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Land Subsidence Assessment by Using Persistent Scatterer Interferometry of Sentinel-1 Data: A Study of Vienna City, Austria

Enton Bedini
International Institute of Geo-information Science and Earth Observation (ITC),
Enschede, The Netherlands
enton_bedini@hotmail.com

ABSTRACT

Persistent Scatterer Interferometry analysis of Sentinel-1 radar images was carried out to assess the land subsidence phenomenon in the city of Vienna, Austria. The analysed dataset consisted of sixty Sentinel-1A Interferometric Wide images of January 2018 – December 2019, acquired in ascending orbit in vertical transmitting - vertical receiving polarization. In the city of Vienna do not occur major anomalies of land subsidence or uplift. However, there were detected few small zones with negative vertical displacement rates of up to -10 mm/year. Land subsidence in the area of the recently constructed Orbi tower detected by the PSI analysis is discussed in more detail. Further monitoring using geological engineering works and geodetic measurements is needed for this area. The study is a contribution on the assessment of subsidence and ground settlement processes in the city of Vienna, by means of satellite radar imagery.

Keywords: Sentinel-1; radar interferometry; time-series; persistent scatterers; Vienna.

1. INTRODUCTION

The Persistent Scatterer Interferometry (PSI) of multi-temporal Synthetic Aperture Radar (SAR) imagery [1], detects millimeter-scale ground motion. The SAR imagery has also found application in the monitoring of subsidence in the urban areas [2-4]. The Sentinel-1 satellite radar imagery constitutes an important dataset for ground motion investigation [5-10]. The Sentinel-1 registers SAR imagery in the C-band (5.3 cm) [11].

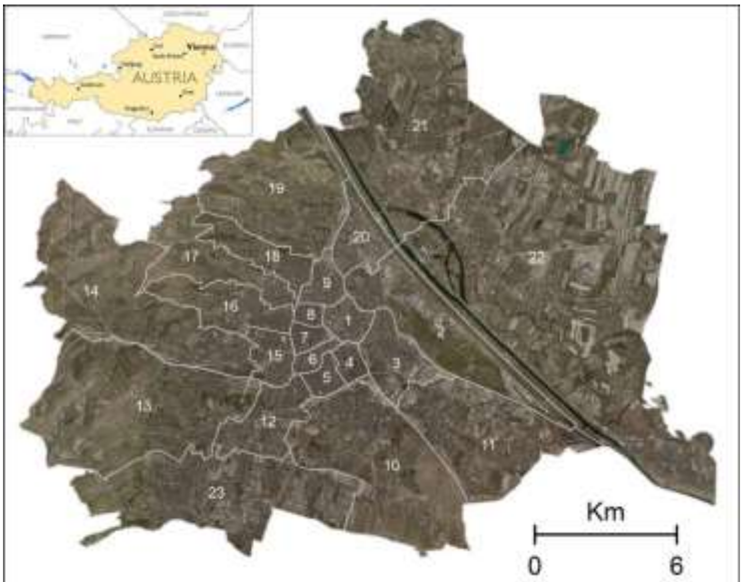

Figure 1. Google Earth^{TM} image of Vienna. The numbered polygons are the districts of the city of Vienna

This paper reports on the assessment of ground motion in the city of Vienna, the capital of Austria by satellite radar imagery. Vienna is located in the east of Austria, along the Danube River as can be seen in the above Figure 1. Vienna is an important political, economic, historical, and cultural centre of Europe. In the literature, there are not reported studies of radar interferometry for the investigation of subsidence and ground settlement phenomena in the city of Vienna. The study uses PSI of Sentinel-1 images of January 2018 – December 2019 to evaluate the occurrence of subsidence and ground settlement processes in Vienna.

2. MATERIALS AND METHODS

The Sentinel-1 SAR satellite images are acquired using the TOPSAR technology [12]. The Sentinel-1 standard swath mode is the Interferometric Wide (IW) [6]. The swath of the Sentinel-1 IW scenes is 250 km. The spatial resolution is 5 m × 20 m.

