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Comparative analysis of MT-InSAR algorithms supported by GNSS data and corner reflectors: Assessing performance and accuracy

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Abstract

This paper presents a comparative analysis of Multi-Temporal Interferometric Synthetic Aperture Radar (MT-InSAR) algorithms in a corner reflector located in Lisbon, Portugal. The reflector was monitored using daily observations from the Global Navigation Satellite System (GNSS) technique with submillimeter precision. The study focuses on comparing the performance and accuracy of different MT-InSAR approaches i) the Persistent Scatterer Interferometry (PSI) method using the open-source software StaMPS, ii) the PSI method using the commercial software SARPROZ, iii) the Quasi-PS method implemented with the SARPROZ software, as well as iv) a hybrid method Persistent scatterer – Distributed Scatterer (PS-DS) obtained from the European Ground Motion Service (EGMS) with SqueeSAR algorithm. The study period assumed was from October 2017 to January 2019, by considering the same initial information (ascending orbit Sentinel images). Statistical analysis of the time series was also performed, and the density of points in the vicinity was evaluated. To provide a comprehensive evaluation of accuracy, the uncertainties associated with both the GNSS and InSAR techniques were assessed. The findings of this comparative analysis offer valuable insights into the strengths and limitations of various MT-InSAR algorithms by using a more precise technique as a benchmark. The results improve the understanding of deformation monitoring in geodetic applications and highlight the potential for enhanced accuracy in such assessments.

Keywords: PSI; QPS; GNSS; accuracy ;and corner reflector.

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1. Introduction

Accurate monitoring of ground movements is of great importance in various fields such as geodesy, environmental studies, and infrastructure monitoring. For this purpose, two widely used techniques are Multi-Temporal Interferometric Synthetic Aperture Radar (MT-InSAR) and Global Navigation Satellite System (GNSS). MT-InSAR is a remote sensing technology that uses synthetic aperture radar data acquired at different times to detect surface deformation with millimeter precision [1]. On the other hand, GNSS relies on signals from a network of satellites to determine precise positioning information on the Earth's surface [2]. Both techniques have proven valuable in studying ground movements and providing useful insights for decision-making. To assess the accuracy and reliability of MT-InSAR, this article presents a comparative analysis between MT-InSAR results and the ground truth data provided by GNSS.

To assess the accuracy and reliability of MT-InSAR, this article presents a comparative analysis between MT-InSAR results and the ground truth data provided by GNSS. To compare the same points with both techniques, the GNSS data was extracted from two stable points. It consists of a corner reflector designed to collect the Sentinel data and a GNSS antenna over a building. The different MT-InSAR herein analyzed involve the use of two software packages (SARPROZ and StaMPS), and the use of different InSAR techniques, i) Persistent Scatterer Interferometry (PSI), ii) Quasi-PS, and iii) Hybrid method Persistent Scatterer- Distributed Scatterer (PS-DS) SqueeSAR algorithm obtained from the European Ground Motion Service (EGMS). A concise overview of the relevant theoretical context, and the techniques and methods used for data processing, is provided. Finally, the obtained results about the accuracy of the different MT-InSAR approaches are thoroughly discussed, leading to a conclusive summary.

2. Materials and Methods

2.1. Test site, corner reflector and data collection

The area under study is located in the National Laboratory of Civil Engineering (LNEC) (38º 45' 31" North; 9º 8' 28" West) in the city of Lisbon, Portugal (Figure 1), where we have access to a corner reflector able to obtain stable points for both orbits (Ascending and Descending) of Sentinel constellation data. The area is in the north of Portugal's capital next to the airport, in the district of Alvalade. The LNEC complex (Figure 1a) was built in 1952 [3], and consists of several buildings associated with different departments. The area is characterized by a significant amount of vegetation. The points monitored are marked in Figure 1a, where the yellow mark represents the GNSS antenna over the concrete dam department building and the red mark represents the corner reflector.

