Methodology for the validation of DInSAR datasets used for monitoring land subsidence

María Inés Navarro-Hernández[1], Javier Valdes-Abellan[1], Roberto Tomás[1], Juan M. Lopez-Sanchez[2], Pablo Ezquerro[3], Guadalupe Bru[3], Roberta Bonì[4], Claudia Meisina[5], and Gerardo Herrera[3]

1 Department of Civil Engineering, Escuela Politécnica Superior, University of Alicante, P.O. Box 99, 03080 Alicante, Spain mainnahe@ua.es, javier.valdes@ua.es roberto.tomas@ua.es

2 Institute for Computer Research (IUII), University of Alicante, P.O. Box 99, 03080 Alicante, Spain; juanma.lopez@ua.es

3 Geohazards InSAR Laboratory andModeling Group (InSARlab), Geoscience Research Department, Geological Survey ofSpain (IGME), Alenza 1, 28003 Madrid, Spain p.ezquerro@igme.es g.bru@igme.es

4 Department of Pure and Applied Sciences, University of Urbino "Carlo Bo", Italy. roberta.boni@uniurb.it.

5 Department of Earth and Environmental Sciences, University of Pavia (Italy), claudia.meisina@unipv.it

Abstract

Land subsidence is a natural or anthropogenic process which can be induced by groundwater withdrawal. Differential Interferometric Synthetic Aperture Radar (DInSAR) is widely used to monitor subsidence. However, validation of DInSAR measurements with in-situ techniques is lacking in many case studies, reducing the reliability of further analyses. The aim of this study is to propose a systematic methodology supported by a MATLAB open-source code to validate DInSAR measurements with in-situ techniques in areas affected by land subsidence. We present a set of statistics to assess the accuracy of the DInSAR estimates, such as a combination of a normalised RMSE with the Pearson correlation coefficient (R2), in order to suggest a classification scheme for accepting/rejecting the DInSAR data.

Keywords: DInSAR, Land Subsidence, Validation, Accuracy, ValInSAR.

Introduction

Land subsidence is a natural or anthropogenic process that consist in the gradual settlement of the ground surface. When this phenomenon is induced by groundwater withdrawal, land deformation is caused by the compaction of unconsolidated sediments of basin-fill detrital aquifers or aquitards, due to the increment of effective stress and the gradual reduction of the soil voids (Galloway & Burbey, 2011). Several geodetic high precision techniques (e.g., Global Navigation Satellite Systems positioning, levelling, and extensometers) have been applied for the monitoring of land subsidence and the identification of temporal and spatial patterns. These monitoring approaches have several limitations. They are point-based measurements providing spatially-sparse observations, and they are very time-consuming, exhibiting a high relative cost for each measurement point (Tomás et al., 2014), meanwhile DInSAR is able to map land subsidence with an extensive spatial coverage, high density of measurement points and high accuracy, depending on the characteristics of the ground (Awange, 2018).

The review of the scientific literature related to the use of DInSAR for monitoring land subsidence disclosed that do not exist any standardised criterion for the validation of datasets. This research aims to develop and evaluate a systematic methodology to assess the differences between DInSAR and others in-situ techniques observations developed by Navarro-Hernández et al. (2022). In addition, a new open-source code called ValInSAR is presented (see the appendix). This work is also intended to recommend validation strategies for any land subsidence product.

Methodology

The proposed approach and the associated validation tool have been divided into four blocks: pre-processing, ingestion, processing and results (Figure 1.). The pre-processing step is aimed at assessing the consistency of geocoded data sets from different monitoring techniques. In particular, all the monitoring data must be projected in the same geographic coordinate system, and the measuring points must be overlaid on an accurate base map. In this step two methods are also proposed for the selection of persistent scatterers for comparison and the application of moving average for high frequency time series.

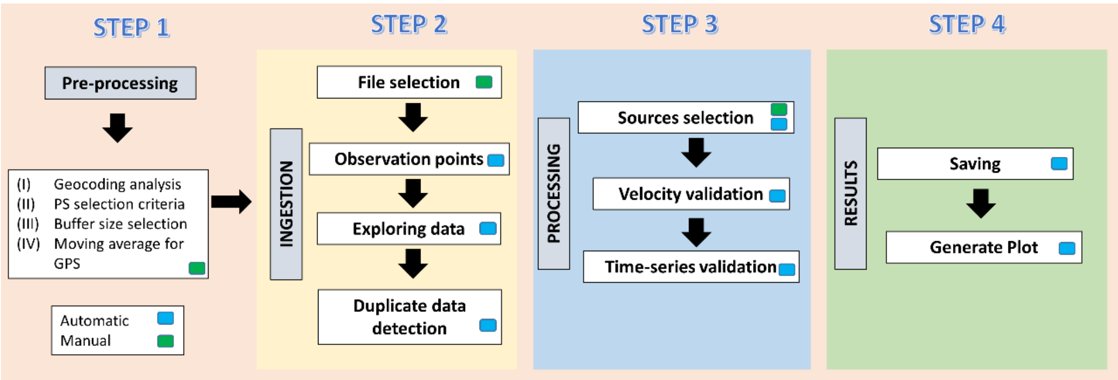

Figure 1 Flowchart used in the validation methodology by the MATLAB application (ValInSAR code) (based on Navarro-Hernández et al., 2022).