The Persistent Scatterer Interferometry (PSI) [1], is rooted in the Differential Interferometric Synthetic Aperture Radar (DInSAR) technique [13]. The DInSAR employs the pixel-per-pixel radar phase (φ) of two co-registered images of an area, to form an interferometric pair [4]. Figure 2 depict the difference of the radar phase (φ) in the two measurements at a target on the ground unexplained from other factors like noise, atmosphere, sensor position, topography and is attributed to displacement (φ_{Displ}). The DInSAR is widely applied in the fields of glaciology, volcanology, seismology, landslides, ground subsidence and uplift [4, 8, 14-21].

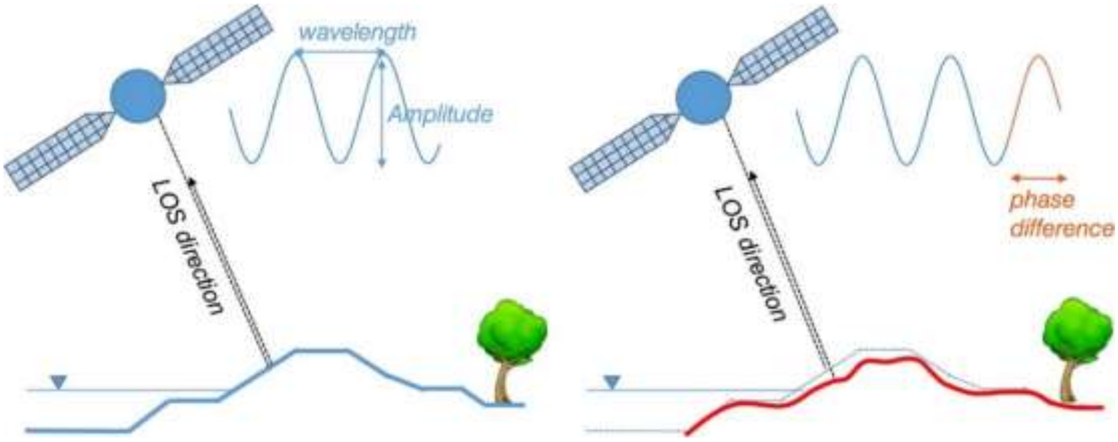

Figure 2. The DInSAR basic concept. Interferometric Synthetic Aperture Radar (InSAR) measurements are carried out before and after the deformation event. Displacement is measured as a fraction of the radar wavelength, modified from [22].

To detect millimetre-scale motion of the ground in the presence of other factors (atmospheric disturbance, topographic height differences, sensor noise etc.) the interferometric analysis of SAR images over targets (Persistent Scatterers) that show strong and consistent radar backscatter is used [1]. One of the techniques to identify the PS in SAR data is the calculation of the amplitude dispersion [1].

The time-series of SAR imagery consisted of 60 Sentinel-1A IW images of January 2018 – December 2019, acquired in ascending orbit 73 in VV and VH polarizations. The VV polarization images were processed for the PSI analysis. The images were de-bursted, and subsetted to the spatial extent of the city of Vienna as can be seen in the Figure 3. As the master image was selected an image recorded on November 30, 2018. All the other images were co-registered with the master image. The time-position relation of the Sentinel-1 images is shown in Figure 4.

The differential interferograms were computed between the master image and each of the images. Digital Elevation Model of the Shuttle Radar Topographic Mission of NASA was used. The interferograms were flattened to remove the Earth's curvature effect. The Amplitude Dispersion Index was employed to locate the Persistent Scatterers (PS). At these Persistent Scatterers locations is estimated the displacement along the line-of-sight of the sensor, or projected to vertical displacement.

