

Synergy in Terra – 2025 – XXX

Title

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SUMMARY

In the scientific publication it has been considered the radar interferometry method (INSAR), which has found effective application in remote detection of earth surface deformations. The accuracy of displacement determination using various INSAR technologies is analyzed. Factors that affect the deterioration of measurement results are researched.

Keywords: Sources of errors; Radar observations; Surface deformation; Geodetic accuracy

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Introduction

In order to detect unstable processes in the Earth's body and on its surface, to ensure the safety of infrastructure facilities, natural landscapes and to predict emergency situations, it is necessary to carry out geodetic monitoring of deformations of the Earth's surface.

Depending on the conditions of observations, various methods can be used to monitor territories and objects: classical leveling, tacheometry, GNSS surveying, laser scanning, SAR interferometry and others. The key parameter for determining the reliability of measurement results during geodetic work is the level of accuracy of geodetic methods. Today, traditional geodetic methods have been sufficiently researched and tested in field conditions. Satellite radar measurements, namely SAR interferometry, are currently a relatively new technology (<https://sentiwiki.copernicus.eu/web/s1-applications>) and require additional observations with analysis of the accuracy of the data obtained.

The goal is to analyze the sources of errors in satellite radar measurements that affect the accuracy of geodetic monitoring of earth surface deformations.

Method and/or Theory

Each geodetic method has its own degree of accuracy. This is due to the complexity and accuracy of the technological process itself, as well as the technical characteristics of the equipment. When leveling with digital levels, the accuracy can vary from 0.3 to 1.0 mm per 1 km of double stroke, with high-precision levels - 0.3 to 0.5 mm per 1 km of double stroke, with medium-precision levels - 1.0 to 3.0 mm per 1 km of double stroke. The results of linear-angular measurements depend on the accuracy of determining distances and angles. For distances up to several kilometers, the accuracy can reach 1–5 cm (El-Ashmawy, 2014). The accuracy of determining the coordinates of points using GNSS surveying can vary widely depending on the operating conditions. In conditions of a good signal using DGPS/RTK corrections, the accuracy can reach 0.5–3 cm, with single positioning without using corrections - 3–10 m. When creating accurate 3D models of the Earth's surface using terrestrial laser scanning, high accuracy of scanning up to 0.3–10 mm is achieved (Dorozhynskyy, 2014). With mobile laser scanning and scanning from UAVs (LiDAR), the accuracy deteriorates to 1–10 cm depending on the calibration accuracy and the scanning range (<https://www.tejy.com/3d-laser-scanning-in-construction-complete-guide/>).

The SAR interferometry method consists in determining the deformations of the Earth's surface based on the analysis of interference between radar images of satellites. The deformation field is obtained by calculating the phase difference between two radar images, which allows determining changes in surface height with an accuracy of up to a millimeter (Burgmann, Rosen, & Fielding, 2000).

InSAR technologies are distinguished by the locality of the survey. For example, in PSInSAR, SBAS, TS-InSAR, MTInSAR, points are selected for observations, on which permanent scatterers are installed, on which automatic interpretation of movement is carried out, the accuracy of observations at local points is 1-2 mm. DInSAR provides a spatial picture of deformations of continuous territories, averaging deformation values over pixels, while the accuracy of determining the displacements of an individual point can be reduced to 1 cm.

Results

The deterioration of measurement results is caused by various factors: the influence of the external environment, the inaccuracy of the initial data, the instrumental characteristics and features of the algorithmic process in the software, random errors (Fig. 1).

The errors associated with the external environment include ionospheric and tropospheric delays of electromagnetic waves, multipath of signals. The largest error is created by ionospheric delays, since the ionospheric layer has dispersion, i.e. the dependence of the phase velocity of the electromagnetic

wave on its frequency when passing through the environment. In this case, a signal delay occurs due to pulse stretching, which makes it difficult to accurately determine the moment of reflection and signal deformation during reception (Herscovici-Schiller et al., 2023). In radar imaging, this factor affects the quality and resolution of images. Therefore, it is important to use images with a resolution of 20 m or less when processing. Due to dispersion, a frequency shift occurs (Doppler dispersion effect), interference losses are possible, i.e. a decrease in the signal/noise ratio, which weakens the detection of fuzzy targets. The troposphere does not have a pronounced dispersion, but meteorological characteristics of the atmospheric state (temperature, humidity, pressure, precipitation) can affect the quality of measurements, causing tropospheric delay (Nesterenko, 2023). To compensate for the hydrostatic component, atmospheric conditions are estimated by correcting the data (Fattahi, 2014). Tropospheric models are used to calculate phase shifts in radar surveys.