From this point, all the process is automatized by ValInSAR. Next step is the ingestion, where the code requires the input information with the temporal series of the different sources of information considered in the pre-processing stage and the incidence angle of the satellite. Second step is the processing. As it is well known, DInSAR provides displacements along the Line of Sight (LOS) of the satellite, and unfortunately, in many cases, the processing of both datasets (i.e., ascending and descending) is not available. Therefore, only the projection of the total displacement along the LOS of the satellite in either ascending or descending pass is known. In these cases, only the vertical component of deformation can be calculated by assuming that no significant horizontal deformations occur. This hypothesis is valid for most of the subsiding areas in which the subsidence is regional and so widespread that regional-scale lateral (horizontal) strains are not significant (rarely as large as 2 ppm). After the projection, the tool proceeds to validate the velocity and deformation series from DInSAR using the in-situ measurements. Once, the validation is finished, several statistical parameters are calculated by the comparison of two different datasets of land subsidence measurements in terms of velocity and time series (i.e., mean difference, maximum and minimum difference, RMSE, NRMSE1 (RMSE normalised with the range of the in-situ observations), NRMSE2 (RMSE normalised with the average value of the in-situ observations) and, last but not least, the R2. Finally, all the results are saved (graphics and output files).

The methodology proposed and ValInSAR code have been applied in Alto Guadalentín aquifer (Spain), located in a valley with a very intensive agricultural activity, which has been monitored during the last two decades by the use of different geodetic techniques (Ezquerro et al., 2017). The methodology has been also applied in Murcia (Spain), a city where the consolidation of deep aquifer due to groundwater extraction have caused damages at buildings, the city has been monitored mainly by the used of extensometers benchmarks (Tomás et al., 2014).

Results and discussion

The buffer size selection depends on the spatial resolution of the InSAR results. For Alto Guadalentín and Murcia city an optimal buffer size was calculated, this optimal size is between 50 m to 150 m. Regarding velocity and deformation time series validation, in Alto Guadalentín, CSK and Sentinel-1 dataset were validated using three CGNSS stations, in this pilot site the DInSAR information are in a good agreement with the in-situ information, with R2 values between 0.934 and 0.999. Meanwhile, in Murcia the ENVISAT dataset was validated using 15 extensometers, with R2 values between 0.06 and 0.976.

After analyse all the results from the different tested sites, we propose several thresholds for the different statistical parameters calculated by ValInSAR which can be used to discriminate whether DInSAR measurements are reliable or not. Results obtained with ValInSAR code reveal the strong influence of the magnitude of land subsidence for the RMSE and MD estimation. Therefore, we conclude that they may be useful to compare results from different sensors or in-situ techniques for the same study area, but not to compare results between different study areas. In order to do so, other statistics that normalise RMSE results can be used alternatively, such as the NRMSE1 and NRMSE2 (Navarro-Hernández et al., 2022).

With the purpose of establishing accuracy estimators for the validation of velocity and time series, R2 and NRMSE1 have been combined in a classification scheme proposed in figure 2. The scheme presents four categories (Figure 2). In this figure, it can be seen that the Alto Guadalentín DInSAR validation shows the best results using GNSS stations, comparing with Murcia city case, which only two extensometers exhibit a high accurate. The main reason of this high dispersion is related to the fact the extensometers were installed at a maximum depth of 15 m, being able only to measure the upper aquifer deformation in areas where soft soil thickness is greater and deeper than 20 m below the surface, meanwhile ENVISAT observation is capable of measuring the absolute displacement values for the complete aquifer system (Navarro-Hernández et al., 2022).

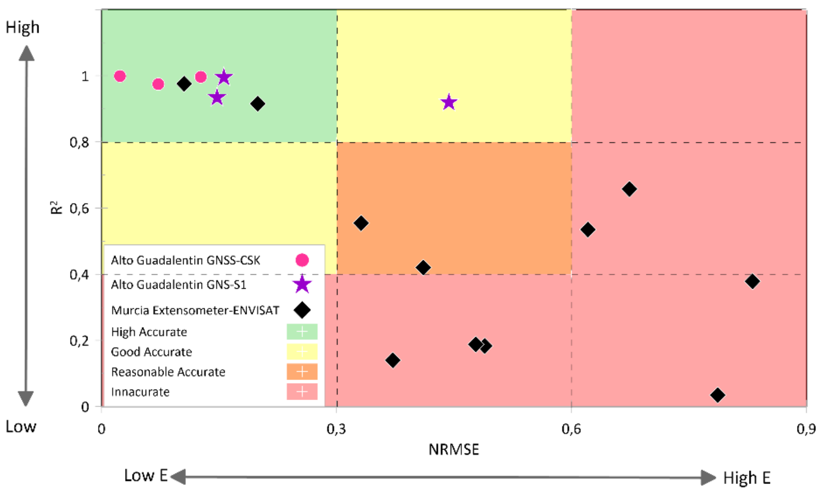

Figure 2 Thresholds proposed for DInSAR validation using displacement time series values by Navarro-Hernández et al., (2022).

Conclusion

ValInSAR provides several statistics, like mean difference, standard deviation of the error, correlation coefficient, or the root mean square error of the discrepancies for velocity and time series validation. All these parameters are very useful to assess DInSAR performance from different sensors against different in-situ techniques for the same study area. However, these parameters are not useful to make relative comparisons between DInSAR results obtained in different study areas, since they are dependent on the subsidence magnitude of each study area. In order to overcome this limitation, in this paper we propose a set of statistics to assess the DInSAR accuracy. For this purpose, RMSE parameters have been normalised with the dynamic range and the average of the in-situ deformation values to obtain NRMSE1 and NMRSE2. Moreover, combining these NRMSEs with R2 coefficient, a classification scheme has been proposed. By applying the accuracy parameters categorization in the test sites, it was possible to determine whether the validation results from each area show DInSAR reliable data or not.

Acknowledgements

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Appendix

ValInSAR open source code can be found and download in:
https://zenodo.org/record/6337377#.Yic9_ujMKM8

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