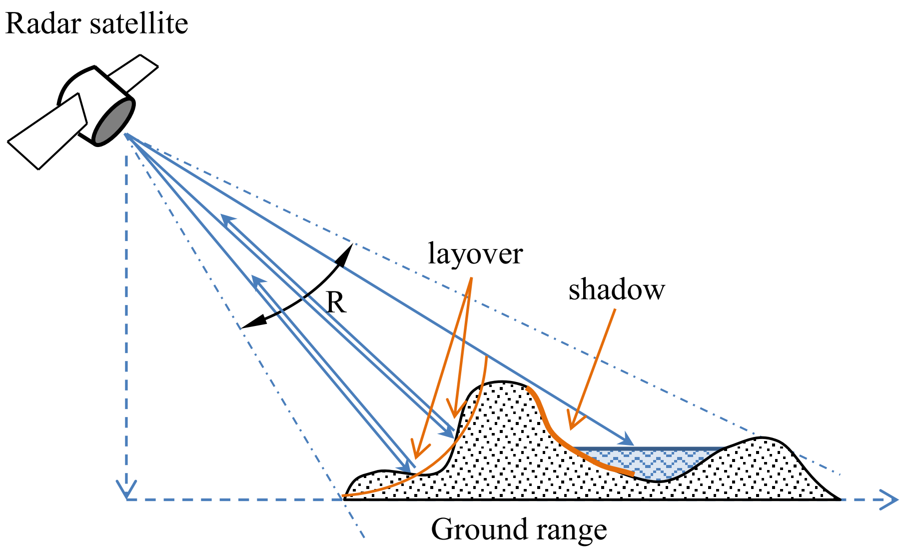

Figure 2. Layover and shadow effects.

2.2 InSAR

One of the approaches to the SAR images is method called Interferometric SAR (InSAR). A satellite with SAR can observe the same area from slightly different look angles. This can be done in two ways. Firstly, this can be done if we there are two radars mounted on the same platform. And secondly, SAR images can be taken at different times by exploiting repeated orbits of the same satellite. The SAR interferogram (image which represents phase difference) is generated by cross-multiplying, pixel by pixel, the first SAR image with the complex conjugate of the second. Thus, the interferogram amplitude is the amplitude of the first image multiplied by that of the second one and its phase (the interferometric phase) is the phase difference between the images [3]. Using this technique we can evaluate topography and find out how terrain is changing. Thus InSAR has many ways of use. For example, we can predict earthquakes, volcanic eruptions, and glacier surges, see how buildings or any other structures are deformed [5].

2.3 DInSAR

Other method is called Differential InSAR (DInSAR). If images in interferometric couple are made from the same place on orbit then phase difference is caused by the ground's moving. And as the phase difference is proportional to the distance between satellite and ground [3], it is possible to measure the deformation what happened between measurements' times. And if images are taken on slightly different orbits then terrain also affects the phase difference. In this case for deformation measurement affection of terrain has to be removed [2].

2.4 PSInSAR

InSAR is a good tool for measuring crustal deformation. But if we have large areas where the signals significantly decorrelate measurement is almost impossible [4]. To solve this problem, persistent scatterer InSAR (PSInSAR) technique was invented. All permanent scatterer interferometry (PSI) technologies are advanced forms of DInSAR. In other words, the interferogram is still at the core of PSI. The fundamental difference is that PSI technologies develop multiple interferograms from a stack of radar images. As a minimum, 15 radar scenes are usually required for PSI methods, even though there are circumstances when an analysis can be conducted with fewer images (typically in urban areas) [18]. PSInSAR overcomes the decorrelation problem by identifying resolution elements whose echo is dominated by a single scatterer in a series of interferograms. Physically, these stable scatterers might be a tree trunk or a single large rock or facet amongst the vegetation [4]. Also, artificial permanent scatterers are created.

Nowadays, this method is quite effective in analysis of urban areas, where stable structures produce efficient reflectors that dominate over background scattering. However, these structures are absent from the most if the Earth`s surface. Furthermore, existing methods identify PS pixels based on the similarity of their phase history to an assumed model for how deformation varies with time, whereas characterizing the temporal pattern of deformation is commonly one of the aims of any deformation study [4].

One of the methods is based on analysis of the amplitude variation, pixel by pixel, in a series of interferograms. Approaches include analysis of each pixel alone and comparison with surrounding pixels. Once an initial set of amplitude-stable pixels has been identified, each candidate pixel is tested for phase stability by examining its phase differences with nearby candidates. Only a pixel whose phase history is similar to the assumed model of deformation is considered stable and not merely the result of random chance. The problem is that this method can fail for two reasons. First, it can fail if the distance between neighboring PS pixels is too large and the contribution to the unmodeled phase from the difference in delay along the ray paths through the atmosphere exceeds the limit for reliable unwrapping. The second limitation is that an approximate model for the temporal variation in deformation is needed to isolate the deformation signal from atmospheric, topographic and other phase errors. As the time dependence of deformation is not usually known, it is usually assumed to be approximately constant in rate, or periodic in nature [4].

3. Data

3.1 ERS

For obtaining permanent scatterers European Remote Sensing satellite (ERS-1 and ERS-2) data was used. This data was ordered from the European Space Agency. For processing total of 14 SAR images were used. Dates of acquisition, perpendicular baselines and absolute Doppler centroids are shown in Table 1.

Date	Perpendicular baseline [m]	Doppler Centroids [Hz]
21-MAY-1995	-204.4	453.02
30-JUL-1995	244.4	476.35
31-JUL-1995	239.3	206.21
03-SEP-1995	-36.5	464.58
04-SEP-1995	-98.6	208.31
19-AUG-1996	117.1	216.52
17-MAR-1997	51.3	232.26

21-APR-1997	561.2	379.73
26-MAY-1997	-101.4	217.37
04-AUG-1997	0	212.34
08-SEP-1997	553.3	230.88
13-OCT-1997	138.4	225.274536
22-MAR-1999	-132.3	262.58
05-JUL-1999	-50.1	251.33

Table 1. Parametrs of processed images.

The ERS-1 was launched on 17 July 1991. It carried many measurement instruments including imaging synthetic aperture radar. ERS-2 was launched on 21 April 1995. It overlapped with ERS-1 and in addition had a sensor for atmospheric ozone measurements. Both satellites had the same Sun synchronous orbit with altitude of 785 km and inclination angle of 98.5° degrees. Time for one orbit was 100 minutes and the same orbit path was repeated every 35 days. At time when they were launched they were the most sophisticated Earth observation spacecraft ever developed and launched by Europe. They successfully collected data on Earth's land surfaces, oceans, and polar caps [10]. The SAR on ERS was working in C band (5.3 GHz central frequency, 5.66 cm wavelenght) with VV polarization (vertical transmit and vertical receive) and bandwidth 15 MHz (160 μm). Ground range resolution is 30 m and swath width 100 km [11].

3.3 Corine Land Cover data

For determination of the type of an area where permanent scatterers are located CLC2000 raster data was used [14]. The CLC inventory was initiated in 1985. Updates have been made in years 2000, 2006 and 2012. It involves 44 different types of land cover with thematic accuracy of 85%. In this work 20 different types of area were used. Minimum mapping units are 25 ha for areal phenomena and minimum 100 m for linear phenomena. CLC images are produced by visual interpretation of optical satellite images. For CLC2000 Landsat-7 ETM data was used [15].

