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Landslide risk evaluation in Cyprus using satellite radar interferometry: the "Rantkat" project

Évaluation du risque de glissement de terrain à Chypre par interférométrie radar: le projet "Rantkat"

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ABSTRACT: Landslides are a major hazard in Cyprus, especially in the district of Paphos and in some areas of Limassol district (Pissouri), with more than 1840 landslides being recorded. Satellite radar interferometry techniques Small Baseline Survey (SBAS) and Persistent Scatterer Interferometry (PSI) have been used to determine ground movement in landslide-prone areas with millimetric accuracy for the period 2014-2018, using imagery acquired by Sentinel-1A/B. Results showed linear and non-linear ground movement, the latter due to the presence of swelling clays. The use of ascending and descending satellite radar data enabled the decomposition of movement into both vertical and horizontal vectors. Analyses identified previously unknown landslides highlighted the potential for the early detection of ground movement. In the Pissouri case study, the perimeter of the rotational landslide was detected. Interferometric-determined ground movement was validated by in-situ information from inclinometers. The detected ground movement data were used together with topographic factors such as ground slope, aspect, flow accumulation, extracted from the Digital Elevation Model (DEM) and other data such as geotechnical, geological and meteorological data for the study areas to evaluate landslide risk. A GIS interface is under development for the hosting of a live map of movements and risk maps. This is part of the project "RANTKAT", funded by the European Union Structural and Cohesion Funds and the Republic of Cyprus as part of the Program for Entrepreneurship and Innovation.

RÉSUMÉ: Les glissements de terrain constituent un danger majeur à Chypre, en particulier dans le district de Paphos et dans certaines zones du district de Limassol (Pissouri), avec plus de 1 840 glissements de terrain enregistrés. Techniques d'interférométrie radar par satellite Les enquêtes SBAS (Small Baseline Survey) et Interférométrie à dispersion persistante (PSI) ont été utilisées pour déterminer les mouvements du sol dans les zones sujettes aux glissements de terrain avec une précision millimétrique pour la période 2014-2018, à l'aide d'images acquises par Sentinel-1A / B. Les résultats ont montré un mouvement du sol linéaire et non linéaire, ce dernier étant dû à la présence d'argiles gonflantes. L'utilisation de données radar satellitaires ascendant et descendant a permis de décomposer les mouvements en vecteurs verticaux et horizontaux. Les analyses identifiées sur des glissements de terrain auparavant inconnus ont mis en évidence le potentiel de détection précoce des mouvements du sol. Dans l'étude de cas Pissouri, le périmètre du glissement de terrain en rotation a été détecté. Les mouvements du sol déterminés par interférométrie ont été validés par des informations in situ fournies par des inclinomètres. Les données de mouvement du sol détectées ont été utilisées avec des facteurs topographiques tels que la pente, l'aspect, l'accumulation de flux, extraites du modèle numérique d'altitude (DEM) et d'autres données telles que les données géotechniques, géologiques et météorologiques des zones étudiées pour évaluer le risque de glissement de terrain. Une interface SIG est en cours de développement pour héberger une carte en temps réel des mouvements et des cartes de risques. Cela fait partie du projet "RANTKAT", financé par les Fonds structurels

et de cohésion de l'Union européenne et la République de Chypre dans le cadre du programme pour l'esprit d'entreprise et de l'innovation.

Keywords: Ground movement; interferometry; landslides.

1 INTRODUCTION

There has been a continuous increase in the number and severity of natural and man-induced disaster events over the years worldwide. Natural disasters such as landslides can result in major loss of life, damage to properties and huge economic impact. The south western side of Cyprus has a long history of slope instability problems (Kyriacou and Hadjigeorgiou, 2008, Hart et al., 2010). A study in 2010 over an area of 545 km^2 in the south western part of Cyprus recorded 1842 landslides, covering an area of 130 km^2 (Hart and Hearn, 2013). In 2011 alone, heavy rainfall resulted in a further 128 landslides being triggered causing enormous damage in the affected areas.

