

REMOTE MONITORING OF SPACEBORNE GROUND DISPLACEMENT DATA VIA CONFORMAL P-VALUE MAPS

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Abstract

The latest advancements in differential interferometric processing have resulted in techniques capable of providing regular high-resolution ground displacement measurements at regular time intervals with millimeter-scale precision [1]. Such spatially extensive and regularly updated observations of ground motion offer unprecedented opportunities for the remote monitoring of multiple areas exposed to environmental hazards. In this study, we analyze Synthetic Aperture Radar data processed with multi-temporal Differential Interferometric techniques to monitor the Phlegraean Fields, Italy, an area notably exposed to high seismic and bradyseismic hazards. We propose a novel distribution-free framework for monitoring sequential ground displacement observations based on conformal p-value maps. The methodology combines functional data analysis and conformal prediction to identify localized anomalous deformation while providing rigorous statistical guarantees [2,3]. Ground displacement observations are represented as functions defined over a two-dimensional spatial domain, enabling the spatial structure of the phenomenon to be modeled directly while avoiding the curse of dimensionality associated with conventional multivariate approaches. Building on recent advances in conformal inference for functional data, we construct prediction bands for new surfaces, and extend the notion of conformal p-values to functional data through the introduction of the conformal p-value map. Rather than providing a single global measure of conformity, the proposed map quantifies the degree of anomaly at every spatial location of a newly observed displacement surface. Locations associated with small p-values are interpreted as departures from the expected deformation pattern and can therefore be flagged as anomalous. A key feature of the proposed methodology is that the anomaly threshold directly determines the maximum tolerated probability of false warnings. Specifically, for any chosen significance level, the probability of incorrectly identifying one or more locations as anomalous on a new non-anomalous surface is provably controlled, independently of the underlying data distribution. This combination of local interpretability and finite-sample statistical validity makes the conformal p-value map particularly attractive for operational monitoring applications. We further extend the methodology to enable sequential monitoring of ground displacement over time.

The proposed methodology is broadly applicable to ground displacement data derived from Small Baseline Subset (SBAS) DInSAR processing and is therefore readily applicable beyond the Phlegraean Fields to the remote monitoring of other areas exposed to volcanic, bradyseismic, and seismic hazards.

Keywords: conformal prediction, functional data analysis, anomaly detection, DInSAR

References

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