



## INTERFEROMETRIC SAR AND MULTISPECTRAL OPTICAL DATA PROCESSING METHODS

Axrorova Sevara Sulaymon qizi

Jizzakh Branch of National University of Uzbekistan named  
after Mirzo Ulugbek

[axrorovasevara57@gmail.com](mailto:axrorovasevara57@gmail.com)

Axrolova Mushtariy Sulaymon qizi

[axrolovamushtariy0@gmail.com](mailto:axrolovamushtariy0@gmail.com)

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### ABSTRACT

*This article discusses methods for processing interferometric SAR and multispectral optical data. The main stages of satellite radar and optical data processing are considered, including data preprocessing, geometric co-registration of radar images, interferogram generation, phase unwrapping, reduction of topographic and atmospheric effects, detection of ground deformation, radiometric and geometric processing of optical images, and calculation of spectral indices. The possibilities of using Sentinel-1 interferometric SAR and Sentinel-2 multispectral optical data are analyzed. The combined processing of radar and optical data provides opportunities to detect ground deformation, assess land cover and natural characteristics of an area, and improve the comprehensive monitoring of hazardous geological processes.*

### Introduction

Today, the development of remote sensing technologies expands the possibilities for observing natural and anthropogenic changes occurring on the Earth's surface. Satellite-based, regular acquisition of radar and optical images allows studying large areas in a short period, comparing data from different periods, and identifying regional changes. In particular, the use of radar and multispectral optical data is of significant importance in monitoring hazardous geological processes.



Processes occurring on the Earth's surface, such as landslides, subsidence, slope displacement, and deformation, sometimes evolve very slowly. Timely identification of such changes through conventional observations can be difficult. Therefore, remote sensing data, which enables systematic and repeated observation of vast areas, has become an essential component of modern monitoring systems.

Interferometric Synthetic Aperture Radar, namely InSAR technology, is one of the modern remote sensing methods that allows detecting ground surface deformations based on radar imagery. In this technology, the phase information of radar images acquired at different times is mutually compared. As a result, data regarding displacements and deformations on the Earth's surface can be obtained. InSAR technology is especially applied in tracking slow-developing ground subsidence, landslides, and other deformational processes.

Multispectral optical data, on the other hand, makes it possible to study the spectral characteristics of the Earth's surface. Through imagery acquired in various spectral bands, vegetation cover, soil, water bodies, built-up areas, and other land cover types can be categorized. Such data serves as an additional information source in assessing the conditions under which geological processes develop.

Radar and optical data possess distinct features. Since radar images are captured using active sensors, in certain cases, they depend less on cloud cover and illumination conditions. Optical images, conversely, reflect the spectral properties of objects in greater detail; however, cloud cover and atmospheric conditions can affect image quality. Consequently, the joint processing of these two data types expands the comprehensiveness of monitoring results.

Improving the methods of processing interferometric SAR and multispectral optical data carries major scientific and practical significance for detecting hazardous geological processes, evaluating their development dynamics, and mapping regional changes. In this context, it is crucial not only to process data separately but also to integrate results obtained from diverse sources into a unified spatial environment.

### **Main Body**

The processing workflow of interferometric SAR data begins with selecting radar images suited to the research objective. In selecting images, spatial coverage of the study area, acquisition dates of images, radar viewing geometry, and data quality metrics are taken into account. When investigating hazardous geological processes, utilizing radar images covering the exact same area acquired at different times is essential. This is because a single image alone may be insufficient to detect deformation processes.

SAR data from the Sentinel-1 satellite is one of the widely utilized data sources for interferometric analysis. The radar system emits an electromagnetic signal toward the ground surface and records the backscattered signal. The amplitude and phase of the backscattered signal provide information on the physical properties of the Earth's surface and the range between the sensor and the target. When radar images acquired at different times are compared,



phase changes reveal ground surface displacements. One of the initial steps in radar data processing is the technical and geometric preparation of the imagery. Here, orbit parameters are refined, images are cropped to the required region, and prepared for subsequent interferometric computations. Predefining the study area reduces the data processing volume and increases computational efficiency. When processing radar imagery, it is necessary to consider the coordinate system and geometric state of the data. The satellite trajectory, sensor viewing geometry, and topographic relief features can influence the location of objects in the image. Therefore, prior to combining radar data with other geographic datasets, their spatial consistency is ensured. In the next stage, radar images belonging to the same area are coregistered. This process is called co-registration (geometric alignment). Bringing identical targets from images acquired on different dates into the same spatial alignment is essential for generating an interferogram. If alignment is not executed with sufficient precision, additional errors may arise in phase differences.

