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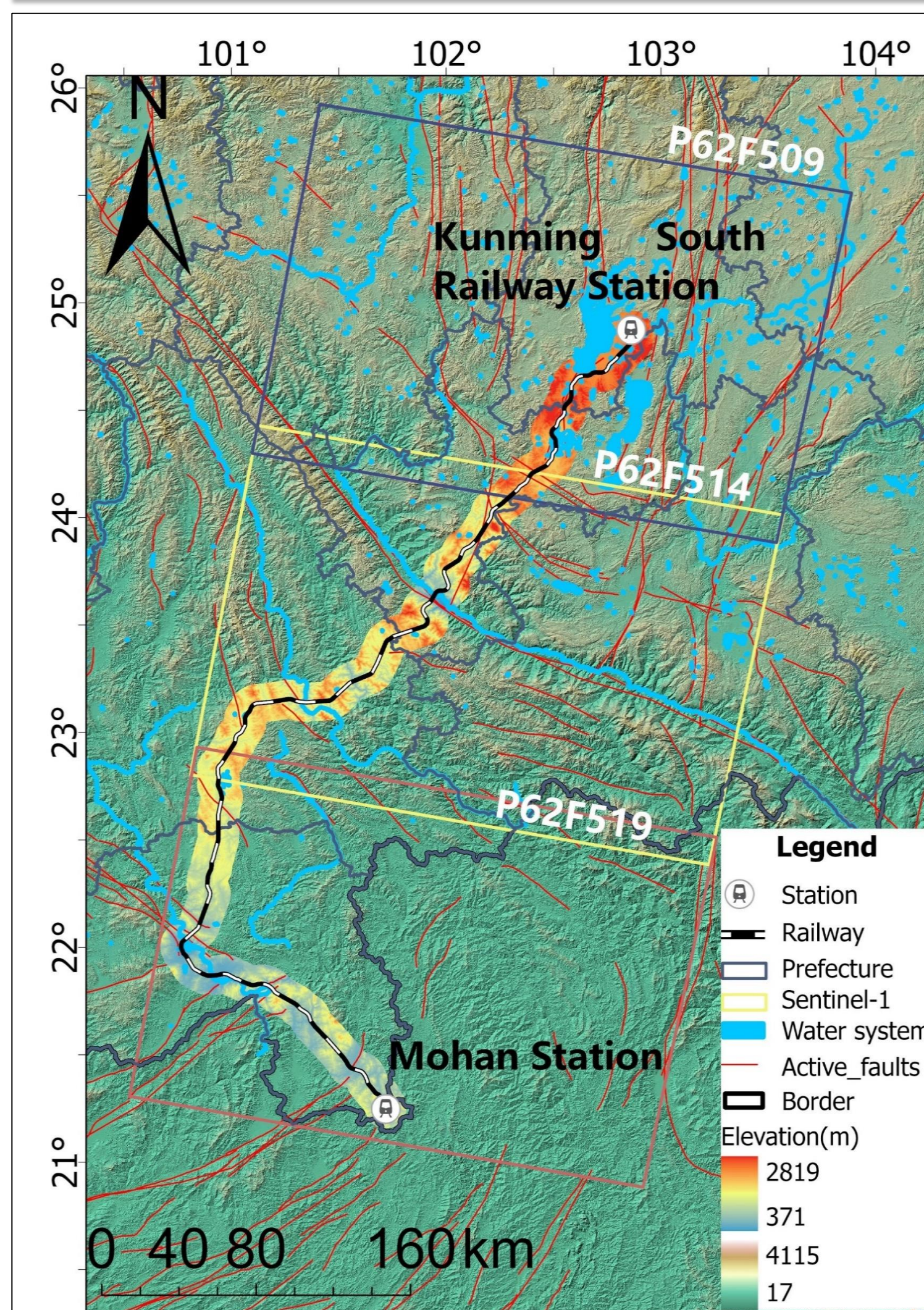
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ABSTRACT

In this investigation, a dedicated InSAR phase gradient stacking framework was developed for extracting railway deformation information. Deformation results along the Chinese section of the China-Laos Railway were mapped using this framework. By incorporating 2D deformation information from both ascending and descending orbits, deformation patterns in localized areas were assessed, enabling the identification of unstable slopes.