The occurrence of landslides in the Paphos district is associated with the presence of the Mamonia melange and the Kannaviou bentonitic clays, geological formations that are prone to landslide occurrence (Alexandris et al, 2016). Pissouri, a village between Limassol and Paphos, close to the southwestern coastline of Cyprus, has faced many slope instability problems over the years due to its morphological and hydrological conditions. Properties were evacuated as a result of landslides in certain areas, some of which are still active. Other areas of concern include the villages of Armou, Episkopi, Marathounta, Kritou Marottou etc., some residents of which were relocated in the past to nearby sites as a result of landslide activity.

Various factors have contributed to the current pattern of slope instability in this area, such as climate change with intensive rainfall, hydrological conditions, land cover and land use changes with tourist developments and expansion of urban areas into landslide-susceptible areas.

Conventional investigations into slope instability problems include installations of in situ ground movement monitoring equipment such as inclinometers and GPS stations. The limitations of both techniques include a) the localisation of their measurements to the points where the data are taken and b) inability to observe data prior to the installation of monitoring instruments, thus the past behaviour of the ground remains unknown. These two limitations can be overcome using satellite remote sensing methodologies such as Interferometric techniques of Synthetic Aperture Radar (SAR) data. This paper presents the results of SAR data analyses using Persistent Scatterer Interferometry (PSI) and Small Baseline Subset (SBAS) techniques using data between 2014 and 2018. This enabled the study of historical ground movement in terms of velocity (mm/year) with millimetric accuracy, thus identifying slow-moving landslides before they became apparent or in cases where access was difficult. In addition, ground movement estimates cover wide areas and are not localised to the point of instrument installation as with conventional ground movement monitoring.

2 STUDY AREA

Three study areas were selected for the purposes of this study as follows:

a) Area A including Pissouri village
b) Area B including the villages of Armou and Episkopi
c) Area C including the village of Kritou Marottou.

The study areas are shown in Figure 1.

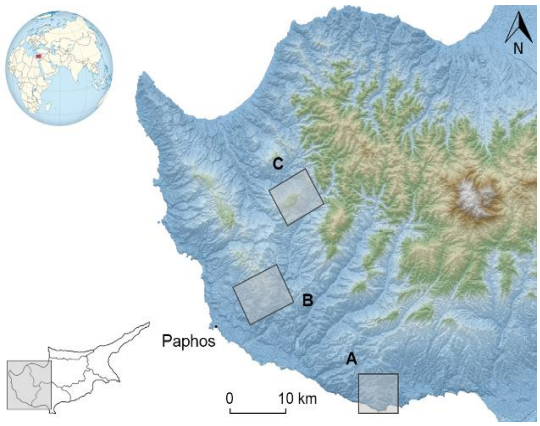

Figure 1. Map of study area

Area A includes Pissouri village with a long history of slope instability problems. A major landslide in the winter of 2001/2002 resulted in evacuation and demolition of homes and the installation of stabilisation measures (piling) along the slope. Area A also includes another area of Pissouri called Limnes with an active landslide destroying roads and housing in the area.

Area B includes the villages of Armou, Marathounda and Episkopi and Area C the village of Kritou Marottou, both of which have suffered from landslide-related problems.

2.1 Geology

The geology of Area A (Pissouri) is characterised by sediments of Pliocene-Pleistocene age, calcarenites, carbonate marls and sandstones of the Nicosia formation. The sandstones are of Pleistocene age, intercalated with widespread red colour paleosols and conglomerates, covered by a layer of sandy weathered sandstone in most areas. Underneath is the Pissouri marl, characterised by occasional sandy interlayers. The marlstone is prone to fast weathering and the fresh marl is covered by a layer of weathered sandstone. It appears as a fractured reddish-brown rock which disintegrates in places into a compound of marl blocks within a matrix of stiff fissured silty/clayey soil. The Limnes site consists of a layer of loose deposits from paleolandslides, reaching a depth of 13 m. This is underlain by a layer of Marls of the Pleistocene age of the Nicosia formation. A third layer of the Kalavassos formation is apparent at greater depths of the Limnes area and is characterised by gypsiferous marls and slickensides as a result of old landslides in the area. The elevation of Area A is around 200m above mean sea level.

