

Introduction

For about 20 years, InSAR technology has been an effective tool for monitoring deformations of the Earth's surface with high resolution regardless of the time of day [<https://insar.space/>]. The radar interferometry allows you to demonstrate the displacement of large areas and individual points (pixels) during a certain period. The method of differential interferometry with synthetic aperture DInSAR combines space images with dimensions of 100x250 km, superimposed on the same area, taken from the same position of the satellite [A. Braun & L. Veci, 2021]. In the interferogram, two SAR images are processed pixel by pixel, that is, the value of deformations is determined between identical pixels of the reference image (master) and the comparative image (slave). To obtain a time series diagram, the oldest first snapshot can be taken as a reference snapshot, then the period between snapshots will increase by arithmetic progression with a difference of 12 days. Deformations can be determined by changing the reference and comparison image each time between each successive pair of images. Then the time series diagram will be obtained by sequentially joining the next results to the previous ones.

The purpose of this work is to assess the accuracy of determining the vertical deformations of a single pixel of space images by the DInSAR differential interferometry method.

Method and/or Theory

The radio wave scanning technology using the Interferometric Synthetic Aperture Radar using the DInSAR differential interferometry method involves the processing of two radar images. The height difference between the pixels of the two images is proportional to the interferometric phase change between the two SAR observations. A differential interferogram is a reflection and a quantitative indicator of the movement of the earth's surface between epochs of shooting.

For research, 80 ascending space images of the same geometric configuration for the years 2020, 2021 and 2022, superimposed on the same area with average values of latitude 46.9° and longitude 33.8°, were selected. The images are acquired at 12-day intervals from the Sentinel-1 satellite in SLC IW mode on the Vertex Web Platform (ASF) [<https://asf.alaska.edu/>].

Image processing and the vertical displacement map construction were performed in SNAP [http://step.esa.int/downloads/6.0/installers/esa-snap_all_unix_6_0.sh] with sequential algorithms: Co-Registration (co-registration) – alignment of both products with subpixel accuracy; Interferogram Formation – creating a differential interferogram; TOPSAR-Deburst – removal of breaks (gaps) between individual packets; Multilooking - averaging values stored in neighboring pixels of the image; GoldsteinPhaseFiltering (Goldstein phase filter) - restoration of the quality of the bands of the phase image (signal/noise); Phase Unwrapping - unfolding of the interferogram phase; Phase to Displacement - construction of a map of vertical displacements [A. Braun & L. Veci, 2021; S.V. Nesterenko, 2022].

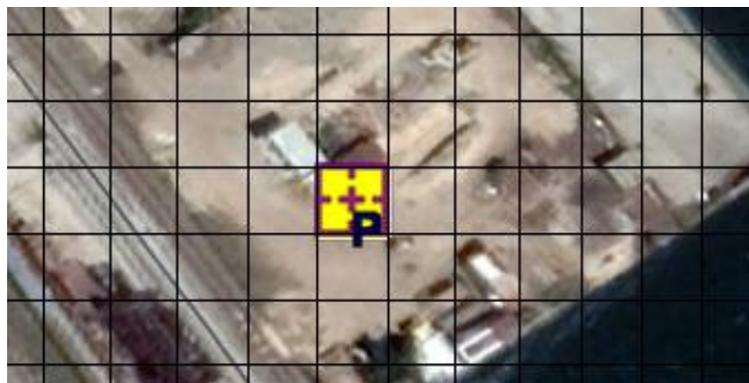


Figure 1 Pixel (P) with a size of 10×10 m on a space image with the coordinates of the center (46.78076, 33.36811)

Results

For the pixel (P) with the coordinates of the center (46.78076, 33.36811) (Fig. 1), time series of vertical deformations were constructed for the periods 01.08.2020-12.21.2020, 01.02.2021-12.28.2021, 01.09.2022-12.23.2022. As a reference image of the master in the first version, the initial image is taken: 01.08.2020 - for 2020, 01.02.2021 - for 2021, 01.09.2022 - for 2022. In the second version, time series diagrams are constructed based on the results of radar interferometry between every next pair of pictures (Fig. 2).