- First, a deformation monitoring framework along the railway was established to achieve rapid extraction of deformation information.
- Then, the surface deformation gradient field along the 586-km Chinese section of the China-Laos Railway was extracted.
- Finally, proactive identification of potentially unstable zones subjected to destabilizing stress along the corridor was conducted.

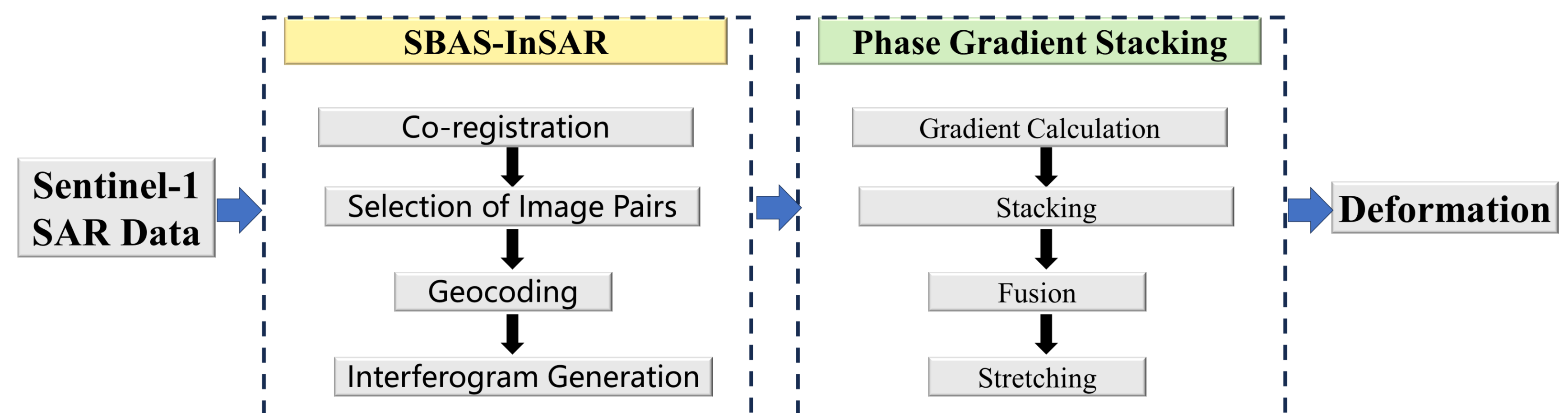
I. Study area and DATASET



The study area comprises the 586-km Chinese section of the China-Laos Railway, extending from Kunming South Station to Mohan Port in Yunnan Province, China. This railway traverses complex and diverse topography characterized by multiple mountain ranges, river systems, and active faults. The map presents the railway corridor, associated terrain features, coverage of Sentinel-1 descending orbit data, and corresponding track numbers employed in this study, with detailed data parameters provided in the table below.

Data	Sentinel-1 Descending		
Time	2022.1.12-2024.12.27		
Path	62	62	62
Frame	509	514	519
Images	87	87	87

II. METHODS



First, the SBAS-InSAR strategy was employed to acquire interferometric pairs covering the study area, yielding differential interferometric phase data, followed by phase gradient stacking:

$$\Delta\varphi_i^{se}(m,n) = \text{Wrap}[\varphi_i(m+s,n+s)] - \varphi_i(m,n)]$$