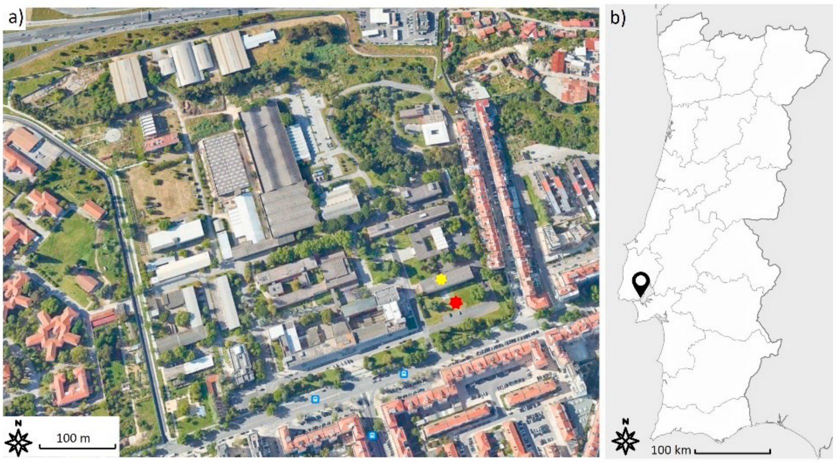

Fig. 1. (a) LNEC complex highlighting the location of the corner reflector in red and the GNSS antenna in yellow; (b) Location of Lisbon in mainland Portugal.

Corner reflectors are artificial targets used in remote sensing applications, like InSAR, to determine displacement uncertainty. These reflectors are capable of reflecting the SAR signals [4]. As shown in Figure 2a, it consists of a heavy permanent concrete foundation with an aluminum structure over it with perforated sheets oriented for both geometries. They act as stable and well-defined reference points for assessing the accuracy and precision of MT-InSAR and GNSS techniques. In this study, the corner reflector and the building roof serve as known points for validation and comparison with the respective MT-InSAR and GNSS results.

Fig. 2. (a) Corner reflector installed in LNEC complex; (b) GNSS system installed in LNEC complex [5]; (c) Sentinel data layout.

The initial data to obtain results from the MT-InSAR are satellite images from the Sentinel constellation. Figure 2c shows the extension of the data. Table 1 contains information about the data.

Table 1. Initial MT-InSAR data information.

Images	Sentinel 1 constellation (L-band)
Number of images	74 (37 for S1A and B respectively)
Time acquisition	18:30 h
Time Period	From 16/10/2017 to 28/12/2018
Path	45
Flight direction	Ascending
Interferometric Wide	2
Incidence angle	40,61º

2.2. InSAR

InSAR is a remote sensing technique that measures ground deformation by comparing the phase information from two or more radar images acquired at different times over the same area [6]. This phase difference is directly related to the displacement of the ground surface. There are different methodologies that can be divided into simple-pass and multi-pass depending on the number of satellite images used for the interferometry. Apart from this, within the multi-pass there are three options depending on the interferometric network, Persistent Scatters (PS), (Distributed Scatterer) DS and combined PS/DS techniques. Each technique has pros and cons depending on the area of study and goals. In that case, three appropiate InSAR techniques were used:

Persistent Scatterer Interferometry (PSI): PSI is a technique that focuses on coherent scatterers, which are stable and persist over time [7]. These scatterers can be natural reflectors, such as buildings or rocks, or artificial ones like corner reflectors. PSI exploits the phase stability of these points, allowing for precise and long-term deformation monitoring with high accuracy. Used in stable manmade areas [8].

Quasi-Permanent Scatterers (QPS): QPS is an extension of PSI that focuses on scatterers with moderate stability over time. The main difference is that a multi-master network of interferograms is considered and only a subset of those interferograms is used to analyze each scatterer. While not as stable as PSI's persistent scatterer, QPS provides a larger number of measurement points and allows for better spatial coverage in areas where PSs are lacking [9].

Hybrid PS-DS methods. They are able to identify PS and DS. The European Ground Motion Service (EGMS) is an advanced service offered by the Copernicus Land Monitoring Service, providing freely and openly continental-scale measurements of ground movement [10]. They use algorithms from a consortium of four InSAR Processing Entities (IPE). The algorithms are Persistent Scatterer Pair (PSP), SqueeSAR, Ground Stable Target Interferometry (GSAR-GTSI) and PSI with Integrated Wide Area Processor (IWAP) [11]. In the test site, the SqueeSAR is the technique used. That relies on stable scatterers with a known temporal baseline between acquisitions. By measuring the phase difference between two radar images, SqueeSAR enables precise deformation monitoring in both urban and natural areas.