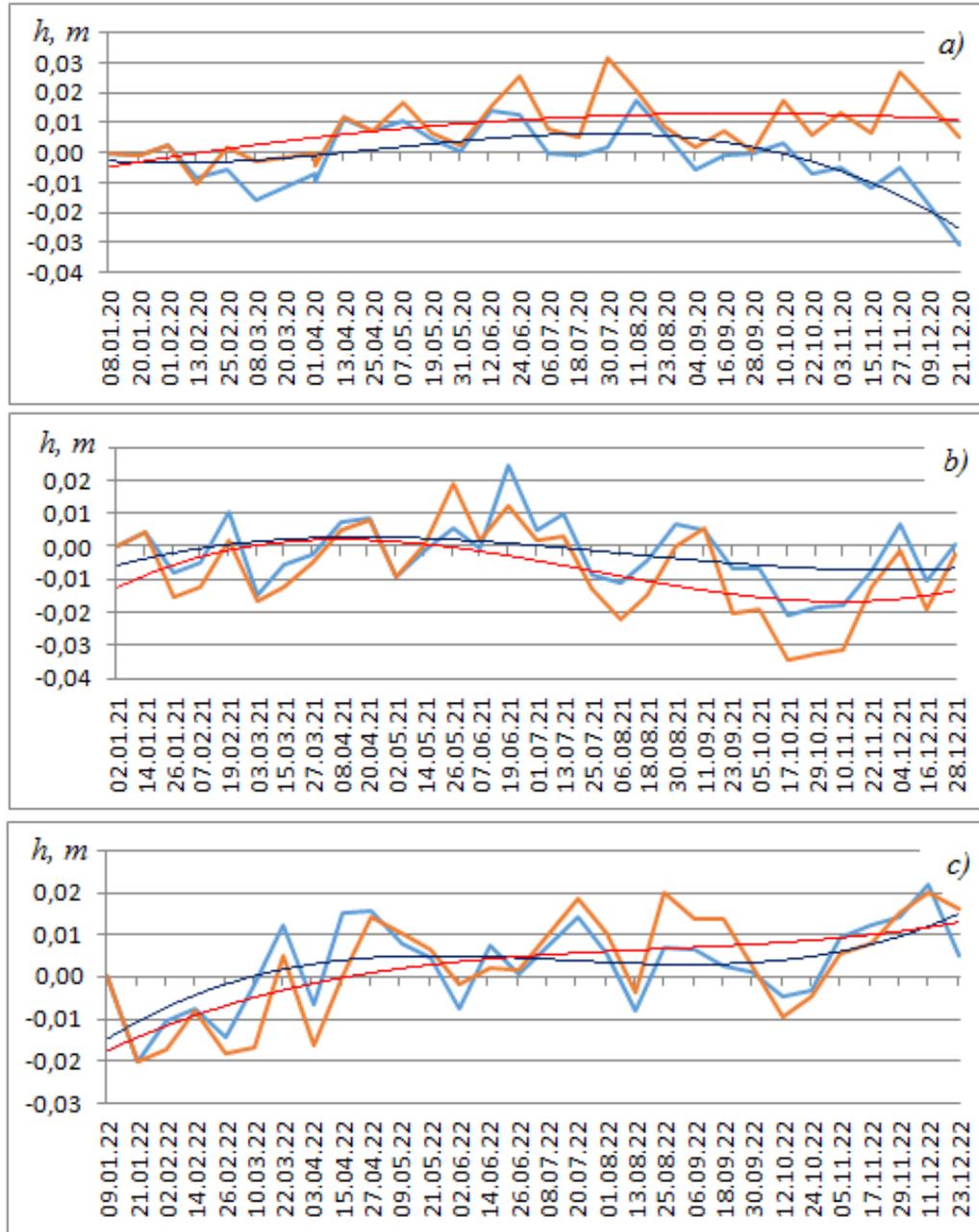


Figure 2 Time series of vertical displacements of a pixel (P) determined by the radar interferometry using the DInSAR method: option 1 - in blue, option 2 - in red; a) for 2020, b) for 2021, c) for 2022

As can be seen from this figure, the average speed of vertical displacements of a pixel (P) is within 3-5 mm/year for each period. A comparison of such diagrams showed the identity of the uplift-subsidence zones of the upper layers of the soil. However, between options 1 and 2, there are

deviations in the trend lines. By the end of 2020, the discrepancy between the deformation values increased to 35 mm. The maximum deviations during 2021 and 2022 were 14 mm and 15 mm, respectively.

To identify the factors that influenced the measurement errors, it is necessary to analyze the technological component of the processing method and the conditions for each algorithmic step.