4. Processing

The processing of SAR images was carried out by using StaMPS software (*Stanford Method for Persistent Scatterers*), which works on Linux operating system. To group permanent scatterers into groups by the type of area open source QGIS program was used. Both StaMPS and QGIS are freeware programs. The values which were analyzed are drift velocity, velocity dispersion and amplitude dispersion of permanent scatterers. Also the correlations between these values are investigated.

4.1 Area of interest

The area of interest was chosen Ida-Virumaa. More detailed area of interest can be seen on Figure 3.

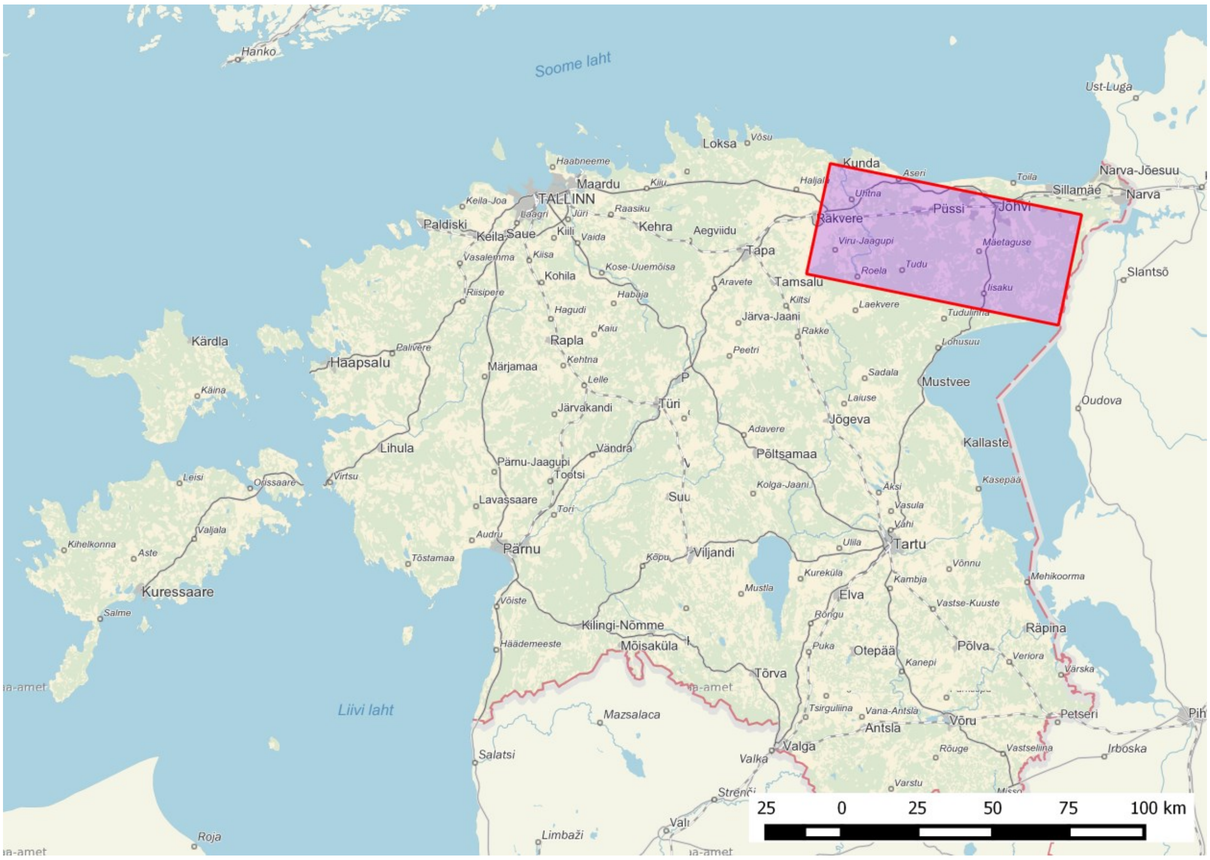

Figure 3. The area of interest in Ida-Virumaa.

4.2 STAMPS

The overview of the PS defining process can be seen on the Figure 4 [4].

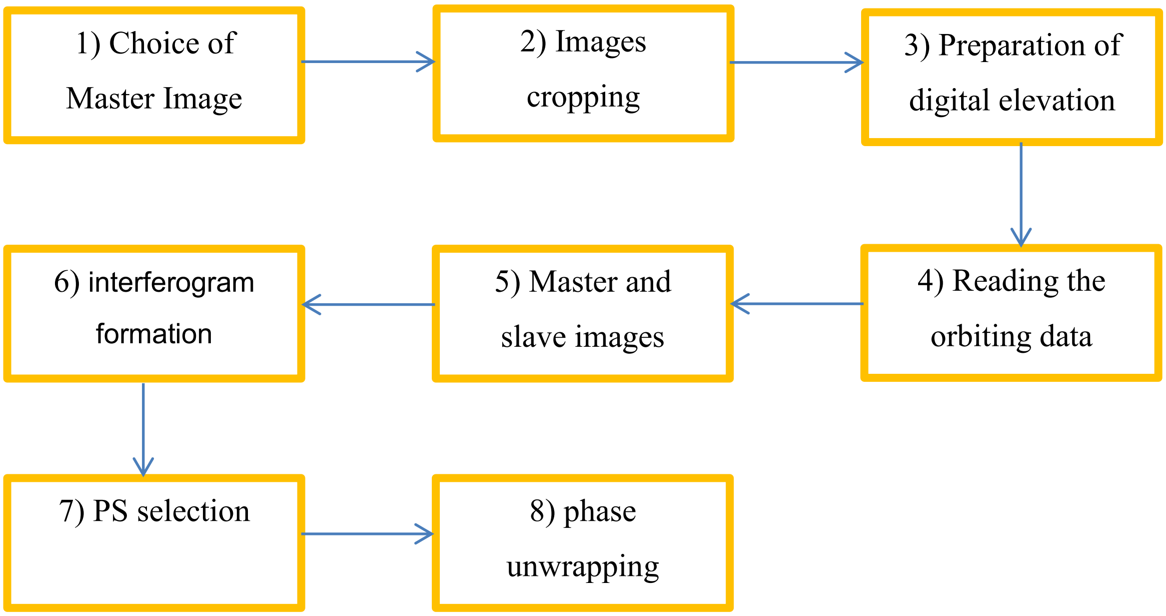

Figure 4. Stages of STAMPS algorithm.

4.2.1 Choice of Master Image

In the first step we have to choose suitable images for further processing. This should be done by choosing the images which have the highest coherence relatively to all other images. In the beginning we actually do not know how high the coherence is so in this step it can be only estimated by using known factors like time difference between images, baselines, Doppler center or coherence loss caused by thermal noise:

$$\rho_{total} = \rho_{time} \cdot \rho_{geometry} \cdot \rho_{Doppler} \cdot \rho_{thermal} \approx f\left(\frac{T}{T^c}\right) \cdot f\left(\frac{B_{\perp}}{B_{\perp}^c}\right) \cdot f\left(\frac{F_{DC}}{F_{DC}^c}\right) \cdot f_{thermal}$$

Equation 1. Estimation of coherence.

