APPEARANCE OF PERSISTENT SCATTERERS FOR DIFFERENT TERRASAR-X ACQUISITION MODES

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ABSTRACT:

Since beginning of 2008 products of TerraSAR-X have been available for the scientific community and the great performance of this satellite system has been proven by encouraging results presented during the recent workshops and conferences. Outstanding technical features of TerraSAR-X are multiple geometric and radiometric imaging as well as the short revisiting time of 11 days. These offer the opportunity to build up data stacks of the same scene very fast and with varying acquisition parameters. Since February 2008 several of such datasets could be acquired for the city of Berlin, Germany, using different incidence angles and track types (i.e. ascending or descending orbits).
A thorough analysis of compliances and differences in these data stacks is of particular importance for Persistent Scatterer Interferometry (PSI). While, in the past, data takes from the long-revisiting ERS and ENVISAT satellites had to be used with similar image acquisition parameters, now first TerraSAR-X data stacks – each acquired with different parameters – can be evaluated and compared. The extremely high resolution of up to 1.1 m in azimuth and 0.6 m in slant range leads to an enormous increase in the number of PS offering new potentials and applications. As different acquisition parameters for one scene are possible, the number and positions of the PS may vary from stack to stack. In this study the change in number and local appearance of PS depending on incidence angle and track type (ascending or descending orbit) are investigated. To this end, six stacks comprising varying parameters have been set up and assessed. The investigation is based on the results of PSI-GENESIS software developed at DLR, Oberpfaffenhofen, which relies on the TerraSAR-X Multi Mode SAR Processor, and includes the analysis of the PS candidates densities and positions with respect to the different parameters mentioned. Especially the question of selecting a suitable incidence angle for PS analysis in urban areas is discussed besides the choice of track type.

1. INTRODUCTION

After the successful launch of TerraSAR-X on June 15th 2007 and the subsequent commissioning phase the German RADAR-satellite went operational on January 9th 2008. Since this phase high resolution SAR data could be ordered by the scientific community using these high-quality SAR images for investigations on different topics. First results using TerraSAR-X data have already been presented during recent conferences where the benefits for different applications of this new instrument could be approved, like varying acquisition modes and the very short revisiting time of only 11 days. Especially the possibility to acquire data based on almost the same geometrical parameters with such a high repeat rate facilitates setting-up interferometric stacks for persistent scatterer interferometry (PSI) about three times faster compared to ERS or ENVISAT. These satellites in addition offered a resolution of only approximately 25m in range and 5m in azimuth wherefore it is very difficult to investigate the nature of strong scatterers, acting as persistent scatterer (PS), in this - comparatively large - resolution cell. Now, using TerraSAR-X in high resolution spotlight mode (300MHz bandwidth), image resolutions of up to 1.1m in azimuth and 0.6m in range can be delivered by the TerraSAR Multi Mode SAR Processor (TMSP) developed at Deutsches Zentrum für Luft- und Raumfahrt (DLR) [2, 4, 7]. This high resolution leads to an enormous increase in number of PS, as has already been shown in [1],

now resulting in many PS showing up on single objects. As data can be acquired from the same area of interest using different orbits, position and number of PS are likely to vary between stacks of datasets based on different incidence angles as well as ascending and descending tracks respectively.
For investigations on the influence of the mentioned parameters on PS density, six data stacks covering the area of Berlin downtown have been set up and the findings of the analysis will be presented in this paper, which include comparisons of the number of PS extracted in each stack and the variation of PS densities in different subregions of the data. Hence, based on the desired spreading and concentration of PS, the essential acquisition parameters for this region - and comparable ones - can be chosen in advance.

2. DATA BASIS

The area of interest in this investigation has been defined to the inner city of Berlin, Germany, centered around the main railroad station. Altogether six different stacks of data takes (all in VV polarisation mode) have been acquired covering approximately one year starting February 2008. Table 1 shows the number of images in each stack which ranges from 16 up to 22 depending on the expired fraction of the orders, originating from overlaps in acquisition time slots of the satellite by other parties. The six stacks can be separated in two groups: one ascending and one descending track, each containing three

different beams, which imply certain incidence angles for data capture. The available angles are 30°, 42° and 51° for ascending beams 28, 57 and 85 and 36°, 47° and 55° for descending beams 42, 70 and 99 respectively, and represent appropriately the incidence angles of the acquisitions at the centre of the dataset. Due to these different viewing directions the covered area ranges from 33km^2 to 51km^2, whereas steep angles produce larger coverage than flat one. The given datasets of six groups represent the input for the following processing in order to obtain PS positions in each set of images.

