Assessment of Season-Dependent Sentinel-1 SAR Coherence Reliability in Freeze-Thaw Dominated Terrain: A Longyearbyen Case Study

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Abstract

Satellite radar interferometry has become a cornerstone of operational deformation monitoring, yet its reliability depends fundamentally on the temporal stability of surface scattering mechanisms. In cryospheric and permafrost-dominated regions, surface conditions evolve rapidly due to freeze–thaw transitions, snow redistribution, liquid water infiltration, and seasonal dielectric changes. These processes alter backscatter phase consistency at scales that are often smaller than the spatial resolution of Sentinel-1, introducing decorrelation that may not correspond to actual ground displacement. As polar regions experience accelerated climate-driven change and increasing human activity, the need for robust, seasonally aware interpretation frameworks becomes critical. A systematic evaluation of coherence behavior under extreme environmental forcing therefore serves not only as a regional case study, but as a stress test for the operational limits of C-band InSAR in high-latitude monitoring applications. Reliable interpretation of Sentinel-1 SAR coherence is critical for polar surface monitoring, but seasonal freeze-thaw processes introduce variability that may complicate data trustworthiness. High-latitude regions are characterized by seasonal snow accumulation, melt cycles, glacier motion, and permafrost dynamics, all of which can degrade interferometric coherence and phase stability. A structured assessment of these limitations is necessary to support risk-aware Earth observation services. We've selected the Longyearbyen region of Svalbard as a controlled Arctic testbed due to its combination of exposed bedrock, active glaciers, thaw-sensitive permafrost, and critical infrastructure within a compact geographic area. This diversity allows direct comparison between stable and highly dynamic surfaces under identical acquisition geometry. Sentinel-1 IW SLC HH-HV data acquired from 2018 to 2024 were processed using a single relative orbit configuration to ensure geometric consistency. Short-baseline interferograms (12-day pairs) were generated to evaluate seasonal coherence variability, temporal baseline sensitivity, and phase noise behavior across multiple freeze-thaw cycles. Preliminary analysis indicates significant coherence degradation during peak melt periods and over snow-dominated surfaces, while exposed rock and infrastructure maintain higher stability and interpretable phase trends. Based on coherence statistics and time-series consistency, a three-tier operational usability classification is proposed: Reliable, Usable with Caution, and Not Reliable. This study provides a practical framework for evaluating Sentinel-1 InSAR performance in extreme environments and supports improved decision-making for deformation monitoring in Arctic regions. By explicitly linking environmental conditions to measurement stability, the results contribute to more transparent operational use of SAR interferometry in high-latitude applications.

Keywords: Sentinel-1, InSAR, coherence reliability, Arctic monitoring, freeze–thaw dynamics, operational limits