An interferogram is generated based on the co-registered radar images. An interferogram represents the phase difference between two radar images, where the interferometric phase contains information regarding relative surface changes. The phase changes observed in an interferogram are not solely caused by ground deformation; they may also encompass the influence of topography, atmosphere, and other factors. Thus, isolating these various influences in subsequent processing steps of the interferogram is mandatory. Phase differences in an interferogram typically appear in colorful or fringe-like visual patterns. The density and orientation of these phase fringes yield an initial impression of regional changes. However, relying solely on the visual appearance of an interferogram is insufficient to determine final quantitative deformation values. Mathematical and geospatial processing steps are required to achieve this.

The utilization of Digital Elevation Models (DEM) is also vital in interferometric processing. By reducing or removing the effect of topography on the phase signal, the capability to determine true ground deformation increases. Hence, employing the study area's digital elevation model and other auxiliary geographic data in InSAR analysis enhances the precision of results.

Elevational variations on the Earth's surface induce specific variations in the radar signal phase. If this topographic effect is not separated from the deformation signal, distinguishing true displacement from topographic influence becomes difficult. Consequently, modeling topographic effects and subtracting them from results constitutes one of the crucial steps in interferometric processing.

In an interferogram, phase is typically expressed in a wrapped state within a specific range. To extract real ground deformation, phase unwrapping must be performed. During phase unwrapping, wrapped phase values are converted into continuous phase values. This stage is a critical component of interferometric processing, directly influencing subsequent deformation



calculations. Signal quality in the image is also factored in during phase unwrapping. In regions where the radar signal is unstable or coherence loss (decorrelation) is severe, phase unwrapping can become complex. Densely vegetated areas, water surfaces, or locations with rapidly changing surface properties may exhibit decreased temporal coherence of radar signals. Hence, data stability and phase coherence hold high significance in interferometric analysis. Following phase unwrapping, the interferometric phase can be linked to ground deformation. Changes in the radar signal phase reflect changes in distance between the sensor and the ground surface. Based on this, the direction and magnitude of deformation are estimated. Nevertheless, since InSAR measurements are conducted along the Line-of-Sight (LOS), interpreting obtained results alongside other geodetic or geographic data is recommended. Converting radar phase changes into deformation accounts for wavelength and observation geometry, linking phase differences to distance changes. Displacement maps of the Earth's surface are thereby generated, where positive and negative values represent displacement directions accordingly. Processing multiple radar images over time allows forming deformation time series using techniques such as PSInSAR and SBAS. PSInSAR utilizes persistent scatterer points that maintain stable radar reflections over time. SBAS forms a set of interferograms with small spatial and temporal baselines. These methods facilitate detecting slow-evolving deformations and evaluating their temporal progression. PSInSAR is particularly beneficial in urban areas, industrial sites, roads, and other structures offering stable radar reflection. Because such structures generate relatively stable radar signals over time, their phase variations can be tracked reliably. SBAS, on the other hand, allows examining broader regional deformation processes through time series.

Noise reduction is another vital step in radar data processing. Noise can emerge in radar imagery due to various physical and technical factors. Suppressing noise in the interferogram helps improve the quality of phase unwrapping and deformation calculations. However, excessive filtering might lead to the loss of genuine deformation signals. Therefore, processing parameters must be selected carefully according to the study area's characteristics. Accounting for atmospheric effects is also a major challenge in radar interferometry. As the radar signal traverses the atmosphere, it can undergo various delays. Phase shifts resulting from atmospheric interference can sometimes mimic ground deformations. Consequently, in long-term interferometric monitoring, mitigating atmospheric effects and validating results against independent observations is imperative. The temporal and spatial baselines between radar image pairs also influence interferometric accuracy. Excessive time gaps between acquisitions reduce radar signal correlation due to land surface changes. Large differences in spatial geometry also degrade interferometric analysis quality. Hence, these parameters are strictly considered when selecting radar image pairs.

Processing multispectral optical data likewise starts with initial data preparation. Sentinel-2 imagery provides data across various spectral bands, encompassing visible light, near-infrared, and other spectral ranges. Each band reflects distinct spectral properties of surface features.



Analyzing bands individually or in combination allows deriving comprehensive land cover information.

Radiometric and geometric corrections are essential in optical image processing. Radiometric processing helps convert image values into physically meaningful parameters. Geometric correction rectifies the spatial alignment of objects in the image and aligns them with other geographic datasets.

In Sentinel-2 data, spatial resolutions across different spectral bands may vary. Therefore, ensuring spatial alignment across bands prior to comparing them or calculating spectral indices is crucial. Bringing bands into a common spatial framework enhances joint analytical capabilities. Reducing atmospheric effects is another key focus area. Atmospheric gases, aerosols, and other factors can alter the signal recorded by the sensor. Thus, atmospheric corrections are applied in certain studies, allowing spectral values to be analyzed in a form closer to actual ground surface properties. Cloud detection and masking are equally essential in optical processing, as clouds and their shadows obscure genuine surface spectral traits. Including cloudy pixels in analysis leads to inaccurate spectral indices and land cover classifications. Selecting high-quality optical images or masking cloudy regions is therefore required.

