3RD CONFERENCE OF THE ARABIAN JOURNAL OF GEOSCIENCES (CAJG)
2–5 NOVEMBER 2020, SOUSSE, TUNISIA

Monitoring ground deformation through time-series analysis of SAR data: An application to Chalkidiki peninsula, Greece

Stavroula Alatza[1], Ioannis Papoutsis[1], Demitris Paradissis[2], Charalampos Kontoes[1]

[1] National Observatory of Athens, 15236, Greece
[2] National Technical University of Athens, 15780, Greece
alatza@noa.gr

Abstract. The objective of the present study is to extract information about the displacement field in the central part of Chalkidiki peninsula, an area poorly investigated by means of SAR interferometry. InSAR time-series analysis was performed on datasets from ERS-2 and Sentinel-1 SAR sensors. Validation was provided by GPS observations near Polygyros city. For Sentinel-1 data, a combination of ascending and descending satellite imaging geometries was performed, to estimate the vertical motion components. SAR results indicate low-rate deformation around Polygyros city, not exceeding -2mm/y to 2mm/y. Negative displacement rates with a maximum value of –5mm/y are observed near Olynthos village, indicating the continuation of aquifer overexploitation phenomena near the Moudania watershed after 2014 and the importance of their mitigation.

Keywords: Chalkidiki, InSAR, time-series, ground deformation, aquifer overexploitation.

1 Introduction

Chalkidiki peninsula is part of Central Macedonia, in northern Greece. The broader area is very seismically active. In the Chalkidiki region and northern Greece in general, several geodetic networks have been established and operated for various time spans, ranging from 1994 to 2016, with the objective to estimate the kinematic behavior of northern Greece [1, 2]. Also, the broader area around Thessaloniki city in the western part of the Chalkidiki peninsula has been studied by means of SAR interferometry, with the objective to map geophysical and anthropogenic deformation phenomena [3-5]. This study focuses on monitoring ground deformation phenomena in the central part of the Chalkidiki peninsula and specifically, the broader area around Polygyros city, by means of SAR interferometry by exploiting both historical and recent satellite data.

2 Materials and Methods

For the InSAR time-series analysis, SLC/level-1 data, from 1992 to 2002 and 2014 to 2018 were employed, to extract deformation in the area of interest (see Fig. 1). Twentyseven (27) SLC images from the ERS-2 sensor of descending track no.7 were selected and analyzed with the combined InSAR method for PS and SBAS of StaMPS/MTI (Multi-Temporal InSAR) [6] software package. The Stanford Method for Persistent Scatterers was implemented on 34 Sentinel-1A and 1B images, of descending track no.7 and 30 images of ascending track no.102 to map deformation from 2014 to 2018. Specifically, for Sentinel-1 data, the Parallelized Persistent Scatterer Interferometry (P-PSI) [7], a processing chain that parallelizes several processing steps of ISCE and StaMPS/MTI software, was employed. To minimize decorrelation phenomena and phase-unwrapping errors, introduced by high relief and dense vegetation, special handling of the parameters during PS processing, was required. This approach resulted in a tradeoff between the number of the selected PS scatterers and a low signal-to-noise ratio. The open-source Toolbox for Reducing Atmospheric InSAR Noise (TRAIN) [8] was employed for the estimation and removal of the tropospheric contribution from the deformation phase. Since the area around Polygyros is characterized by intense topography, the linear correction provided a satisfying accuracy.

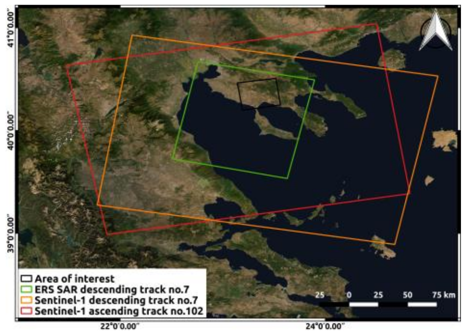

Fig. 1. Map of the area of interest in the Chalkidiki peninsula and the corresponding satellite footprints. The broader area of Polygyros city is depicted with the black rectangle, while the colored rectangles represent the satellite footprints.