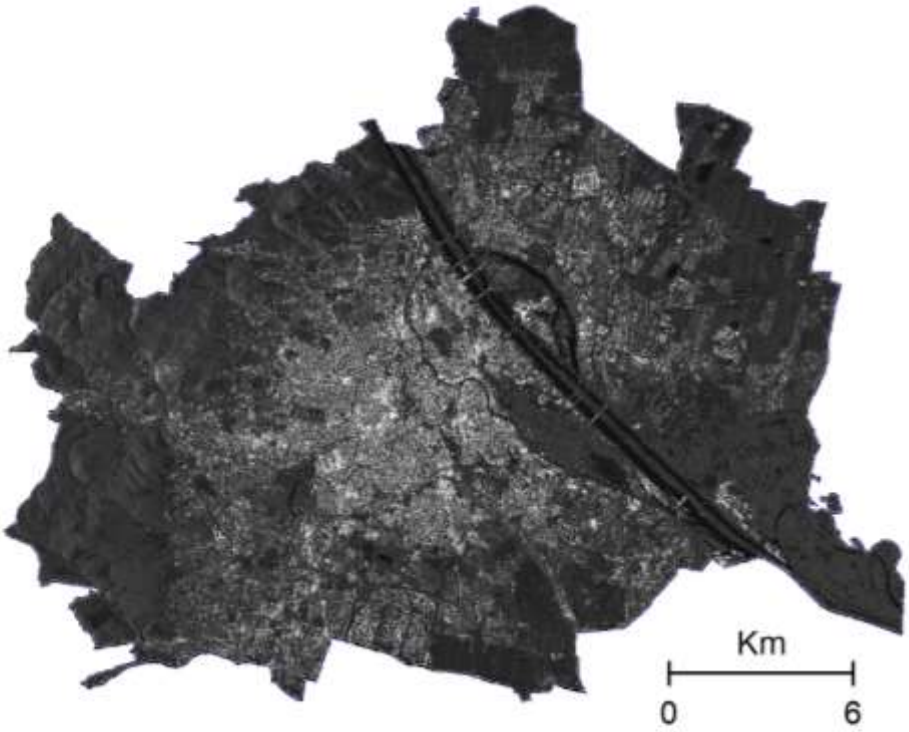

Figure 3. Sentinel-1 radar image of the city of Vienna.

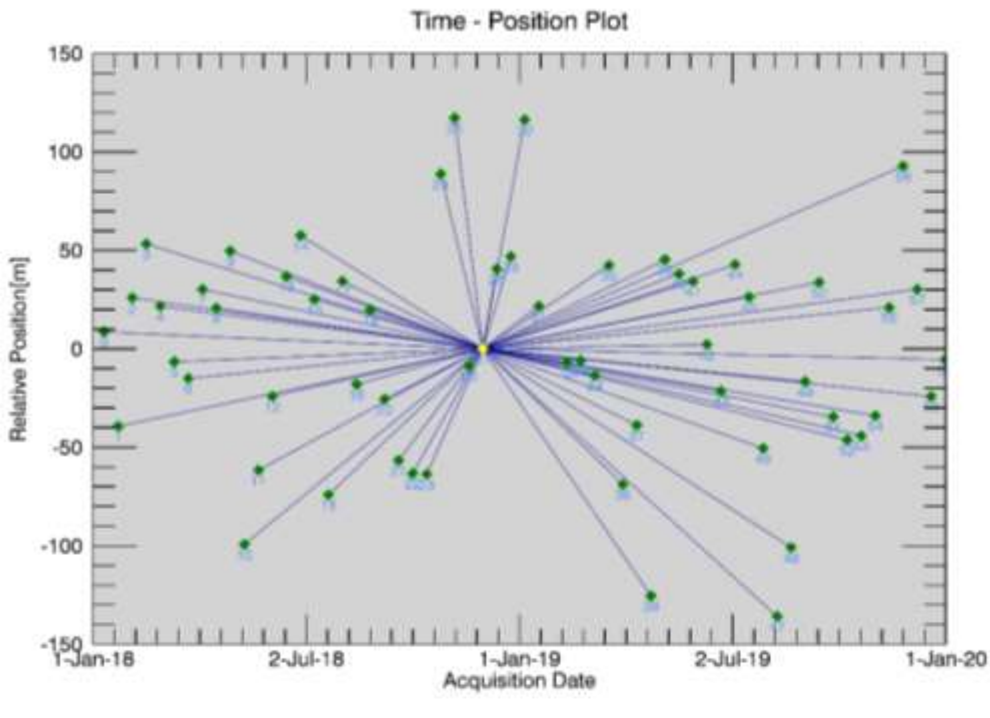

Figure 4. The temporal and relative spatial position of Sentinel-1A images.