Where $(x) = 1 - x$, c denotes the critical parameters. The critical values depend on data set and typically for ERS satellites are$T^c = 5 years$,$B_{\perp}^c = 1100m$, $F_{DC}^c = 1380Hz$ and $f_{thermal}$ can be may be regarded as constant. Coherence equals to 0 means that interferogram contains no information and if it is 1 the interferogram is noise-free. In case coherence is too low, the image should be excluded. Also in case of Estonian weather conditions we should exclude the images which have snow cover, because snow cover masks many of the permanent scatterers. Finally image with relatively high coherence and acquisition time close to the middle of investigation period should be chosen as master image. In this work the image with date of acquisition of 17 march 1997 was chosen as master image. Relatively to this image interferograms with other images will be created. So, if we have n SAR images, then we will have n-1 interferograms respect to master image.

To obtain reliable result with PSInSAR analyses at least 12 interferograms are required. The needed minimum number of images can different strongly depending on the area of interest but it is desirable to use as many images as possible.

4.2.2 Image cropping

By cropping image we can choose the area we are interested in and also reduce processing time proportionally to the cropped area. Images were cropped to size 84.8 km in latitude and 37.7 km in longitude with center coordinates 59.3 ° N, 27.1° E. Cropped area is shown on Figure 5.

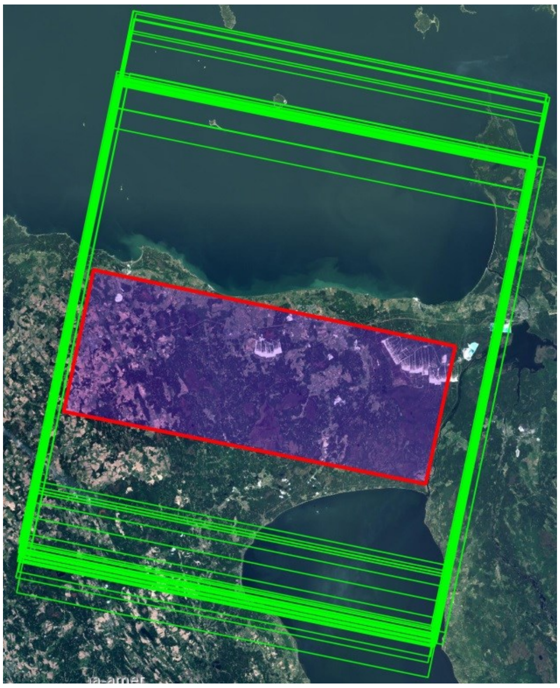

Figure 5. Cropped area is shown with red borders, margins of SAR images are shown with green.

4.2.3 Preparation of digital elevation model

Digital elevation model (DEM) is a digital representation of elevation information of an area. In StaMPS processing it is used for subtracting topographic phase component and to support coregistration between images. In this work SRTM (Shuttle Radar Topography Mission) DEM was used. The SRTM model's spatial resolution in Estonia is 90 m.

4.2.4 Reading orbiting data

We need to know orbit data for determining the exact relative position of satellite relative to surface. Based on that we can calculate the distances between every pixel in interferogram and satellite. From distances we can calculate topographic phase contribution which should be subtracted from interferograms.

4.2.5 Master image and slave images coregistration

For calculating phase differences corresponding pixels on the images should represent the same area. So, images should be spatially aligned (coregistered). The coregistration is based on cross-correlation. This step is divided into 2 sub-steps – coarse coregistration and fine coregistration. In coarse coregistration small number of relatively large windows is cropped from master and slave image, and cross-correlation of the amplitude patches is computed. Then in second step initial values of first step are used and in fine coregistration master and slave images are divided in to many smaller windows than in first step.

4.2.6 Interferogram formation

For interferogram formation DORIS (Delft object-oriented radar interferometric software) program was used. This step involves calculating the differences between master image's pixels phase and slave images' pixels phase.

4.2.7 PS selection

This step involves many sub-steps. Firstly, we have to set the amplitude dispersion threshold. In our case it was 0.4. Then we had to estimate the phase noise of every PS candidate in every interferogram and based on it select next PS candidates. Then pixels which likely due to neighborhood elements are permanent scatterer candidates are removed. The next step is phase correction. In this step the phase of the candidate pixels are corrected for spatially-uncorrelated look angle (DEM) error.

4.2.8 Phase unwrapping

The pixels of SAR images are represented by complex numbers $a + ib$ where $|a + ib|$ represents amplitude value of a signal and $\arctan(\frac{b}{a})$ represents the phase. The phase has 2π cyclic nature (wrapped). Because of this initial interferograms also have this cyclic property. For clarity, interferogram on Figure 6 has abrupt transitions and repeated interferometric phase values. In order to get the absolute phase variation the correct integer multiple of 2π to the interferometric fringes should be added. This process is called phase unwrapping. There are several techniques for this operation and usually there is no unique solution. In this work for phase unwrapping SNAPHU (Statistical-Cost, Network-Flow Algorithm for Phase Unwrapping) program was used.

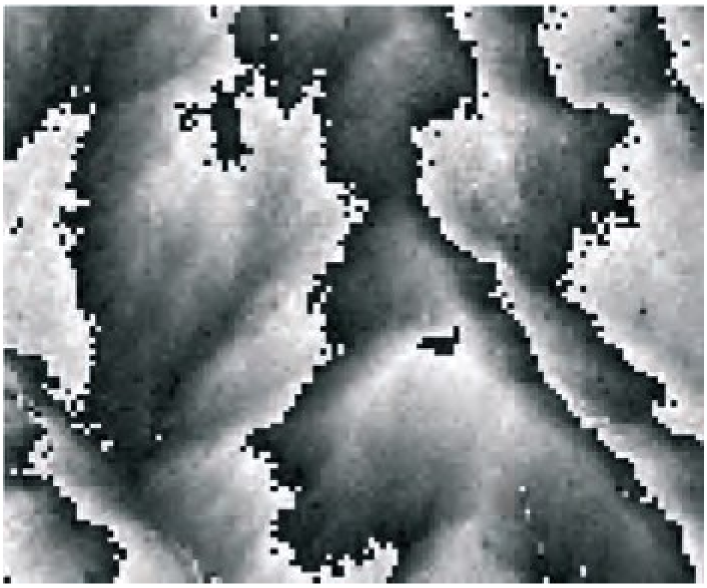

Figure 6. SAR interferometric phase generated by means of two ERS images [2].

4.3 Permanent scatterer analysis in QGIS

According to Corine data there are 20 different types of land cover in the area of interest. For further analysis the land cover types are divided into three groups – “artificial surfaces”, “agricultural areas” and “forest and semi natural areas”, see Table 2, Fig.7. These groups are labelled in Corine data. Then for assignment the group to every permanent scatterer Point sampling tool developed by Borys Jurgiel was used [17]. For calculating areas occupied by each values of raster map Semi-Automatic Classification plugin developed by Luca Congedo was used.

Groups		
Artificial surfaces	**Agricultural areas**	**Forest and semi natural areas**
Continuous urban fabric	Non-irrigated arable land	Broad-leaved forest
Discontinuous urban fabric	Pastures	Coniferous forest
Industrial or commercial units	Complex cultivation patterns	Mixed forest
Road and rail networks and associated land	Land principally occupied by agriculture, with significant areas of natural vegetation	Natural grasslands
Mineral extraction sites		Moors and heathland
Dump sites		Transitional woodland-shrub
Construction sites		Beaches, dunes, sands
Green urban areas		Sparsely vegetated areas
Sport and leisure facilities		

Table 2. Different areas are divided into three groups.