The interferometric phase of each pixel of the SAR image will depend on the difference in the paths between the pixels of the two radar images. The phase shifts are estimated taking into account the noise caused by the influence of reflected signals (multipath of signals). In the case of volumetric scattering or reflection from variable surfaces (complex vegetation, water bodies), various obstacles (buildings, vehicles, rocks, etc.), phase measurements are performed on the total signal, which has significant deviations. The maximum magnitude of such distortions can reach 90° , or 5 cm or more in linear measure. The presence of noise is difficult to model, so it is advisable to choose satellite images taken in the dry season and with a small perpendicular baseline (Braun, A., Veci, L., 2021).

The inaccuracy of the original data is due to possible orbital drift (Pawluszek-Filipiak, 2020). Satellite position metadata is downloaded together with the image raster. The Precise Orbit Determination provides reconstructed orbit files and Precise Orbit Ephemerides for the Sentinel-1 satellite. However, such data are available no less than 20 days after the acquisition. For radar interferometry, using “fresh” images, orbit reconstruction can be performed in the SNAP software. It is important to choose images with the same geometric configuration. It is not recommended to combine Sentinel-1A and Sentinel-1B, as there may be a shift in the products along the track. It should be noted that SNAP has a digital terrain model available between 60°N latitude and 54°S latitude. If the area under study is outside this range, the SRTM is downloaded in GeoTiff format and in the WGS84 coordinate system.

Minor deviations in measurements may occur due to the transformation shift of vertical velocities of points (pixels) when switching from the inclined-band geometry to the orthogonally projected SAR product in the WGS-84 coordinate system using the Digital Terrain Model (DEM) (Braun, 2021). Radar image processing software, such as SNAP, has built-in functionality to mitigate atmospheric and orbital errors, and geometric distortions can also be removed using geocoding. Co-registration in SNAP applies range and azimuth offset corrections to the second image, and the quality of image bands can be improved with special phase filters (Cruz, H. et al., 2022).

The main assessment of the accuracy of the final InSAR result is the coherence between radar images, which is an indicator of the quality of phase information. Coherence is calculated as a separate raster band and shows the degree of similarity of pixels between radar images in the range of 0–1. After interferometric data processing, pixels with coherence up to 0.4 are usually selected. The loss of coherence is affected by timing errors over vegetation and water bodies, inaccuracies in orbit metadata, and scattering from volumetric structures (Jianjun, 2017). To refine the results, it is necessary to increase the number of observations under favorable conditions, but it is necessary to take into account that vegetation, as a rule, has poor coherence and is reflected as dark spots in the images. Buildings, on the contrary, have very high coherence and are brightly reflected.

The impact of random errors on radar measurements is the most significant of all. These are uncontrolled and unpredictable changes in measured quantities, caused mainly by the human factor. They can be reduced or avoided by using a large number of individual measurements and checking them with external reference data. The combination of satellite geodetic methods with ground-based ones can give real refined results (Tretyak, 2023).