3. RESULTS

The analysis of this dataset of Sentinel-1 images of January 2018 – December 2019 shows that in Vienna there are no problematic areas of subsidence, with the exception of few small zones. This is visible in the general picture as can be seen in the Figure 5 or by the close-up of particular areas. In Figure 6 and 7 are shown close-up examples of the PSI results in a part of Vienna historic center and of the area of Belvedere gardens. These areas are stable and minor variance in the data could be related to noise or the thermal expansion effect (e.g., [23]). An exception is the Parliament Building, Figure 6, which based also on Google Earth images has been under renovation works in this time, a factor that may have caused some instability also in parts of the building that have remained coherent in the radar imagery of 2018-2019 time period. In this case the negative rates detected from the PSI analysis are related with the renovation works, and not with ground motion processes.

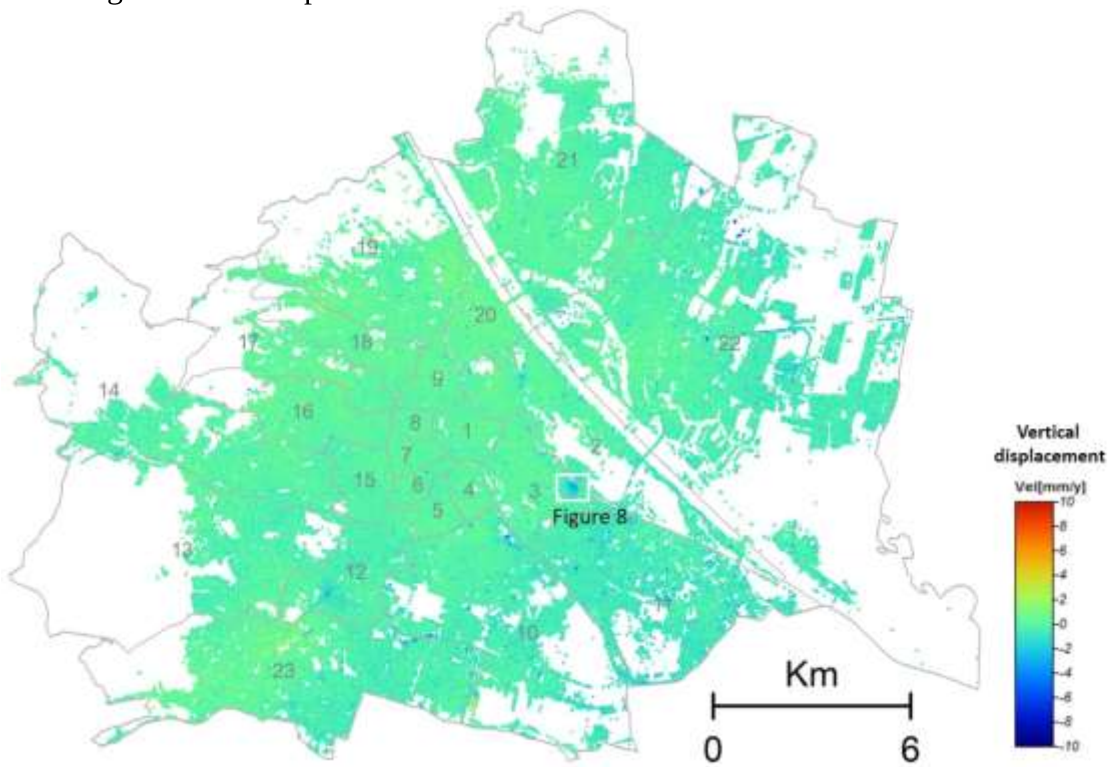

Figure 5. Results of PSI analysis. The numbered polygons are the districts of Vienna for reference with Figure 1.

Few small areas with negative displacement rates up to -10 mm/year were detected. One example is shown in Figure 9. The subsidence occurs in the area of Orbi tower that is constructed in the recent years close to Danube Canal. The Danube Canal once an original branch of the Danube River is regulated as a water channel since 1600. In addition, based on the PSI analysis recently constructed roads in the same area also display ground subsidence or ground settlement processes.

Figure 6. Close-up of the PSI results in a part of the Vienna historic centre. The background image is from Google Earth™.

Figure 7. Close-up of the PSI results in area of Vienna with the Belvedere Gardens at its centre. The background image is from Google Earth™.