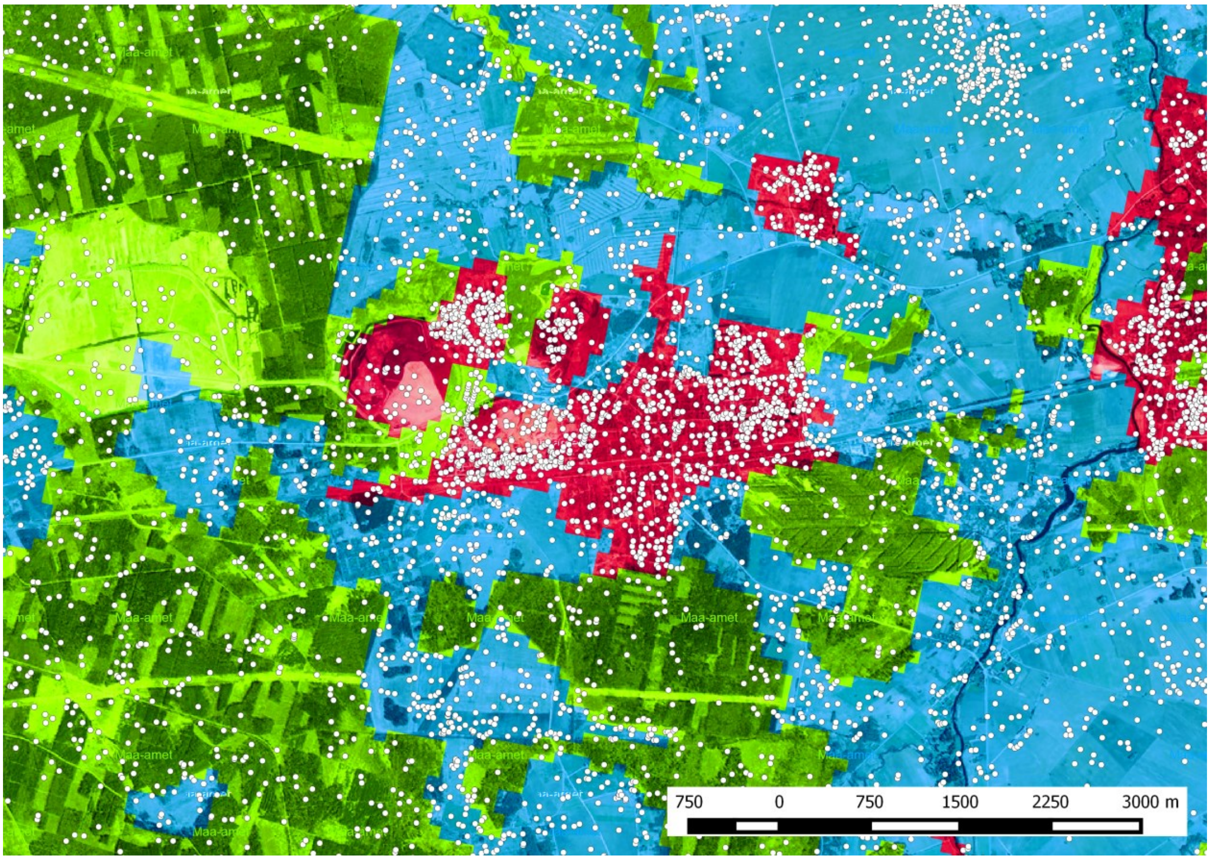

Figure 7. Artificial surfaces are highlighted with red, agricultural areas with blue and forest and semi natural areas with green. Permanents scatterers are shown with white dots.

5. Results

5.1 PS Densities

Type of land cover	Area $[km^2]$	Number of PS	PS density $[PS/km^2]$
Artificial surfaces	115	20 521	178.4
Agricultural areas	766	39 390	51.4
Forest and semi natural areas	2296	67 946	29.6
Total area of interest	3220	136 852	42.5

Table 3. Mean PS densities depending on the type of land cover.

From 39 480 000 pixels 136 852 were selected as pixels with permanent scatterer. The area of investigated surface is $3220\,km^2$. The mean density of permanent scatterers is 42.5 PS/km^2. There are 20521 permanent scatterers on artificial surfaces, on agricultural areas there are 39390 permanent scatterers, on forest and semi natural areas there are 67946 permanent scatterers and rest were not included to any group due to specific land cover or their number. Respectively, the areas of these surfaces are $115km^2$, $766km^2$ and $2296km^2$. Relation of these values gives us permanent scatterers density on artificial surfaces 178.4 PS/km^2, 51.4 PS/km^2 on agricultural areas and 29.6 PS/km^2 on forest and semi natural areas. This result can be well explained by the specific nature of these surfaces. For instance, there are many man-made structures on artificial surfaces which have straight geometry what in many cases makes them good persistent scatterers. Also, some buildings are built on foundation what makes them more stable. Altogether, these factors entail to great number of permanent scatterers. Then on agricultural areas there are much fewer stable structures and most of this area is covered with a cultivation patterns and pastures. But still this kind of flora cannot hide stable objects as houses or shacks and as a result we still have quite big number of permanents scatterers. On forest and semi natural areas there are many trees which can easily hide permanent scatterers. Also, due to foliage and branching of a tree, trees can be the source of amplitude and phase noise. As a result this group has lowest density of permanent scatterers.

5.2 Velocities

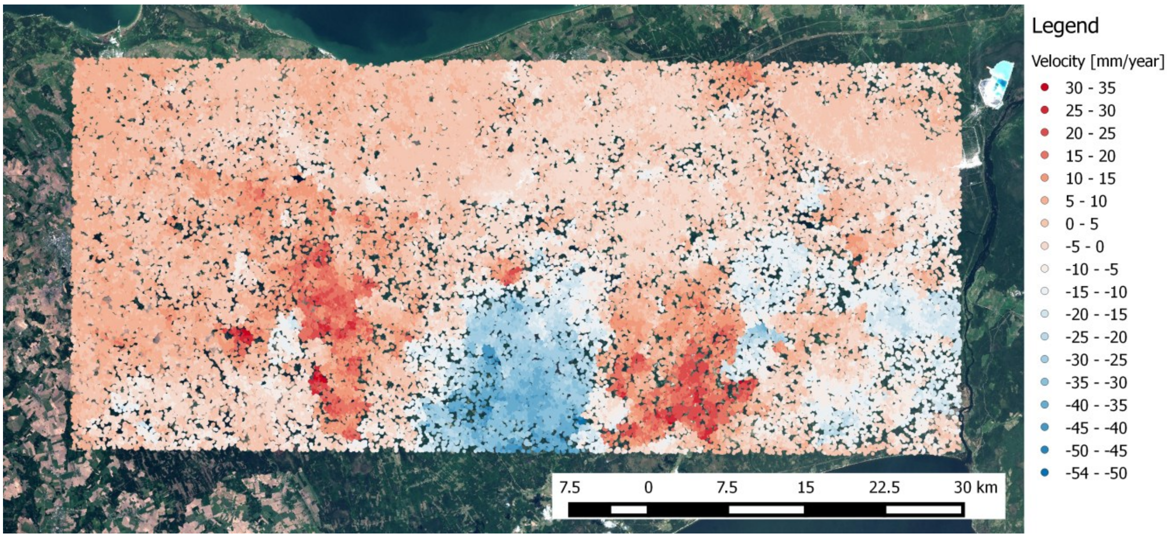

Figure 8. Velocities of permanent scatterers.