3 Results and discussion

Low-rate velocities, not exceeding 2mm/y towards and away from the satellite, are observed in the majority of the area under investigation (see Fig. 2). No alterations in the LOS deformation pattern between the two time periods are observed (see Fig. 2a, 2b, 2c). Low mean standard deviation LOS velocities (0.5mm/y for Sentinel-1 data of ascending track no.102, 0.6mm/y for Sentinel-1 data of descending track no.7 and 0.7mm/y for ERS-2 data) hint that low-rate linear deformation occurs and that there is no bias in the estimated displacements. As expected, a higher rate of PS scatterers per km^2 (188 PS/km^2 for ERS data, 354 PS/$km^{2,}$ and 260 PS/km^2 for Sentinel-1 data of ascending and descending tracks, respectively) is detected in the city of Polygyros. The PS density is significantly reduced (19 PS/km^2 for ERS data, 14 PS/$km^{2,}$ and 5 PS/km^2 for Sentinel-1 data of ascending and descending tracks, respectively), near Mt. Cholomon Forest, to the north of Polygyros. An area around a GPS station, located near Vrastama village was selected as a reference, based on its stability in the north motion component. A subsiding area is identified near the Olynthos site, with a maximum deformation of -5mm/y (see Fig. 2b, 2c). For Sentinel-1 results, a decomposition of the line-of-sight displacements in the descending look direction was performed to estimate the vertical displacements (see Fig. 2d) by implementing the system of equations of [9] and the methodology proposed by [10]. Available observations from the PLGR GNSS station from 2013 to 2016 were compared to SAR results for the 2014-2018 time period. An absolute comparison between these two datasets is unfeasible. However, a transformation of the PLGR NEU motion components (N = 0.00526 m/y, E = 0.00251m/y, U = -0.00077m/y) to the slant range direction, using Equation 1 by [11], resulted to 0.1408 mm/y in the LOS direction, which also denotes a non-deforming area around Polygyros city.

$$u = u_{Up}\cos(\theta_{inc}) - \sin(\theta_{inc})\left[u_N \cos\left(\alpha_h - \frac{3\pi}{2}\right) + u_E \sin\left(\alpha_h - \frac{3\pi}{2}\right)\right] \quad (1)$$

where $\alpha_h - \frac{3\pi}{2}$ corresponds to the perpendicular to the satellite heading angle in the azimuth look direction, for a right-looking satellite and θ_{inc} corresponds to the incidence angle.

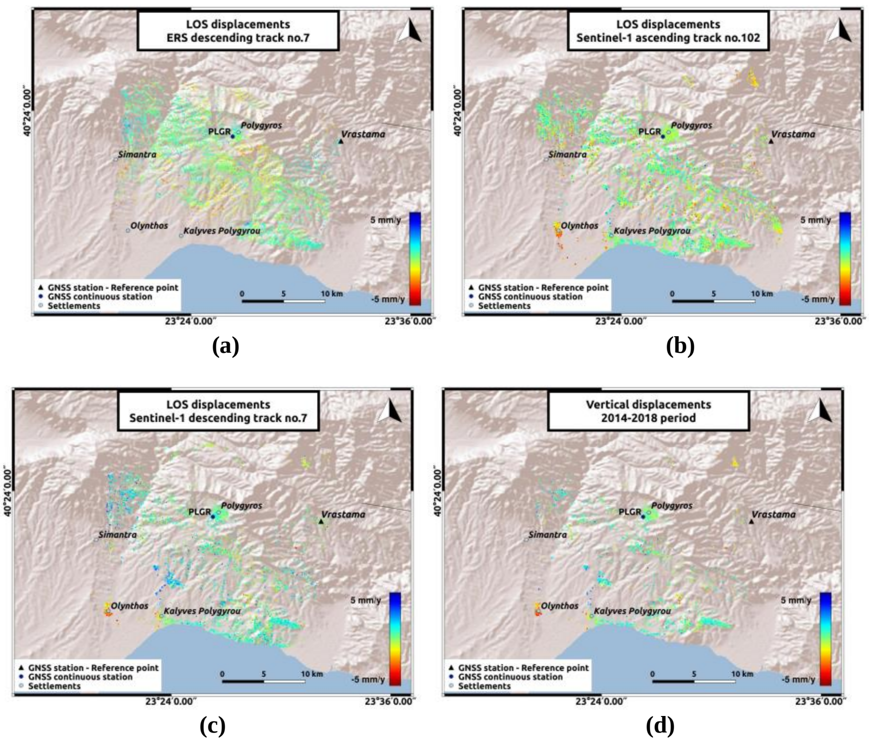

Fig. 2. a) PS-SBAS combination LOS displacements for ERS data. b) PS LOS velocities of Sentinel-1 data (ascending track 102). c) PS LOS velocities of Sentinel-1 data (descending track 7). d) Vertical displacements for the 2014-2018 period. The reference area near Vrastama village is marked with the black triangle. Also, the location of the GNSS continuous station PLGR is presented.

Considering the geodynamic field of the western Chalkidiki region, which belongs to a weakly deformed block [12], the stability observed in the broader area of Polygyros city, during both time periods, appears to be a reasonable conclusion. Evidence that the aquifer of Nea Moudania, in the western part of the Chalkidiki region, is over-exploited is provided by several piezometric studies [13, 14]. Olynthos is among the sites where a piezometric decline is observed for the 2003-2014 time period. Negative LOS (see Fig. 2b, 2c) and vertical (see Fig. 2d) displacements, estimated for the 2014-2018 time period, near Olynthos village, clearly depict that water balance in the area might not have been restored after 2014, and that over-exploitation of the Moudania watershed continues. This observation is also highlighted in [15], through an InSAR analysis from 2015 to 2019, validated by ground truth data.