The greater Paphos district (Areas B and C) comprises bentonitic clays, mudstones and tuffaceous sandstones, clay-rich melange and a sedimentary melange, overlaid by chalk and limestones. The area extends between the western coastline and the Troodos mountain range including river valleys, characterised by steep slopes and canyons. The village of Armou (Area B) is characterized by bentonitic clays of high plasticity and up to 10 m thick. As at the Limnes site, the area of Armou may have been affected by old landslides in the area. The elevation of areas B and C is around 350m and 540m above mean sea level, respectively. The village of Kritou Marottou is located in an area characterized by bentonitic clay deposits of the Kathikas formation which cover the Kannaviou clay formations.

2.2 Precipitation data

South-western Cyprus' climate is characterised by hot dry summers and mild winters. Loss of water by evaporation is high during the summer and winter. Thirty-year annual rainfall averages range from less than 500 mm at the coast to more than 800 mm in the Troodos Mountains to the east (Hart and Hern, 2013). Rainfall is limited to the winter and spring months with almost negligible precipitation during the summer months. However, there are events of locally intensive rainfall causing flooding and triggering landslides (Hart and Hern, 2013). Landslide events such as a major one in Pissouri village was associated with intensive rainfall in the winter of 2001-2002. Similarly, a landslide in the Armou village was also associated with intensive rainfall

during the winter 2011-2012. Precipitation data from nearby meteorological stations show increased precipitation during these winter periods.

3 METHODOLOGY

The methodology involves the use of Differential Interferometry techniques for the measurement of ground displacement using spaceborne data. The data used are freely available satellite data provided by the European Space Agency's Sentinel-1 A/B satellites. The Sentinel-1A satellite was launched in 2014 and is capable of mapping the entire globe every 12 days. The two-satellite constellation offers repeating mapping over the same area every 6 days (alternating between ascending and descending modes which have a 12-day revisit time each). Ascending mode includes mapping of an area to the east of the satellite antenna while descending mode includes mapping of data to the west of the satellite antenna. Combination of both constellations (ascending and descending) enables the decomposition of displacement into vertical and horizontal vectors. Synthetic Aperture Radar (SAR) such a Sentinel-1 A/B is an active system, meaning that it transmits radio waves from a satellite antenna and receives a reflected wave from a target. Therefore, it does not rely on sunlight and thus can operate both during day and night. Radar measurements can be made under any weather conditions as the propagation of radio waves through the atmosphere is not affected by the presence of clouds.

3.1 Differential Interferometry

SAR data consist of two types of measurements: phase and amplitude. Phase is used to measure the position of a target in time and is translated as the distance between the antenna and the target. Amplitude is related to the surface roughness and target characteristics. For ground movement estimates, phase measurements are used, applying different techniques known as Differential Interferometry. The principle is based on the fact that displacement of a target on the earth surface (settlement or uplift) will result in a difference in phase between two observations (from the same satellite) of the same target, due to the longer or shorter travel distance of the scattered wave (due to subsidence or uplift) and can be converted into a measurement of ground movement over that period (Gabriel et al., 1989).

PSI and SBAS techniques are extensions of conventional 'Differential Interferometry'. They are also known as 'Interferometric Stacking' techniques and are employed for obtaining precise terrain displacements of millimetric accuracy.

3.2 PSI

The PSI technique is based on the analysis of long temporal stacks of satellite SAR data, providing annual velocities of the ground (mm/year). The PSI technique is used widely for detecting and measuring ground movement with high accuracy (Ferretti et al., 2001). In PSI, interferograms are formed using a single master scene (minimum of 20 time-series images) and analysed at single look resolution to maximise the signal to clutter ratio of resolution cells containing a single dominant scatterer. Such scatterers known as 'Persistent Scatterers' are objects which are coherent reflectors. Examples of such targets include buildings and exposed rocks with highly angular shape. The clutter is part of the backscattered signal from non-PS scattering elements within a resolution cell. The PSI technique is particularly useful in urban, semi-urban and non-vegetated dry areas. More importantly, the PSI technique is particularly useful for ground movements that follow a linear trend. For those points with strong reflectance over time, the velocity is measured over time (mm/year). The results obtained from the application of the PSI technique are velocity estimates along the satellite's Line of Sight (LOS) which depends on the orbit direction (ascending or descending). By combining two different geometries the signal can be decomposed into vertical and horizontal movements.