Beam no.	Inc. Angle	Track Type	Area [km^2]	No. of Data
28	30°	Ascending	50.8	22
57	42°	Ascending	40.7	15
85	51°	Ascending	33.0	21
42	36°	Descending	42.9	20
70	47°	Descending	36.8	21
99	55°	Descending	34.2	22

Table 1. Stack Acquisition Parameters

3. EXTRACTION OF PERSISTENT SCATTERERS

In order to identify PS points in the area of interest, all stacks have been processed separately by using the interferometric and persistent scatterer processing system PSI-GENESIS of DLR. To meet the requirements of the data processing the SLC data is oversampled during import. In addition a digital elevation model (DEM) of the area is needed which has been extracted from existing shuttle radar topography mission (SRTM) data, which is usually sufficient for removing the phase contribution induced by terrain heights. Further steps include, among others, the selection of the master image, which has been chosen near the temporal mean in each stack, the necessary co-registration of the slave images to the master image and finally the calculation of the differential interferometric phase values and coherence for each pair between master and slave datasets. The consideration of the baseline between the acquisitions for the selection of the master image is non-critical, as baselines are kept relatively small by mission control (approximately smaller than 500m). Further details on the processing procedures can be found in [6]. Nonetheless, it should be mentioned that no further calibration of the input TerraSAR-X data is required in contrast to recent PSI processing of ERS or ENVISAT data.

In order to obtain PS points a mean map and a subsequent signal-to-clutter ratio (SCR) map is calculated in each stack which represents the basis for the following PS detection. In the original PS algorithm presented in [3], scatterers are selected by choosing a threshold for the amplitude dispersion index. Another possibility shown in [5] considers the SCR as an appropriate selector for PS candidates. This has also been used in the investigations presented here, whereby the threshold was left unchanged for all stacks.
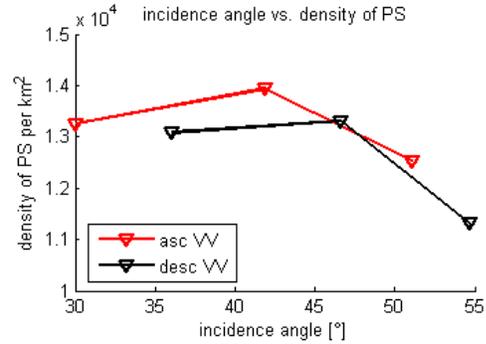

Figure 1. PS density from different incidence angles using VV polarisation - ascending tracks in red, descending in black

4. PERSISTENT SCATTERER DENSITIES

The locations of the detected PS are the basis for the following analyses. A first look on the total number of selected points normalized by the covered areas shows that the PS densities slightly increase starting with steep incidence angles up to about 42°-47° while the decrease for higher angles is faster than the gain before (see Figure 1). This behaviour can be explained by considering many PS to be created by di- and trihedrals, e.g. a path of rays from satellite to building walls, reflection to streets and back to the sensor or vice versa. If the looking direction exceeds a certain threshold, unique for each geometrical configuration including certain building height and distance to other constructions, the sensor cannot "see" these scatterers anymore as and many PS get lost (cp. Figure 2). In the Berlin case this seems to happen for incidence angles roughly between 42° and 47° and can be validated by density maps in the following.

For the Berlin scene the densities of PS in descending tracks is slightly lower for steep angles which could stem from disadvantageous alignment of buildings in this configuration. The drop for oblique viewing directions is even larger than in the ascending case, but both plots show a common basic behaviour as described above. Unfortunately no additional incidence angles are possible with the current configuration of the satellite orbits to further confirm the investigations.
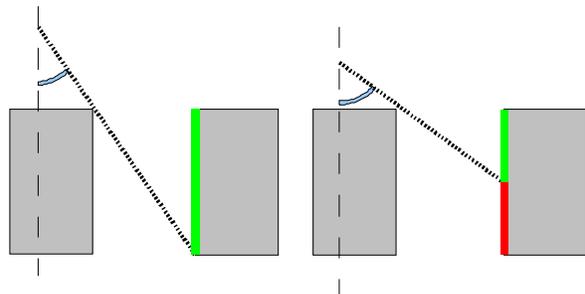

Figure 2. Decrease of PS from facades resulting from larger incidence angles (right side), depending on building height and distance of constructions. Left: whole facade of building contribute with PS (green area); Right: Area of potential PS lost displayed in red, remaining facade with radar returns in green.