A key advantage of multispectral data is the ability to compute various spectral indices. For instance, the Normalized Difference Vegetation Index (NDVI) is used to assess vegetation cover. NDVI is based on vegetation reflectance properties in near-infrared and red bands, expressed as:

$$\text{NDVI} = (\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red})$$

This index allows analyzing the relative state of vegetation cover and its changes over time. In monitoring geological processes, NDVI serves as an auxiliary indicator to detect land cover changes and evaluate natural conditions in deforming areas. To evaluate water bodies and moisture-related characteristics, spectral indices such as NDWI can be utilized. These indicators assist in identifying surface water and moisture variations, which is vital in geological monitoring since moisture fluctuations correlate with the triggers of slope and soil movements. Multispectral imagery is also used for land cover classification, segmenting the area into vegetation, water, bare soil, built-up areas, and other classes. Combining land cover maps with geological and deformation data yields a detailed evaluation of hazard-prone areas.

Temporal comparison is equally important when utilizing optical images. Comparing Sentinel-2 images acquired on different dates enables detecting changes in vegetation, water bodies, urban developments, and other land cover elements. When cross-referenced with InSAR-derived deformation processes, this information forms a comprehensive overview of regional dynamics.

A prominent direction in processing radar and optical data is integrating them into a unified geographic system. For this purpose, coordinate systems, spatial resolution, and geographic positioning are mutually adjusted. Subsequently, InSAR-derived deformation data can be



overlaid on Sentinel-2 optical images, creating opportunities to gather additional insights into land cover and environmental conditions in deforming areas.

For instance, if InSAR analysis reveals ground subsidence in a specific area, Sentinel-2 data can be used to analyze land cover, vegetation health, water bodies, and anthropogenic modifications in that exact zone. Such an integrated approach not only detects deformation itself but also aids in investigating the underlying conditions of its occurrence.

When radar and optical data integration is carried out within a GIS environment, research findings can be effectively visualized in map form. Deformation maps, multispectral imagery, digital elevation models, geological maps, and other layers are unified within a single spatial environment, enhancing the ability to determine spatial relationships between factors and assess the region comprehensively.

Utilizing the layer principle in GIS is convenient for merging processed datasets. Each data type is represented as an individual layer and subsequently compared. For example, combining deformation velocity maps, NDVI maps, NDWI maps, DEMs, and geological maps enables broader analysis of hazard-prone zones.

Quality control is paramount throughout data processing. Atmospheric interference, decorrelation, noise, and elevation-related phase variations affect radar results. In optical imagery, cloud cover, atmospheric conditions, and illumination play major roles. Comparing and validating results against independent datasets improves monitoring reliability.

Comparing InSAR results with GNSS or other geodetic measurements helps evaluate the accuracy of deformation magnitudes. High consistency between independent measurements and interferometric results enhances the scientific validity of monitoring. Where discrepancies exist, identifying their root causes is crucial for refining processing methodologies.

Utilizing time series holds immense value in processing interferometric SAR and multispectral optical data. While a single image reflects surface conditions at a specific moment, a time series unveils the trajectory of changes over time. Analyzing multi-temporal radar and optical images allows cross-evaluating changes in deformation, vegetation, moisture, and land cover.

Time-series results can be presented in graphical and mapping formats. For instance, observing deformation values over time at a specific point enables assessing deformation dynamics. Similarly, tracking NDVI or other spectral indices over time aids in understanding regional ecological and land cover status. In modern processing workflows, automated algorithms and machine learning techniques are expanding rapidly. Manually processing vast volumes of satellite data can be time-consuming; automated methods accelerate image sorting, change detection, land cover classification, and deformation data analysis.

Machine learning algorithms enable automated land cover classification based on diverse spectral and spatial features. This requires high-quality training datasets, as model outputs depend directly on data quality and feature selection. Consequently, automated classification



results must be supervised and manually verified when necessary. Automation is also applicable to InSAR workflows—sequential radar image processing, interferogram generation, time series formation, and deformation map creation can be automated via software tools, increasing efficiency when handling large coverage areas and high image counts.

However, automated processing should not be conducted without specialist oversight. Geological conditions, topography, land cover, and atmospheric characteristics vary significantly from region to region. Hence, software-generated results must be inspected by experts and interpreted in light of local geographic conditions.