The analysis involves two widely used software packages for MT-InSAR data processing: commercial SARPROZ [12] and open-source Stanford Method for Persistent Scatterers (StaMPS) [13].

To sum up, it has been collected four different MT-InSAR results: i) PSI using SARPROZ software; ii) PSI using StaMPS software; iii) QPS using SARPROZ software; and iv) Hybrid method obtained from EGMS [14] using the SqueeSAR algorithm from the group Tre Altamira. Table 2 presents some processing information.

Table 2. Information about the MT-InSAR results.

	PSI		QPS	Hybrid
Softwares	SARPROZ	Preprocessing: SNAP Processing:StaMPS	SARPROZ	SqueeSAR
Interferograms	73		866	Not reported
Master image	01/06/2018			Not reported
Scatters in LNEC complex	220	270	380	800
Extra information	Reflector scatter consistent 0,99 coherence	Reflector scatter not found with normal processing	Reflector scatter consistent 0,99 coherence	Calibrated product (Level 2B) A12-045 Reflector needed analysis

2.3. GNSS

GNSS is a navigation system based on constellations of satellites, like Galileo, (Global Positioning System) GPS, (*Global'naya Navigatsionnaya Sputnikovaya Sistema*) GLONASS or BeiDou. That system enables the determination of position, velocity and time at any location on the Earth's surface. GNSS was used in this study as a benchmark for MT-InSAR displacements. A relative positioning strategy was followed, with two antennas continuously monitoring two points at the LNEC complex. The reference antenna was permanently installed on a metallic rod located on the roof of the Concrete Dam Department building (Figure 2b), while the second antenna was permanently installed on top of a corner reflector (Figure 2a) located in the nearby garden. The baseline between both antennas had a length of 38 m.

Topcon GB-1000 receivers were used, together with choke-ring antennas at both monitored points. Observations were performed in static mode, every 30 seconds.

The displacements of the antenna on the reflector with respect to the antenna on the building were computed using Topcon Pinnacle software, considering daily monitoring periods. Due to the small baseline between the antennas, many error sources were minimized (e.g., atmospheric effects) and submillimeter precision was achieved [5].

3. Results and discussion

3.1. InSAR

As a result of each InSAR technique, a map of monitored points was obtained, including the analysis of errors and coherences to detect the points that we want to analyze (reflector and GNSS antenna). The time series in Figure 3 were obtained with the relative displacements between these points for each MT-InSAR approach.

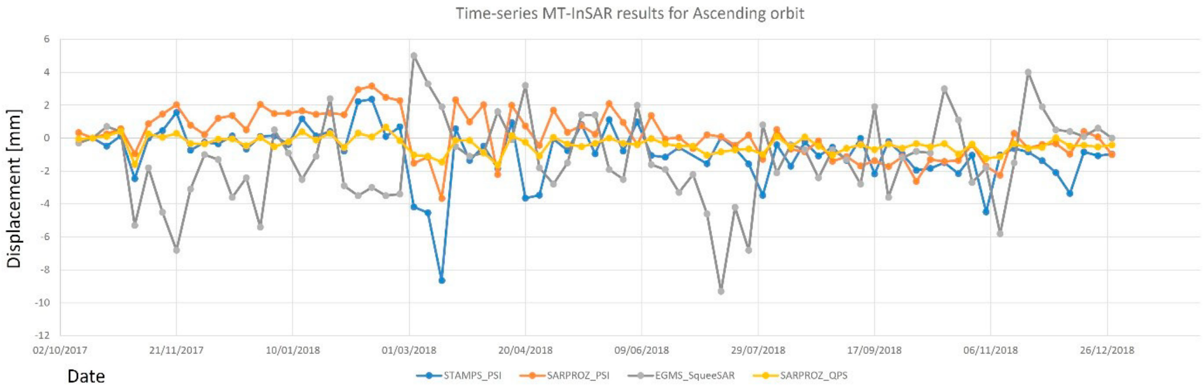

Fig. 3. Time-Series obtained from the different InSAR methods (PSI, SqueeSAR, QPS) and software between the points corner reflector and GNSS antenna.