3.3 SBAS

The SBAS technique is based on the analysis of the so-called distributed targets, as opposed to the persistent scatterer targets used in the PSI technique. The deformation signal is derived from a set of multi-looked interferograms formed over highly correlated areas. In this way, the phase estimation is significantly improved through the reduction of signal noise. Furthermore, the use of a network of interferograms formed through pairs with a perpendicular baseline over a certain threshold helps limit the effects of geometric decorrelation and increases the accuracy of the final displacement result. The SBAS technique applies to non-linear movements such as areas characterised by swelling clays and in rural, sparsely vegetated areas. The technique has been successfully used in many ground displacement applications (Sansosti et al., 2014).

3.4 Other parameters

The combination of the PSI and SBAS interferometric stacking techniques enables the determination of ground and infrastructure displacement estimates in the majority of cases. The ground displacement estimates from PSI and SBAS analyses are used together with other parameters for the development of a customised developed GIS for landslide risk evaluation. The topographic related parameters were extracted from the Digital Elevation Model of the study areas and include mapping of the slope, aspect, flow accumulation, curvature, elevation, land cover, distance to fault, distance to river, etc. Additional information such as the lithology (acquired from geological inventory maps) and precipitation data – intensity in mm/day, cumulative in mm/month or seasonal – from nearby meteorological stations are also used. The parameter's relative importance will be assessed via the application of a machine learning algorithm (Ciampalini et al, 2016).

3.5 Landslide risk evaluation map

In this section the development of the risk evaluation map procedure is described. The risk evaluation map is produced by implementing a machine learning algorithm such as the Random Forest algorithm (Catani et al., 2013, Duro et al., 2012). This is a non-parametric multivariate classification (Breiman, 2001), based on classification trees with high classification accuracy and no overfitting (Ciampalini et. al., 2016). A training set is randomly selected covering a set proportion of the landslide inventory (registered landslides in Cyprus). The standard deviation and the variance will be calculated for each variable using a window of 100m by 100m. It should be noted that the DEM has a 20m x 20m spatial resolution. Resampling will be applied to average the estimates to a 100m x 100m window. The average value inside a 100m x 100m pixel will be calculated and 4 susceptibility classes will be used for the assignment of each pixel as follows: a) low to null, b) moderate, c) high and d) very high. Cut-off values for the determination of the classes will be determined based on the best Receiver Operating Characteristic curve (Frattini et al., 2010, Ciampalini et al., 2016).

For the integration of the susceptibility map with the radar-derived ground displacement estimates, a numerical value will be assigned to each of the four categories of land susceptibility such as a) low to null =1, b) moderate = 2, c) high = 3 and d) very high = 4. The ground displacement values will be averaged within a 100m x 100m cell so that they can be integrated with the land susceptibility map already developed.

The susceptibility degree will then be increased for the cases where ground displaement was detected. The susceptibility degree increase (i.e. from one class to the next one or from one class to two classes up) will depend on the standard deviation. For example, the susceptibility degree will be increased by 1 degree if the measured displacement lies between 1 and 2 standard deviations of the stability

threshold. A detailed description of the methodology is provided in Ciampalini et al., 2016).

4 RESULTS

PSI analyses were applied for each of the three study areas. Results showed subsidence of magnitude 12 mm/year in areas B and C, as shown in Figures 2 and 3 respectively.

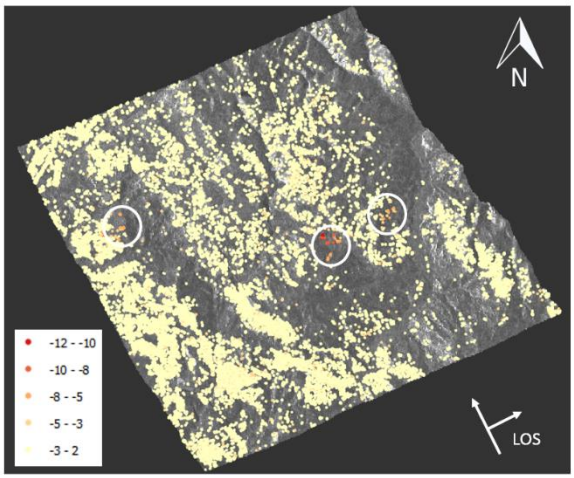

Figure 2: Velocity in area B along the satellite line of sight (LOS). Maximum velocity in the area was estimated at -12 mm/year (shown in red).