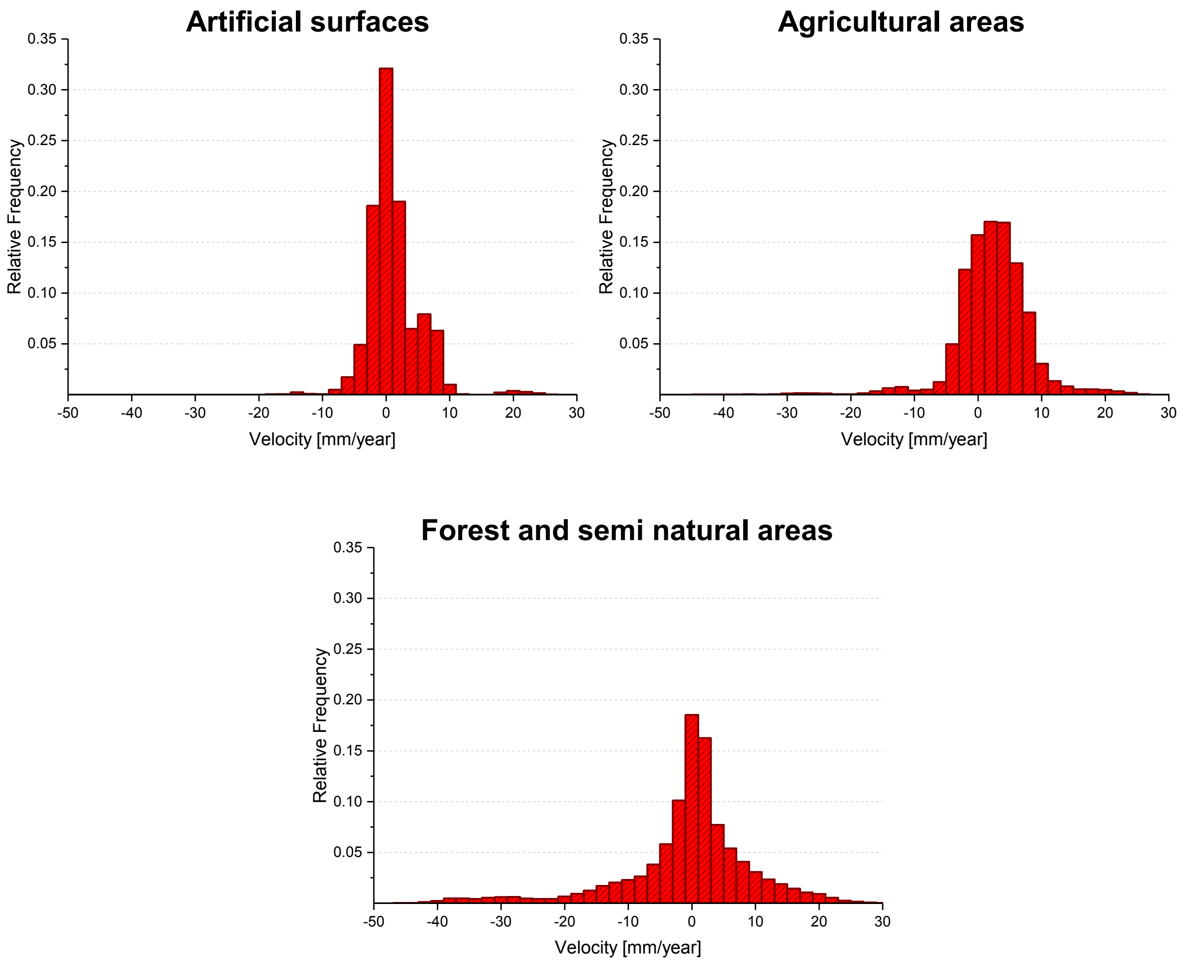

Figure 9. Relative frequencies of velocities.

Type of land cover	Mean velocity [mm/year]	Velocity standard deviation [mm/year]
Artificial surfaces	1.2	4.0
Agricultural areas	2.3	5.9
Forest and semi natural areas.	-0.6	10.2
Total area of interest	0.6	8.4

Table 4. Mean velocities depending on the type of land cover.

The territory on the bottom of the studied area which is located near the wetlands is subsiding with speed 20-50 mm/year, see Fig.8. This territory is located near waterlands that is the fastest subsiding on the area of interest. Near this territory are territories of fastest uplifting. But they are not correlated with any type of land cover. Velocity of permanent scatterers on remaining territory varies from about -15 to 15 mm/year.

Permanent scatterers on artificial surfaces are quite stationary, see Fig.9. Around one third of them have about zero velocity what can be explained by stable foundation of buildings. Permanent scatterers on agricultural areas have a wider distribution, but not as wide as persistent scatterers on forest and semi natural areas. This can be explained by human intervention. Every year it plows and fertilizes same areas making them to stay unchangeable. Also, on agricultural areas chance of permanent scatterer to be covered by tree is less than in forests. Finally, Permanent scatterers on forest and semi natural areas have shown highest mobility. This can be explained by absence of stable buildings. Also, in this case human almost does affect this area and as a result natural processes which lead to surface deformation occur there. In addition, such mobility can be explained by the absence of stable buildings.

5.3 Velocity standard deviations

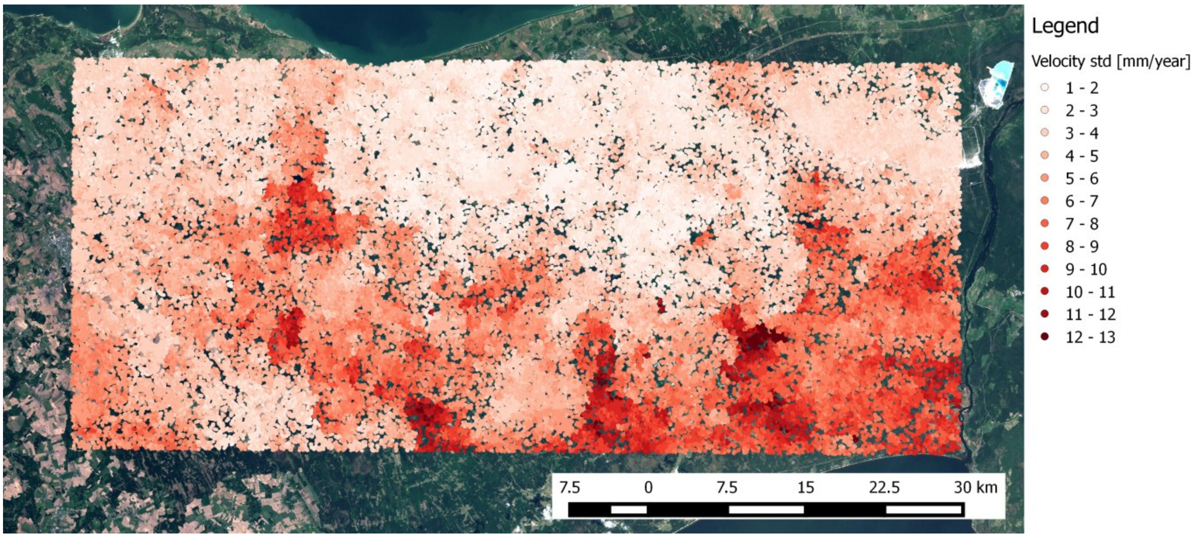

Figure 10. Standard deviations of permanent scatterers.