4 Conclusions

An extensive study was performed focused on the central part of Chalkidiki with the objective to identify the type of deformation that occurs and its relation with natural processes or human activities. SAR results indicate low-rate deformation in most parts, around Polygyros city, not exceeding -2mm/y and 2mm/y, an observation which is also verified by GPS measurements. A noteworthy phenomenon is subsidence near Olynthos village with a maximum rate of -5mm/y, attributed to over-exploitation of the Moudania watershed, denoting a continuous phenomenon from 2003 to 2018, which needs to be addressed. Finally, with the addition of SAR results for the intermediate time period between 2002 to 2014, which is a work in progress, we aim to achieve a complete overview of the deformation field in the central part of the Chalkidiki peninsula and its association with tectonic or anthropogenic activities.

References

1. Mouslopoulou, V., Saltogianni, V., Gianniou, M., Stiros, S.: Geodetic evidence for tectonic activity on the Strymon Fault System, northeast Greece. Tectonophysics, 633:246–255 (2014).
2. Rontogianni, S.: Comparison of geodetic and seismic strain rates in Greece by using a uniform processing approach to campaign GPS measurements over the interval 1994–2000. Journal of Geodynamics, 50:381–399 (2010).
3. Raucoules, D., Parcharidis, I., Feurer, D., Novalli, F., Ferretti, A., Carnec, C., Lagios, E., Sakkas, V., Le Mouélic, S., Cooksley, G., et al.: Ground deformation detection of the greater area of Thessaloniki (Northern Greece) using radar interferometry techniques. Nat. Hazards Earth Syst. Sci., 8, 779–788 (2008).
4. Mouratidis, A., Briole, P., Ilieva, M., Astaras, T., Rolandone, F., Baccouche, M.: Subsidence and deformation phenomena in the vicinity of Thessaloniki (N. Greece) monitored by Envisat/ASAR interferometry. In Proceedings of the Fringe 2009 Workshop: Advances in the Science and Applications of SAR Interferometry, Frascati, Italy, 30 November–4 December 2009.
5. Svigkas, N., Papoutsis, I., Loupasakis, C., Tsangaratos, P., Kiratzi, A., Kontoes, C.H.: Land subsidence rebound detected via multi-temporal InSAR and ground truth data in Kalochori and Sindos regions, Northern Greece. Eng. Geol., 209, 175–186 (2016).

6. Hooper, A.: A multi-temporal InSAR method incorporating both persistent scatterer and small baseline approaches. Geophys. Res. Lett., 35: L16302 (2008).
7. Papoutsis, I.; Kontoes, C.; Alatza, S.; Apostolakis, A.; Loupasakis, C. InSAR Greece with Parallelized Persistent Scatterer Interferometry: A National Ground Motion Service for Big Copernicus Sentinel-1 Data. Remote Sens. 2020, 12, 3207.
8. Bekaert, D.P.S.; Walters, R.J.; Wright, T.J.; Hooper, A.J.; Parker, D.J. Statistical comparison of InSAR tropospheric correction techniques. Remote Sens. Environ. 2015, 170, 40–47.
9. Samieie-Esfahany, S., Hanssen, R., van Thienen-Visser, K., Muntendam-Bos, A.: On the effect of horizontal deformation on InSAR subsidence estimates. In Proceedings of the Workshop Fringe 2009, Frascati, Italy, 30 November–4 December 2009.
10. Papoutsis, I., Kontoes, C., Paradissis, D.: Multi-track Persistent Scatterer Interferometry Analysis in Wider Athens, Greece. Remote Sensing, 9(3):276 (2017).
11. Hanssen, R. Radar Interferometry: Data Interpretation and Error Analysis. Remote Sensing and Digital Image Processing, 2nd ed.; van der Meer, F., Ed.; Kluwer Academic Publishers: Dordrecht, The Netherlands, 2001.
12. Kougoulis, C., Arvanitis, A., Kolios, N., Koutsinos, S., Kougoulis, J.: Geothermal exploration in the Sani-Afytos area of the Kassandra peninsula (Chalkidiki peninsula, Northern Greece). Bulletin of the Geological Society of Greece, 40(3):1162–1176 (2007).
13. Veranis, N., Nimfopoulos, M., Christidis, C., Chrysafi, A.: granular aquifer system of west chalkidiki area, region of central macedonia, northern greece. bulletin of the geological society of greece, 50(2):1016–1026 (2016).
14. Siarkos, I. and Latinopoulos, P.: Modeling seawater intrusion in overexploited aquifers in the absence of sufficient data: application to the aquifer of Nea Moudania, northern Greece. Hydrogeol J, 24:2123–2141 (2016).
15. Svigkas, N., Loupasakis, C., Papoutsis, I., Kontoes, C., S. Alatza, S., Tzampoglou, P., Tolomei, C., Spachos, T.: Insar Campaign Reveals Ongoing Displacement Trends at High Impact Sites of Thessaloniki and Chalkidiki, Greece. Remote Sensing, 12(2396) (2020).