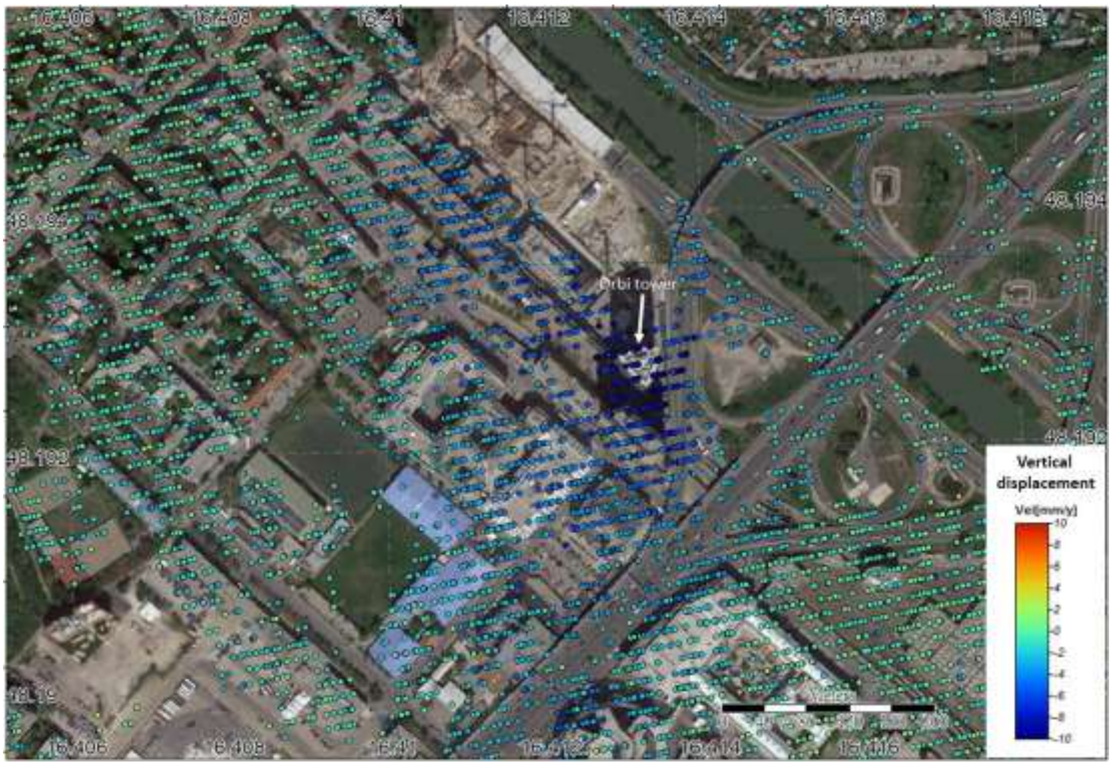

Figure 8. The PSI results at the area of the recently constructed Orbi tower, Vienna. Note the negative displacement rates (shown by light blue to dark blue circles) at the Orbi tower and in the surrounding area. The background is an image of April 5, 2019 from Google Earth^{TM}.

The extent of the negative displacement rates also on buildings that have not been recently constructed indicates that the construction of the Orbi tower, and other construction activities in this area have probably had impact on the ground water level. In this way the negative vertical displacement rates in this area are not interpreted as usual ground settlement process. The changes that have occurred in this area due to the recent constructions of buildings and roads can also be observed in Google Earth^{TM} historical imagery. Ground subsidence and prolonged ground settlement processes are characteristic hazards for construction works in river bank areas [24].

4. CONCLUSION

This study was conducted for the period January 2018 until December 2019 and 60 Sentinel-1 images were processed with the PSI technique to investigate the land subsidence and ground settlement processes in the city of Vienna, Austria. No major anomalies of ground motion were noted in the city of Vienna. However, in the Vienna study area were detected few small zones with vertical displacement rates up to -10 mm/year. Especially notable is a subsidence zone in the area of the Orbi tower of Vienna. This area occurs close to the Danube Canal and is characterized by several construction works in the recent years, including the Orbi tower. Based on the spatial extent of the zone with negative vertical displacement rates, the cause of the subsidence cannot be assigned to usual ground settlement processes, but is probably related with the lowering of the groundwater table.

Further monitoring using geological engineering works and geodetic measurements is needed for this area.

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CONFLICT OF INTERESTS

The author confirms that there is no conflict of interests associated with this publication and there is no financial fund for this work that can affect the research outcomes.

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