Software tools play a decisive role in processing interferometric SAR and multispectral optical data. Specialized remote sensing and interferometry software are used for radar processing, while GIS and remote sensing platforms handle optical data. Software selection depends on research objectives, data types, and processing volume.

In the final processing stage, visualization and mapping of results are performed. Deformation maps, spectral indices, land cover maps, and other outputs are presented with geographic coordinates, serving as key tools to evaluate the distribution and dynamics of hazardous geological processes. Thus, interferometric SAR and multispectral optical data processing function as complementary processes. InSAR provides insight into ground deformation states, while multispectral optical data reveals surface cover and spectral traits. Unifying them in GIS enables comprehensive spatial and temporal assessment of geological processes. A crucial advantage of this combined approach is that changes detected in one data type can be cross-verified using another. For example, zones identified with deformation in radar data are compared against land cover shifts in optical imagery. Identifying spatial correlations between the two sources significantly expands analytical depth. Overall, the methodology consists of several sequential stages: data selection and preparation, execution of radar and optical processing steps, integration in GIS, and final evaluation of spatial-temporal changes in deformation, land cover, and other metrics.

This methodology applies not only to monitoring hazardous geological processes but also to investigating urban subsidence, mining deformations, transport infrastructure stability, and natural landscape dynamics. Therefore, joint SAR and multispectral optical processing stands out as a promising frontier in geoinformation research.

### **Conclusion**

Processing interferometric SAR and multispectral optical data represents a key domain in modern remote sensing technologies. Radar data processing allows detecting ground surface deformations, while optical data analysis facilitates evaluating land cover, vegetation, water bodies, and other natural attributes.

In InSAR processing, steps such as image selection, preprocessing, geometric co-registration, interferogram generation, topographic removal, phase unwrapping, noise filtering, and deformation extraction are paramount. In Sentinel-2 optical processing, geometric and



radiometric corrections, atmospheric mitigation, cloud masking, spectral channel analysis, and index calculations are effectively applied.

Because radar results can be influenced by atmospheric, topographic, and decorrelation factors, cross-validating interferometric outputs with independent geodetic observations in conjunction with local geographic conditions is critical. In optical data, cloudiness, atmospheric haze, and lighting conditions must be accounted for. Combined radar and optical processing significantly enriches monitoring quality. Deforming areas detected via InSAR can be thoroughly examined through multispectral optical data, fostering a deeper understanding of geological hazard mechanics.

GIS technologies allow unifying deformation maps, multispectral imagery, spectral indices, DEMs, and other geographic datasets within a single spatial environment. As a result, comprehensive spatial analysis and map-based representation of changes are achieved. In the future, expanding the integration of artificial intelligence, machine learning, and automated geospatial analysis into interferometric SAR and multispectral optical processing workflows will elevate monitoring system efficiency. These methodologies widen capabilities for rapid big-data processing, change detection, and hazard mapping. Consequently, integrated interferometric SAR and multispectral optical data processing serves as a robust scientific-methodological foundation for monitoring hazardous geological processes, detecting land surface changes, and evaluating geological status.

### **References**

1. Resolution of the Cabinet of Ministers of the Republic of Uzbekistan dated May 25, 2026, No. 275. On approval of the State Environmental Monitoring Program in the Republic of Uzbekistan for 2026–2030.
2. Botirov Sh.S., Nomdorov R.U. Theoretical foundations of radar interferometry technology and possibilities for monitoring surface deformations. Digital Technologies in Industry. 2026. Vol. 4, No. 3.
3. Usmonov F. Satellite monitoring of slope deformation in Qalmoqqir open-pit mine based on Sentinel-1 PSInSAR technology. Engineering and Economics. 2026. Vol. 4, No. 9. Pp. 173–180.
4. Botirov Sh.S., Nomdorov R.U., Abdisamatov B.A. Monitoring of Surface Deformation Caused by Underground Mining Activities Using the InSAR Technique Based on Sentinel-1 Imagery. Digital Technologies in Industry. 2026. Vol. 4, No. 1. Pp. 69–74.
5. European Space Agency. Sentinel-1 Mission: Earth Observation and Radar Interferometry. European Space Agency, 2025.
6. European Space Agency. Sentinel-2 Mission: Multispectral Imaging and Land Monitoring. European Space Agency, 2025.



7. Copernicus Land Monitoring Service. European Ground Motion Service: Ground Motion Monitoring Using Sentinel-1 InSAR Data. European Commission, 2025.
8. United Nations Office for Disaster Risk Reduction. Global Assessment Report on Disaster Risk Reduction 2025. United Nations, 2025.
9. Copernicus Programme. Sentinel-1 User Guides and Synthetic Aperture Radar Interferometry. European Commission, 2025.
10. Copernicus Programme. Sentinel-2 User Guides and Multispectral Data Processing. European Commission, 2025.