For Co-Registration, pixel-by-pixel co-registration of Sentinel-1 SAR images, the TOPS module is used, which allows processing of data obtained by TOPSAR technology to form an interferogram [Yagüe-Martínez et al. 2016]. At this stage, the satellite product was divided into bands by swath, polarization, and bursts. A prerequisite for high-quality interferometric processing is the selection of images with one geometric frame (with number 149). With the use of a file with orbital data Apply orbit file, the location of the pictures was clarified. The tracks of the satellites coincided (with number 14), which means that the correct images were chosen for research. When it is used in Back-Geocoding co-registration, the order of master-slave images is very important, as this tool uses reverse geocoding to convert image pixel coordinates to geographic coordinates based on satellite orbital information and the Earth's surface model. Changing the order of the images will change the direction of the deformations.

Interferogram formation took place at the Interferogram Formation stage. Differential SAR interferometry removes the flat earth phase and the topographic phase from the interferogram, which are the same for both images. Based on the obtained phase change, the displacement between the pixels of both images is calculated. We will get high-quality results on the condition that atmospheric, topographic and other noises were minimal, so it is advisable to choose images with satisfactory atmospheric indicators in the dry season. If the processing of a series of space images takes place relative to the initial image, then the extraction of data for periods with abundant precipitation will not affect the overall time series. But in the second option, when processing neighboring images, it is impossible to reject unsuitable material, therefore, the measurement error will accumulate.

In addition to the interferometric phase, there is coherence between the master and slave images, which is evaluated as an indicator of the quality of the phase information. The low coherence can be caused by temporal or geometric errors (inaccuracies in the orbit metadata) and volumetric decorrelation errors (reflectivities of bulky, complex structures). The loss of coherence can cause coarse interferometric results. To reduce speckle noise (incoherent accumulation), the Multilooking tool is used - combining several neighboring pixels of the SAR image into one pixel by averaging the amplitude or intensity values. Such averaging reduces variations caused by speckle noise [A. Braun & L. Veci, 2021].

The interferometric phase could be corrupted by noise from temporal and geometric decorrelation, scattering volume, etc. The quality of the bands in the interferogram is improved by using specialized phase filters such as Goldstein Phase Filtering, which uses a fast Fourier transform to improve the signal-to-noise ratio [R.M. Goldstein & C.L. Werner, 1998].

To link the interferometric phase with the topographic height, Phase Unwrapping was performed - phase unwrapping to remove an integer number of heights equivalent to the entire number of 2π phase cycles using the SNAP plugin. As a result of the integration of the phase difference between neighboring pixels, the ambiguity height is resolved, which is defined as the interferometric phase change of 2π after a flat interferogram.

Accordingly, the expanded results are the relative displacements between the pixels of the two images [Chen et al. 2003]. The results were re-imported into SNAP to eliminate geometric distortions, and data accuracy was assessed.

The imported phase is a raster containing information in radians. Phase to Displacement was performed to convert radians to absolute displacements, thus performing a phase conversion to surface changes along the line-of-sight between the sensor and the LOS pixel in meters, where positive values indicate elevation and negative values indicate lowering of the surface. The final product of the processing is a continuous map of vertical deformations - an orthotransformed image with information on the absolute displacements in meters of each pixel, with relief correction according to the geographic coordinate system [Unwrapped Interferograms: Creating a Deformation Map].

Therefore, an error may occur at each interferometric step, which may affect the final results. In addition, it should be taken into account that the DInSAR method does not involve the study of a

single point, but of pixels measuring 10×10 m. That is, at the beginning of processing, the program divides the selected band into pixels, which may not have an accurate submillimeter resolution during repeated processing (for example, according to option 2) coincidence. This will affect the final result, because the deformation values are averaged over the entire pixel.

Conclusions

Therefore, the technology of radio wave scanning by the method of differential interferometry DInSAR is a modern and very progressive way of monitoring deformations of the Earth's surface. For the construction of time series diagrams of the displacements of a single pixel, for the accuracy of the results, it is necessary to calibrate the images according to the "purity" of the images and to use the initial image for the entire period as a reference image, but at the same time it is necessary to limit yourself to small time intervals. The differential method has limited use in urbanized and forested areas, in snowy areas.

The accuracy of determining the vertical deformations of an individual pixel is affected by factors related to spatial and temporal decorrelation, with signal delays due to atmospheric and tropospheric artifacts, orbital and topographical errors. Part of such noise is eliminated by the sequence of algorithms. The most important limitation of DInSAR is the loss of coherence. Values with a low index (up to 0.4-0.6) should be filtered from the obtained data, values close to one indicate a satisfactory signal-to-noise ratio.

Following the guidelines listed, differential interferometry can be used to obtain reliable strain estimates.

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