In order to compare the results of each MT-InSAR approach with a more precise method, these same points were monitored with the GNSS technique. A relative Line of Sight (LOS) offset was applied to the GNSS data to make the comparison as accurate as possible. 430 measurements were obtained on which their propagation of uncertainty was studied, obtaining the confidence interval of each measurement (Figure 4a). In addition, the standard deviation and the mean variance (0,7 mm and 2,14 mm^2 respectively) were obtained.

Finally, Figure 4b shows the GNSS and InSAR results together. Table 3 presents a complete statistical analysis at different levels (tendency with Spearman coefficient, difference between groups (mean) and error analysis).

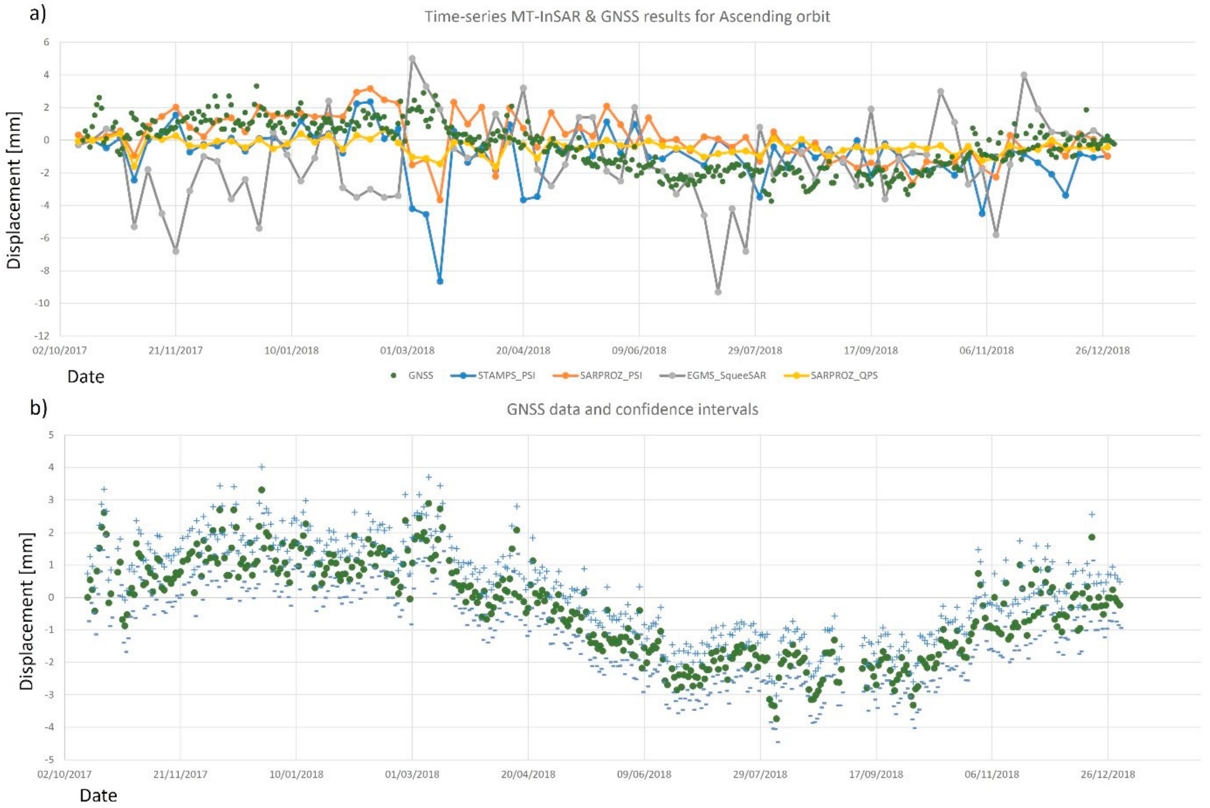

Fig. 4. a) Time-series MT-InSAR and GNSS results between the reflector and the Dam building antenna in the LNEC complex and b) GNSS measurements with its confidence interval.

Table 3. Statistical study for the different InSAR algorithms.