Ground displacement from PSI analysis was compared with in situ inclinometer data in Area B (Armou village). The selected point is adjacent to the borehole where an inclinometer was installed by the Cyprus Geological Survey and a comparison showed very similar trends between radar-determined displacements and inclinometer measuerements as shown in Figure 4. The inclinometer data show greater displacement than the radar data due to the fact that these values are along the line of sight of the satellite while the inclinometer measurements are along the slope of the landslide. Reprojection of the radar estimates to the slope of the landslide will provide more comparable results.

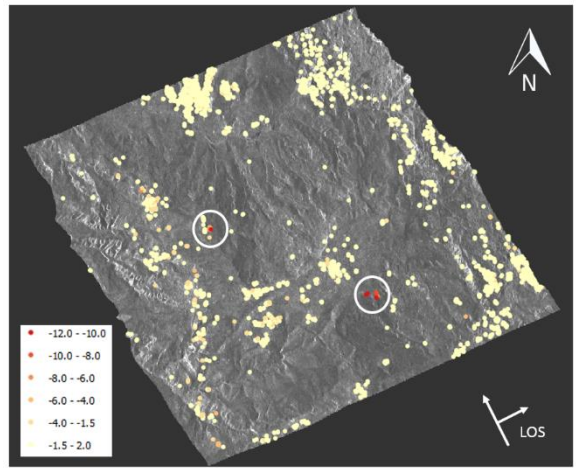

Figure 3: Velocity in area C along the satellite line of sight (LOS). Maximum velocity in the area was estimated at -12mm/year (shown in red).

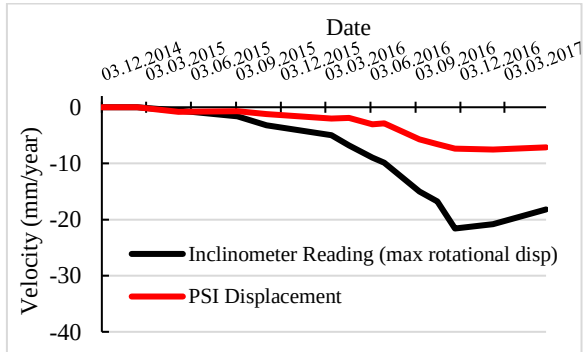

Figure 4: Comparison of PSI and inclinometer data at Armou village.

PSI did not perform very well (no detection of point targets) in Area A due to the non-linear ground movement. SBAS was performed in this area from both ascending and descending data sets which were decomposed into vertical and horizontal movements (Figures 5 and 6 respectively). Vertical displacement was in the magnitude of 23 mm/year subsidence while horizontal displacement was determined as 20mm/year.

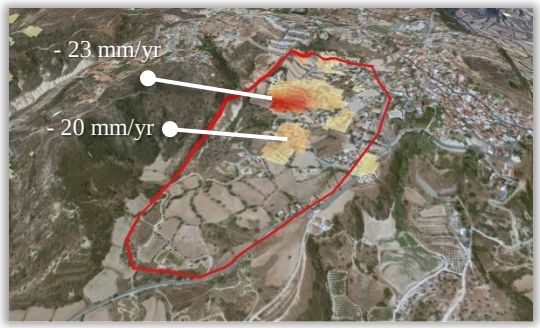

Figure 5: Vertical displacement of Area A with values up to -23mm/year using SBAS analysis

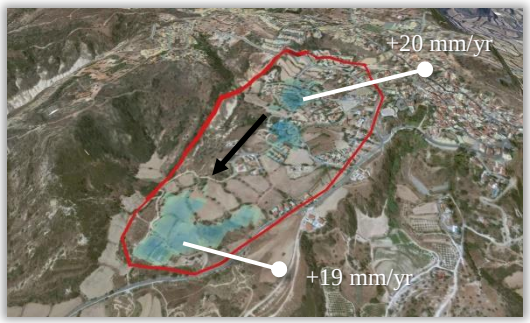

Figure 6: Horizontal displacement of Area A with values up to 20mm/year using SBAS analysis. Black arrow shows direction of movement