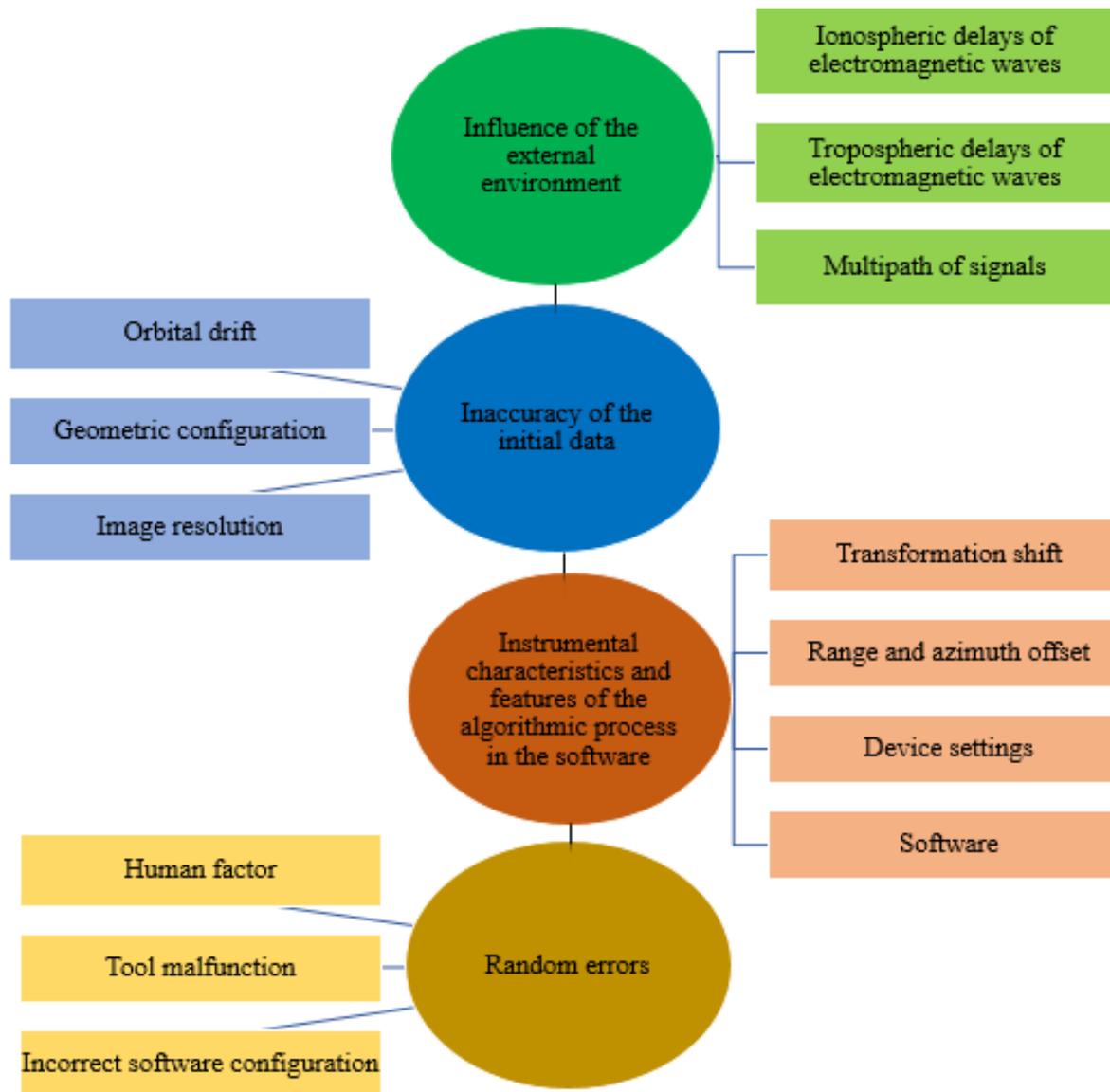


Figure 1. Sources of error in satellite radar measurements.

Conclusions

The accuracy of geodetic methods depends on the type and technical conditions of measurement work, the equipment and software used, the availability and quality of the reference network, and natural conditions. Radar observations are considered to be modern satellite technologies that allow achieving high accuracy, if all factors affecting the accuracy of the results are taken into account. The sources of errors in satellite radar measurements are diverse and have different origins. Systematic errors that arise during the processing of radar images are practically taken into account during data post-processing. Decorrelation of results is eliminated by repeated measurements or changing a pair of images. The most dangerous is the human factor, when operator errors can significantly distort the results. To avoid false results, combined data verification by other geodetic methods is necessary.

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