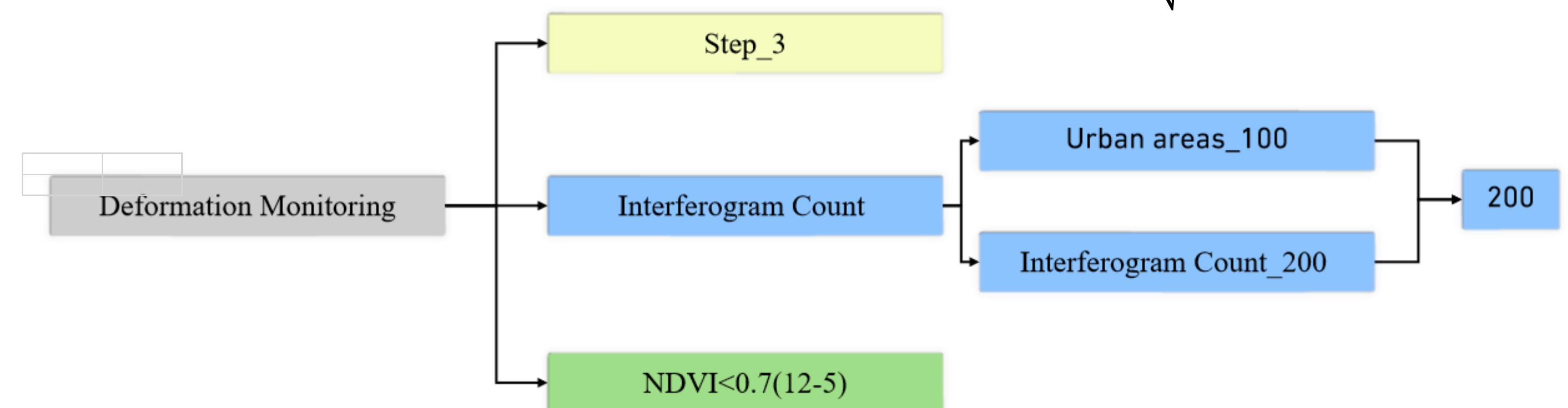
The formula represents the core step of gradient calculation, which involves computing phase differences between neighboring pixels in the differential phase map regulated by step size S

Upon completing the gradient calculation in the same direction, we stack the gradient values from all M differential interferograms:

$$\Delta\varphi^{se}(m,n) = \sum_i^M \Delta\varphi_i^{se}(m,n)$$

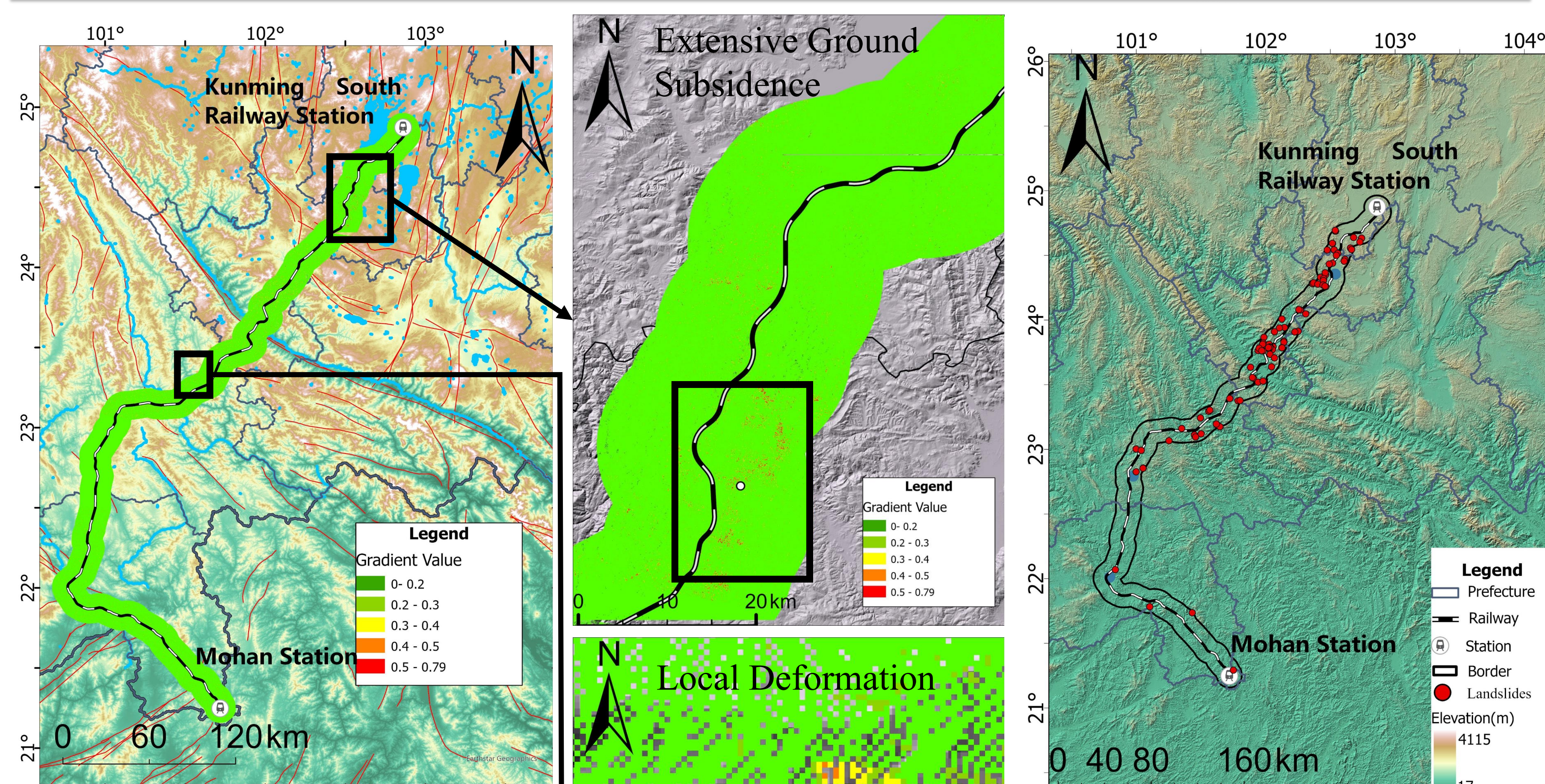
Subsequently, the gradient stacking results from four directions (East, South, Northeast, Southeast) are combined to derive the final deformation gradient result characterizing surface deformation.