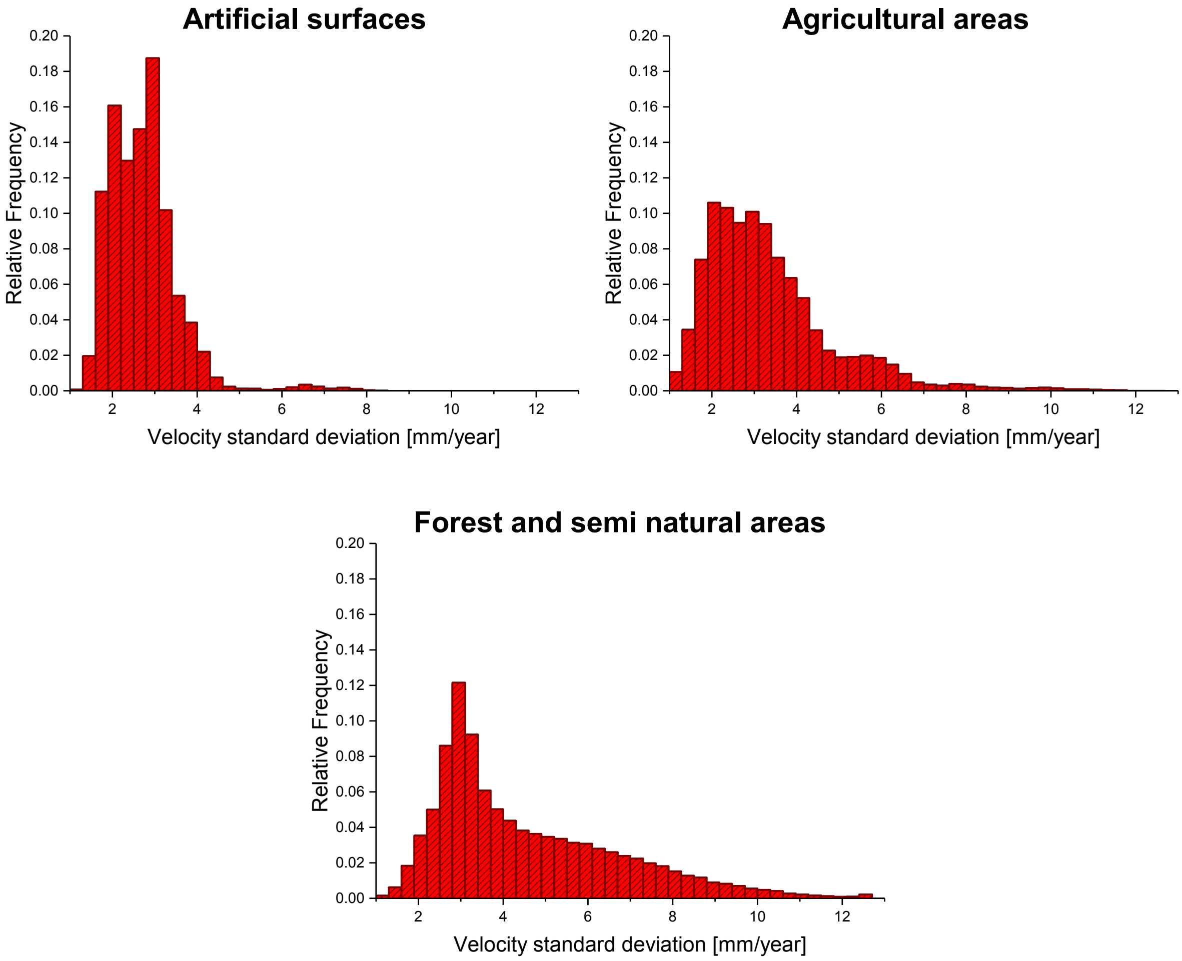

Figure 11. Relative frequencies of velocity standard deviations.

Type of land cover	Mean velocity standard deviation [mm/year]	Standard deviation of velocity standard deviation [mm/year]
Artificial surfaces	2.7	0.8
Agricultural areas	3.4	1.5
Forest and semi natural areas	4.6	2.1
Total area of interest	3.9	2.0

Table 5. Mean velocity standard deviations depending on the type of land cover.

From Figure 10 it can be seen that there are differences in velocity standard deviations of permanent scatterers on different types of cover. Pixels with permanent scatterers on artificial surfaces have smallest dispersion of standard deviations and on forest and semi natural areas – the biggest dispersion. Also from Table 4 it can be seen that permanent scatterers on artificial surfaces have smallest mean value. This means that these scatterers move with more stable velocity than others. This can be explained by the type of cover. On artificial surfaces there are fewer trees than on agricultural areas and forest and semi natural areas which could cover permanent scatterers and reduce their contribution to the main signal. Also because trees are flexible and have branch structure, they can be a sourse of phase noise.

5.4 Amplitude dispersions

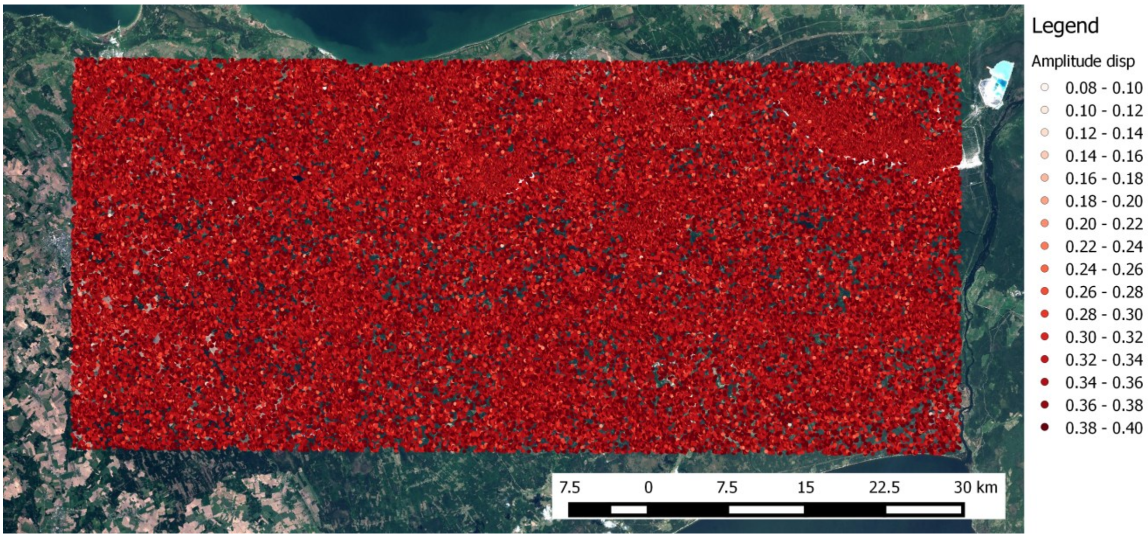

Figure 12. Amplitude dispersions of permanent scatterers.