			PSI_StaMPS	PSI_SARPROZ	QPS_SARPROZ	SqueeSAR_EGMS
Tendency	Spearman	P_value	6,64E-03	2,36E-05	0,041	0,908
		Correlation	0,315	0,473	0,240	0,014
Average	T-student	P_value	0,039	0,025	0,927	0,014
	Mean difference [mm]		-0,541	0,524	-0,023	-0,882
Error	Mean Absolute Error (MAE) [mm]		1,448	1,246	1,158	2,329
	Standard Deviation [mm]		2,125	1,531	1,439	2,933
	Euclidean Distance [mm]		76,643	47,557	52,305	131,067
	Dynamic Time Warping (DTW) distance [mm]		235,248	191,092	229,696	309,693

Spearman's coefficient informs about the strength and direction of the monotonic correlation between two data groups (GNSS and each InSAR case), with values ranging from -1 to 1. A p-value below the threshold of 0,05 accepts the hypothesis that there is a correlation between the two variables. In this case, three of the four cases accept the existence of a significative correlation and a positive correlation of (0,315; 0,473 and 0,240, for the PSI_StaMPS, PSI_SARPROZ and QPS_SARPROZ, respectively).

The t-student test informs about the significant difference between two data groups. In this case, a p-value lower than 0,05 accepts the hypothesis that the difference is significant. Therefore, only the QPS case demonstrates that the averages of both groups are similar. This is evident by observing the difference between the means of the groups (-0,023 mm in the case of QPS).

In addition, the error of each case was analyzed, showing four complementary statistics: i) the MAE informs about the accuracy between both groups regardless of the direction, ii) the standard deviation informs about dispersion and outliers. Meanwhile, iii) DTW and iv) Euclidean distance inform about the accuracy and precision between MT-InSAR-GNSS using different algorithms.

In this case, the results are relative. Hence, the comparison allows evaluation of which case provides better results. Regarding MAE, a value close to a millimeter is an optimal result, considering that InSAR has millimeter precision and GNSS submillimeter precision, (like 1,158 mm in the case of QPS). Regarding standard deviation, a low value indicates that the MT-InSAR results are consistent with the GNSS data, (like 1,439 or 1,531 in the case of QPS and PSI_SARPROZ, respectively).

Finally, the two distance metrics use different algorithms to compare the summation of the distance between two data groups. While the Euclidean distance compares groups with the same number of data, the DTW can compare groups of different sizes. Therefore, the smaller the distance, the better the relationship between the two data groups. In these metrics, the best result is obtained by the PSI case performed with the SARPROZ software (47,557 and 191,092).

4. Conclussion

This work compares results from a total of 4 InSAR cases: PSI with StaMPS software, PSI with SARPROZ software, QPS with SARPROZ software, and SqueeSAR obtained from EGMS. These cases were derived from the same initial data, which involved Sentinel constellation images from the Ascending orbit. The study used selected scatters from reference points, including corner reflector and GNSS antenna, which were monitored using the GNSS technique. Data from GNSS was then analyzed to determine uncertainties and confidence intervals.

The paper carried out a comparison between the four InSAR cases and the results from GNSS, and additionally performed a statistical analysis to quantify the findings. It can be concluded that the SqueeSAR technique yielded the worst results, being the only one with non-significant outcomes. However, the other cases provided valid results, with the SARPROZ software contributing more realistic values.

Comparing QPS and PSI, it was observed that QPS showed a weak positive correlation and a non-significant difference in means with respect to GNSS. On the other hand, PSI demonstrated a higher and more significant positive correlation, along with a smaller total distance compared to GNSS. This observation led to the hypothesis that PSI might require more calibration than QPS, as the latter had a significant mean but performed poorly in terms of DTW and Euclidean distance.

Overall, the comparative analysis of Multi-Temporal InSAR techniques using SARPROZ and StaMPS software, along with GNSS data, provides valuable insights into the accuracy and reliability of ground deformation monitoring. The use of corner reflectors as known points offers a comprehensive understanding of both MT-InSAR and GNSS techniques' strengths and limitations. The findings contribute to advancements in remote sensing and geodetic studies, supporting more accurate decision-making in various applications.

Further work could involve expanding the analysis to include more software packages (like ENVI SARscape, Gamma or InSAR Scientific Computing Environment [ISCE]) and more specific extension techniques (like Temporary Coherent Points [TCP], Quasi Coherent Targets [QCT] or Coherent Scatterer Insar [CSI]) to provide a more comprehensive understanding of performance and accuracy. Moreover, proposing a calibration method and assessing the improvement index for these techniques could be interesting.

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