$$\varphi = \sqrt{\frac{\Delta\varphi^e{}^2 + \Delta\varphi^s{}^2 + \Delta\varphi^{se}{}^2 + \Delta\varphi^{ne}{}^2}{4}}$$



Through experimental investigation of the joint regulation effects of varying step sizes and interferometric pair quantities, and considering the NDVI (Normalized Difference Vegetation Index) of the study area, the final monitoring framework was established. It was determined that a step size of 3 with 200 interferometric pairs achieves optimal monitoring effectiveness.

III. RESULT ANALYSIS



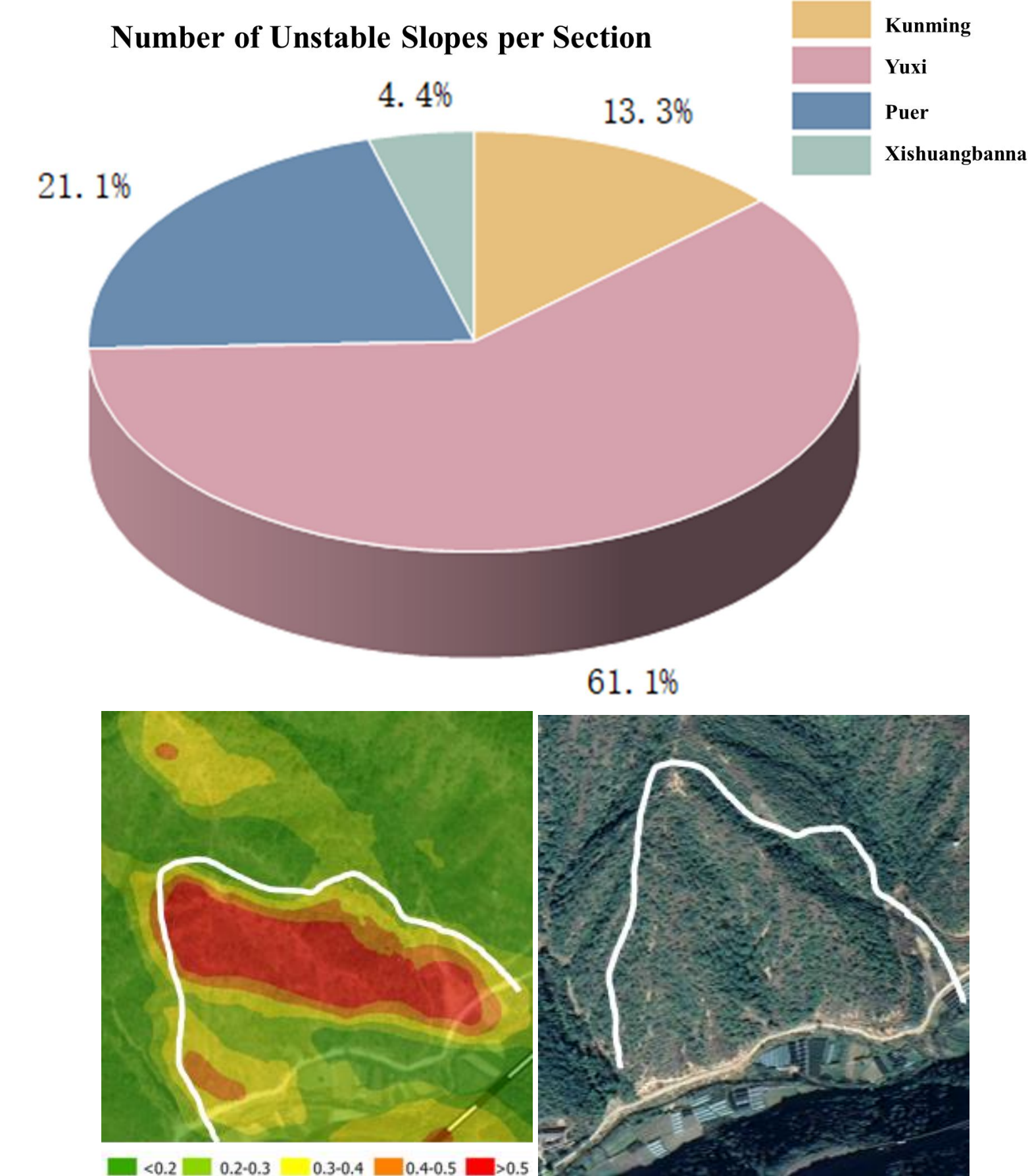
The figure depicts the deformation gradient field within the 10-km buffer zone along the Chinese section of the China-Laos Railway, extracted using the InSAR phase gradient stacking technique integrated with multi-track datasets. However, owing to the extensive spatial span of the railway infrastructure, deformation details are obscured in the full-scale results. Thus, we magnify localized regions exhibiting significant deformation to more clearly demonstrate the monitoring outcomes.

The InSAR phase gradient stacking technique enables rapid acquisition of deformation information and facilitates preliminary localization of high-deformation zones. By setting deformation gradient thresholds and integrating topographic features with optical imagery, we proactively identify potentially unstable slopes along the corridor. The red dots in the figure denote the proactively identified unstable slopes and their spatial distribution along the railway corridor.

The figure specifically illustrates magnified results of representative areas along the railway.

IV. VALIDATION

Statistical quantification of unstable slopes distribution along the railway corridor reveals the following sectional proportions: Kunming Section 13.3%, Yuxi Section 61.1%, Puer Section 21.1%, and Xishuangbanna Section 4.4%.



Additionally, detailed profiles of deformation gradients and corresponding optical imagery for representative unstable slopes are presented.

V. CONCLUSION

The InSAR phase gradient stacking technique, with its high computational efficiency and rapid deformation extraction capability, provides an effective tool for monitoring surface deformation and enabling early identification of geohazards along railway corridors. We extracted the deformation gradient field within the 10-km buffer zone of the Chinese section of the China-Laos Railway, achieving preliminary localization and verification of unstable slopes through integration of slope attributes and optical imagery.

ACKNOWLEDGEMENT

We gratefully acknowledge the support of the ESA-MOST Dragon Programme Phase 6 [Project ID 95473] for providing the Sentinel-1/2 datasets. This work was financially supported by the National Natural Science Foundation of China [Grant Nos. 42474040, 42101450], the Yunnan Fundamental Research Projects [Grant No. 202301AT070145], and the Yunnan Revitalization Talent Support Program.