Deeper analyses are based on PS density maps which have been created simply by sliding a window of certain extent across the area of interest, counting the PS within it and writing the number to the centre position of the window. Normalization by the window area in square kilometers leads to maps of PS densities, which of course can show extremely high values due to the local high density of points within the small window area. For this investigation the window area has been chosen to be 15 or 30 meters respectively in order to get an impression on the densities in different resolutions. The choice of 30m is more suitable for large area density comparisons, whereas the plots of data using a smaller window show more information in detail. In the following different subregions are selected for further analysis.
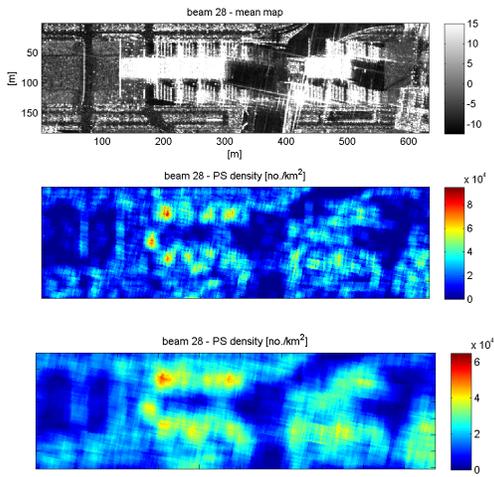
Figure 3. beam 28: Mean map (top), PS density map with window size 15m x 15m (middle) and window size 30m x 30m (bottom), both color coded using density in number of PS per km^2 in a range up to $9*10^4$ and $6.5*10^4$ respectively; Roof of building showing scattering area at steep incidence angles, for which reason PS density is low for this part of the building
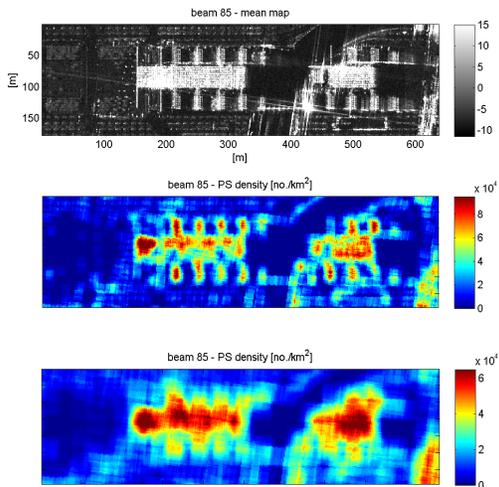
Figure 4. beam 85: Mean map (top), PS density map with window size 15m x 15m (middle) and PS density map with window size 30m x 30m (bottom); coloration equal to last figure; Compared to beam 28 scatterers could be extracted from roof of building (horizontal area with many windows)
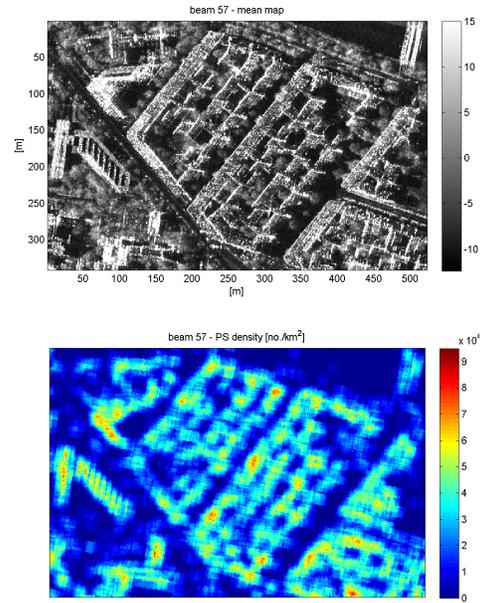