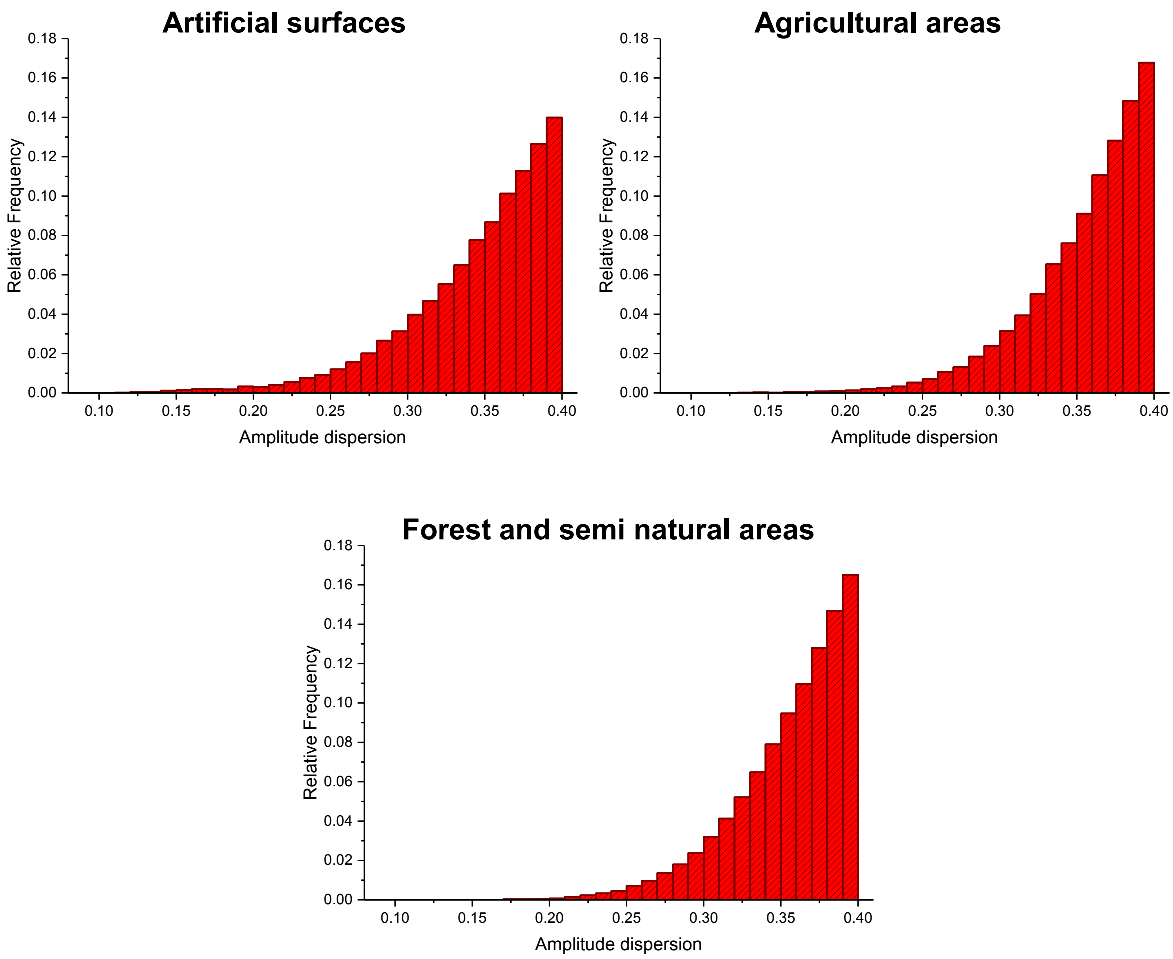

Figure 13. Relative frequencies of amplitude dispersions.

Type of land cover	Mean amplitude dispersion
Artificial surfaces	0.346
Agricultural areas	0.355
Forest and semi natural areas	0.356
Total area of interest	0.354

Table 6. Mean amplitude dispersions depending on the type of land cover.

Analysis of amplitude dispersion has shown that there is no regularity in this value, see Fig 12. As it is seen from Figure 13 distributions of amplitude dispersions are almost the same. The amplitude dispersion threshold of 0.4 was set in StaMPS when permanent scatterers were determined and as it seen from Figure 13 the change of this threshold can change the number of permanents scatterers significantly. The reason why we have amplitude dispersion is because of different incidence angles of signal for different images. This is caused by difference in locations of satellites at times of images' acquisitions. In result, reflected signal in most cases will also have different angle of reflection. And as satellites were 785 meters above the Earth surface even insignificant change in angles can have serious consequences. As a result every acquisition SAR receiver will register different amplitudes what leads to high distribution of this component. And as incident angles do not depend on land cover type, amplitude dispersions of permanent scatterers on different land covers will have same distributions, see Fig. 13.

As on different types of land covers are same distributions of amplitude dispersions, mean values are also almost the same. With amplitude dispersion threshold of 0.4 mean values of amplitude dispersion are 0.35, see Table 6.

5.5 Correlation between velocity and velocity standard deviation

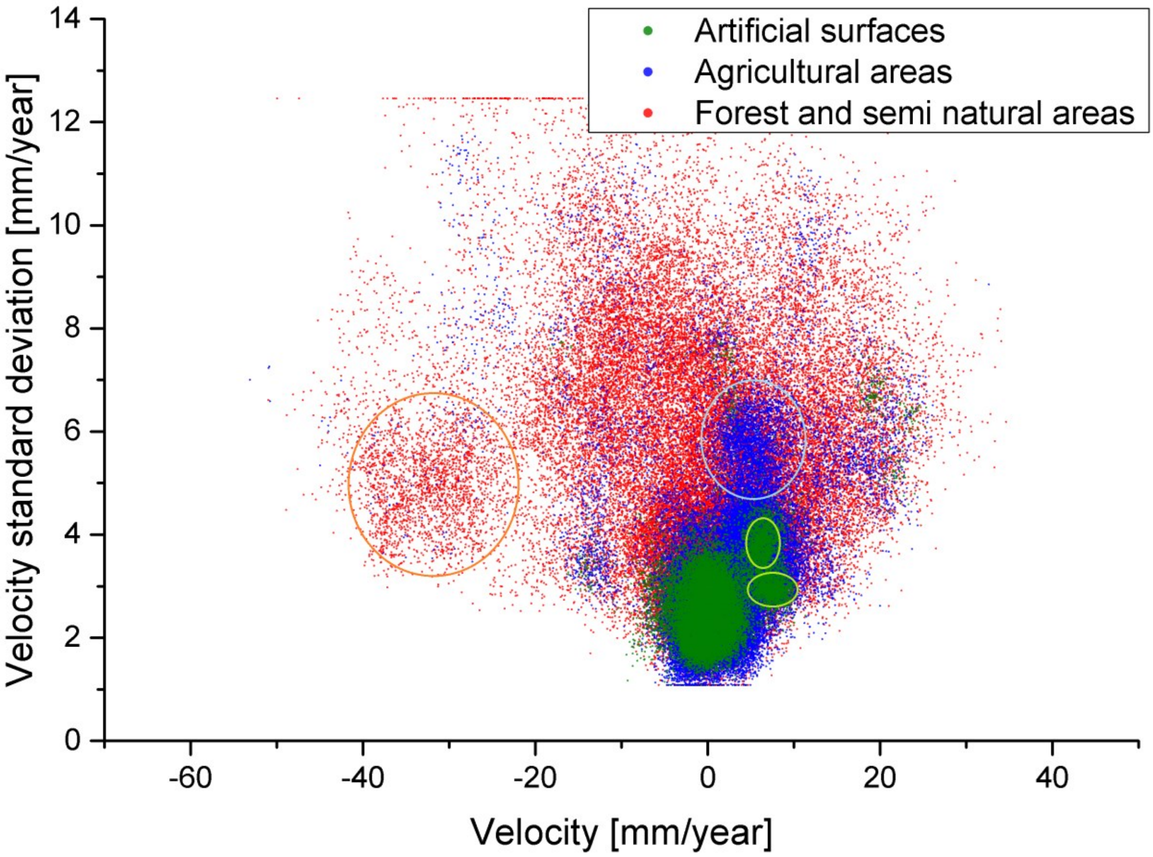

Figure 14. Correlation between velocity and velocity standard deviation. Sub groups are shown with ovals.