5 CONCLUSIONS

Interferometric stacking techniques PSI and SBAS were used in three areas in Cyprus, aimed at identifying landslides and determining ground movement. Radar-determined data will be combined with other parameters derived mainly from the Digital Elevation model of the area, from rainfall data and from lithology characteristics of the site to develop risk evaluation maps for landslides using machine learning algorithms. The developed risk evaluation maps will be hosted in a customised GIS interface. This paper presents some of the results from the PSI and SBAS techniques. These techniques showed their great advantages compared with conventional in situ measurements of ground movement as they detected already known landslides and the extent of their boundaries as well as unknown landslides (sites within Area B). Measurements were taken at different points within the landslides, enabling understanding of the behaviour of the ground as opposed to the localised characteristic of the in situ measurements. Subsidence exceeding 60mm was determined during the 3-year period of measurements in Area A. Results of Area B were compared with in situ measurements from inclinometers installed in adjacent boreholes, showing good agreement. Both methods showed a very similar trend of the displacement over time.

Freely available Sentinel-1 data from 2014 onwards, acquired every 6 days in ascending and descending modes with a global coverage, opens new opportunities in the monitoring of ground and infrastructure movement more economically than in situ measurement as well as retrospectively.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

Alexandris, A., Katsipi, Griva, I., Abarioti, M. 2016. Remediation of the Pissouri Landslide in Cyprus, *International Journal of Geoengineering Case Histories* **4**, 14-28.

Breiman, L 2001. Random forests, *Mach. Learn.* **45**, 5-32.

Catani, F., Lagomarsino, D., Segoni, S., Tofani, V. 2013. Landslide susceptibility estimation by random forests technique: sensitivity and scaling issues, *Nat. Hazards Earth Syst. Sci*, **13**, 2815-2831.

Ciampalini, A., Raspini, F., Lagomarsino, D., Catani, F., Casagli, N. 2016. Landslide susceptibility map refinement using PSInsSAR

data, *Remote Sensing of Environment*, **184**, 302-315.

Duro, D.C., Franklin, S.E., Dube, M.G. 2012. Multi-scale object-based image analysis and feature selection of multi-sensor earth observation imagery using random forests, *Int. J. Remote Sens.*, **33**, 4502-4526.

Ferretti, A., Prati, C., Rocca, F. 2001. Permanent scatterers inSAR interferometry, *IEEE Trans. Geosci. Remote Sens*, **39**, 8–20.

Frattini, P., Crosta, G., Carrara, A. 2010. Techniques for evaluating the performance of landslide susceptibility models, *Eng. Geol*., 111, 62–72.

Gabriel, A.K., Goldstein, R.M., Zebker, H.A. 1989..Mapping small elevation changes over large areas: differential radar interferometry, *J. Geophys. Res.* **94**, 9183–9191.

Hart, A.B., Hearn, G.J. 2013. Landslide assessment for land use planning and infrastructure management in the Paphos District of Cyprus, *Bull Eng Geol Environ*, **72**, 173-188.

Hart, A.B., Ruse, M.E., Hobbs, P.R.N., Efthymiou, M., Hadjicharalambous, K. 2010. Development of a landslide inventory to assess landslide hazard in Paphos District, Cyprus, *Geologically Active, Proceedings of the eleventh IAEGE congress*, Auckland, New Zealand, Taylor and Francis Group, London, pp 229–239.

Kyriakou, E., Hadjigeorgiou, J. 2008. Ignoring engineering geology, a costly mistake at Pentalia, Cyprus, *Proceedings of the 4th Canadian Conference on Geohazards: From Causes to Management*, 594.

Sansosti, E., Berardino, P., Bonano, M., Calò, F., Castaldo, R., Casu, F., Manunta, M., Manzo, M., Pepe, A., Pepe, S., Solaro, G., Tizzani, P., Zeni, G., Lanari R. 2014. How second-generation SAR systems are impacting the analysis of ground deformation, *International Journal of Applied Earth Observation and Geoinformation* **28**, 1-11.