Figure 5. beam 57: Mean map (top) and PS density map with window size 15m x 15m (bottom); coloration equal to last figures; For middle range incidence angles several floors can be seen, each containing several PS
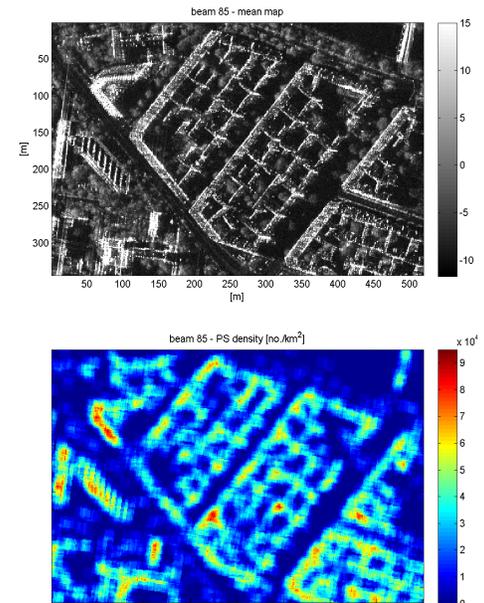

Figure 6. beam 85: Mean map (top) and PS density map with window size 15m x 15m (bottom); coloration equal to last figures; Compared to beam 57 less PS can be detected from facades because of shadow areas and reduced resolution in elevation direction.
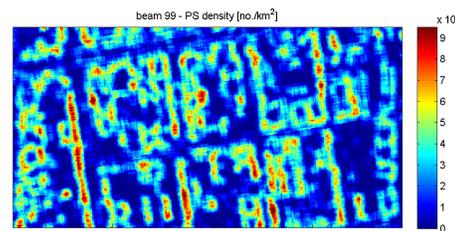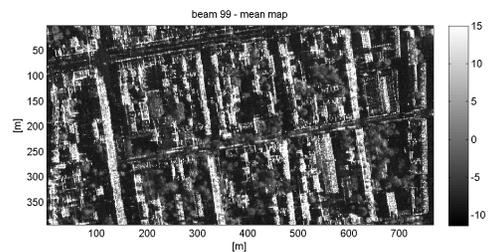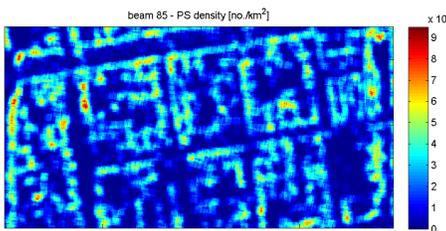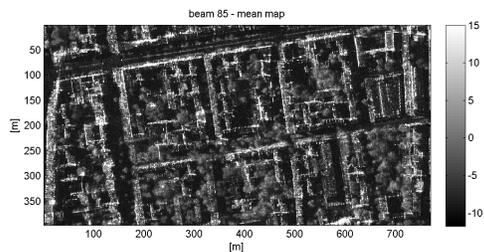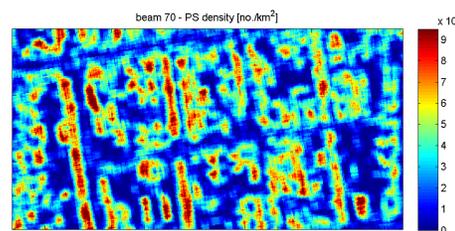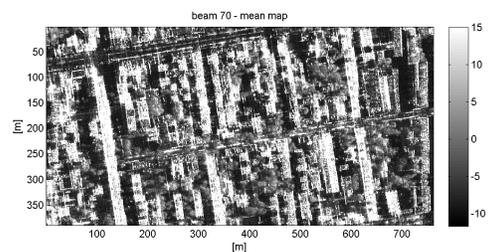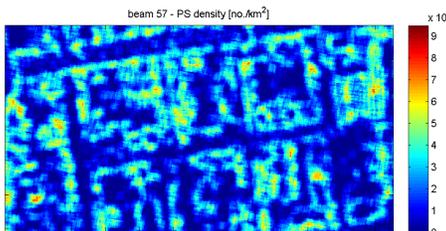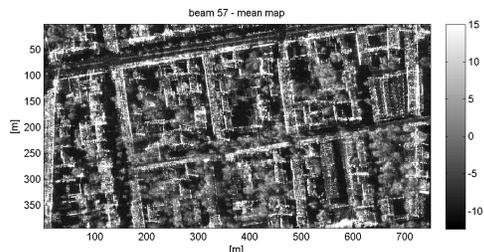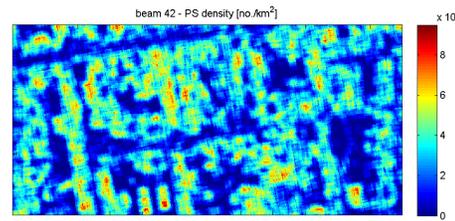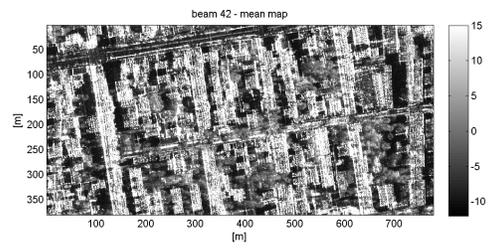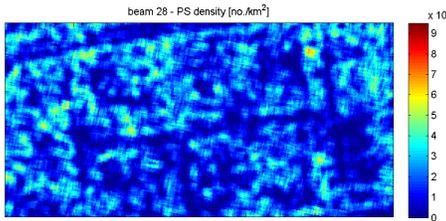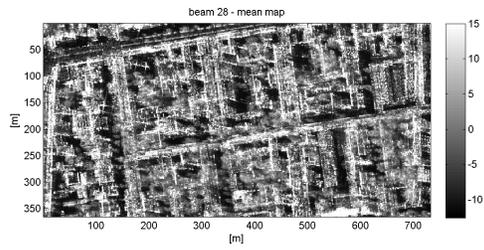
Figure 7. Top to bottom: Ascending beam 28, 57 and 85 mean map and PS density map with window size 15m x 15m; coloration equal to last figures; Increased density from beam 28 to 57, but loss to beam 85 as shadow areas and reduced resolution in elevation eliminates PS from facade (floors)