As it was previously observed, dispersion of velocity and dispersion of velocity standard deviations of permanent scatterers on artificial surfaces have smallest value compare to others. This fact can also be seen on the Figure 14 above. And in addition to that, on Figure 14 it is seen that these permanent scatterers are divided into three groups. Same division goes to permanents scatterers on agricultural areas and less obvious on forest and semi natural areas. This segmentation can be explained by location of these permanent scatterers. Some permanent scatterers' groups are located on area of uplifting, some are stationary and others are subsiding.

6. Conclusions

Permanent scatterers on different land covers have quite different properties. For instance, on artificial surfaces the areal permanent scatterers density is 178.4 PS/km^2, on agricultural areas it is more than three times less - 51.4 PS/km^2 and on forest and semi natural areas it is about six times less - 29.6 PS/km^2. This result can be easily explained by the presence of big number of buildings which are stable and have straight geometry and as a result often identified as permanent scatterers.

Velocities of permanent scatterers on different land cover types have different distributions. Velocities of permanent scatterers on artificial surfaces are more stationary and their distribution is concentrated around zero value between -5 mm/year and 5 mm/year. Distributions of velocity on others types of land covers are wider.

Distributions of permanent scatterers' velocity standard deviations on artificial surfaces are focused in narrow values' diapason – from about 1 to 5 mm/year. Distribution of velocity standard deviations of permanent scatterers on agricultural areas is wider and on forest and semi natural areas it is the widest. Wider distributions also lead to different mean velocity standard deviations. On artificial surfaces permanent scatterers' mean standard deviation is 2.7 mm/year, on agricultural areas - 3.4 mm/year and on forest and semi natural areas - 4.6 mm/year.

Analysis of amplitude dispersion was also made but no difference in distributions of this value on different type of land covers was found.

Finally, velocities and their standard deviations relation was studied. Permanent scatterers on artificial surfaces have smallest dispersion, permanent scatterers on agricultural areas relatively medium dispersion and permanent scatterers on forest and semi natural areas – the biggest dispersion. Also, from plot it can be seen, that in land cover types groups permanent scatterers are also divided into groups. This division can be explained by different location of these permanent scatterers' groups.

7. Summary

The objectives of this work are to identify and analyze properties of permanent scatterers on different types of land cover. Permanent scatterer is a radar target, within a resolution cell, that displays stable amplitude and phase properties, throughout the images in a data stack. Permanent scatteres are used in PSInSAR method which allows to measure crustal deformation very precisely. For identifying permanents scatterers 14 ERS SAR images were processed through the STAMPS program which allows to find PS also on not-man made surfaces. When permanent scatterers are identified, their properties as drift velocity, velocity standard deviation and amplitude dispersion were studied. Also, the permanent scatterers density on area and correlation between different properties were objects of study.

The Ida-Virumaa was chosen as the area of interest. On area of 3220 km^2 136 852 permanent scatterers pixels were identified. For further analyzing of their properties these were divided into three groups: “artificial surfaces”, “agricultural areas” and “forest and semi natural areas”. It was done by using QGIS program and Corine data. Permanent scatterers which did not belong to any of these groups were excluded from studying.

Every group of permanent scatterers has shown different permanent scatterers density. For instance, permanent scatterers density on artificial surfaces is about 3.5 times higher than on agricultural areas and about 6 times higher than on forest and semi natural areas. This result is very expected. To artificial surfaces were included units and sites which have many straight geometry objects. Also many of these objects are buildings which are built on foundation what in sum with straight geometry gives a bigger chance to these objects to be identified as a permanent scatterer. On the other hand, forest and semi natural areas almost completely consist of trees which can hide potential permanent scatterers.

Permanent scatterers velocities’ and velocity standard deviations’ distributions are different depending on the type of land cover. For instance, permanent scatterers on forest and semi natural areas have the biggest dispersion of these values. On the other hand, permanent scattereres on artificial areas have the smallest dispersion of these values. Distributions of values of permanent scatterers on agricultural have average properties of listed above. Amplitude dispersions were also objects of study. But these distributions were the same and could not be distinguished by the type of land cover.

Also relation of velocities and their standard deviations were studied. This analysis has shown that permanent scatterers within every land cover type group are divided into smaller sub groups. This is explained by the different locations of these sub groups.

8. Kokkuvõte

Käesoleva töö eesmärgiks on tuvastada püsivaid peegeldajaid ja analüüsida nende omadusi sõltuvalt maakattetüübist. Püsiv peegeldaja on objekt maapinnal, millelt peegeldunud signaali amplituud ja faas on stabiilsed läbi kogu piltide aegrea. Püsivaid peegeldajaid kasutatakse PSInSAR meetodi rakendamisel, mille abil on võimalik väga täpselt mõõta maapinna deformatsiooni. Püsivate peegeldajate tuvastamiseks töödeldi 14 ERS SAR pilti, kasutades programmi StaMPS, mis annab võimaluse leida püsivaid peegeldajaid ka väljaspool linnapiirkondi. Kui püsivad peegeldajad olid tuvastatud, uuriti nende omadusi, näiteks triivkiirust, kiiruse standardhälvet ja amplituudi dispersiooni. Veel uuriti püsivate peegeldajate tihedust pinnaühiku kohta ja korrelatsiooni erinevate omaduste vahel.

Töös uuritud ala on Ida-Virumaa. 3220 km^2 suurusel pindalal leiti kokku 136 852 püsivat peegeldajat. Omaduste uurimiseks jagati püsivad peegeldajad kolme rühma: linnapiirkonnad, põllumajanduspiirkonnad ning metsad ja poollooduslikud alad. Seda tehti geoinfosüsteemiga QGIS ning CORINE andmebaasiga. Püsivad peegeldajad, mis ei kuulunud ühtegi rühma, jäeti uurimisest välja.

Iga püsivate peegeldajate grupi kohta leiti erinevad püsivate peegeldajate tihedused. Näiteks püsivate peegeldajate tihedus linnapiirkondades on umbes 3.5 korda suurem, kui põllumajanduspiirkondades ja umbes 6 korda suurem, kui metsas ja poollooduslikel aladel. See tulemus on teooriaga kooskõlas. Linnapiirkondade rühma olid lisatud maakatted, millistel on palju sirge geomeetriaga objekte. Paljud neist objektidest on hooned, mis on ehitatud vundamendi peale ja see annab suurema võimaluse saada tuvastatud püsiva peegeldajana. Teisalt, metsad ja poollooduslikud alad koosnevad suures osas puudest, mis võivad kergesti peita potentsiaalseid püsivaid peegeldajaid.

Püsivate peegeldajate kiirused ja kiiruste standardhälbed on samuti erinevad sõltuvalt maakattetüübist. Näiteks metsas ja poollooduslikel aladel on nendel suurustel suurem dispersioon. Püsivad peegeldajad linnapiirkondades omavad jällegi kõige väiksemat eelpool nimetatud suuruste dispersiooni. Samade suuruste jaotusel põllumajanduspiirkondades on keskmised omadused. Ka uuriti amplituudide dispersioone. Nende jaotused olid ühesugused ja ei olnud võimalik eristada neid maakattetüübi põhjal.

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