Figure 8. Top to bottom: Descending beam 42, 70 and 99 mean map and PS density map (window size 15m x 15m); coloration equal to last figures; Changes of PS densities comparable to ascending track, but all together much more PS extracted, as orientation of buildings parallel to sensor flight direction

From different regions in the given scene it seems that fewer candidates for steep incidence angle cases could be extracted due to weaker returns in addition to possible separation difficulties of isolated targets from background in these cases as areas of overlay are very large for small incidence angles. In addition, some features of buildings produce scattering areas (compare Figure 3), whereby a threshold for the relative quantity of signal to surrounding clutter would have to be chosen very small in order to get any PS from these areas. But the same object shows an enormous increase in PS density - based on the same SCR threshold used - if a larger incidence angle is chosen, e.g. beam 85 in this case, shown in Figure 4. In this example the scattering is generated by a horizontal roof of a building which consists of many windows arranged like tiles.

In Figure 6 compared to Figure 5, the reason for the decrease of PS densities for large incidence angles can be seen. An increasing angle will lead to a decrease in resolution in elevation direction. Hence, the visible number of floors of houses, which can easily be extracted in high resolution SAR images, will drop and the number of PS lessens. In addition shadow areas appear evoked by the height of buildings, which also reduces the visibility of facades of nearby houses, dependant on the distance and heights of the constructions, which is also clearly observable in Figures 7 and 8.

Differences between ascending and descending orbits in the Berlin case arise from the different viewing directions resulting from the path of the satellite with respect to ground. As commonly known, response of objects change considerable if acquired by SAR from different sides what is the reason for different densities comparing ascending and descending tracks. This effect can be seen especially in Figure 7 compared to Figure 8, as the density of PS is much smaller for beam 28, 57 and 85 compared to the three descending beams. Of course this example is an extreme one as the facades of the buildings in this case are aligned parallel to the sensor and produce many scatterers, but nevertheless emphasizes the high correlation of PS density to geometrical circumstances.

5. SUMMARY AND OUTLOOK

This investigation gave a first insight to PS densities obtained for the region of Berlin from different incidence angles and track types. It has been shown that incidence angles in the mid range of approximately 40° to 47° are the best choice for PSI as potential persistent scatterers can be extracted from facades and top of buildings while larger angles will reduce the density due to growing shadow areas and loss of stories of buildings, which are likely to generate many PS. In addition steep looking directions can lead to scattering areas, which will have to be treated in a particular manner in order to extract PS points. The most appropriate incidence angles depend of course on the local relations of building heights and distances in between in addition to given possibilities from orbital positions. From comparison between ascending and descending tracks, it could be shown that the main orientation of the buildings should be considered for maximizing the potential number of scatterers in the scene chosen, if this is feasible for the order.

Further investigations will include density analysis of more subregions as the whole scene could not be examined to all extents. In the meantime HH polarized datasets could be obtained and will be included in the following investigation on PS densities which will complete the analysis on the dependence on acquisition parameters.

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