

Time-Series InSAR Analysis Using PS-InSAR, SBAS-InSAR, and Merged Approach: A Case Study of Khun Dan Prakarn Chon Dam, Nakhon Nayok, Thailand

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Abstract

This study compares Persistent Scatterer InSAR (PS-InSAR), Small Baseline Subset InSAR (SBAS-InSAR), and the StaMPS merged processing mode for line-of-sight (LOS) ground-motion screening around Khun Dan Prakarn Chon Dam, Thailand, using 43 ascending Sentinel-1 Interferometric Wide Swath scenes acquired from January 2015 to July 2025. EZ-InSAR, ISCE, and StaMPS were used to generate mean LOS-velocity products and evaluate point density, standard deviation, normalized median absolute deviation (NMAD), mapped interferometric coherence, and agreement on spatially matched points. PS-InSAR produced the smallest velocity dispersion (STD = 0.601 mm/yr; NMAD = 0.513 mm/yr), whereas SBAS-InSAR showed greater dispersion (STD = 1.417 mm/yr; NMAD = 0.882 mm/yr). The merged result provided the greatest spatial sampling (35,143 points; 65.08 points/km²), with intermediate dispersion (STD = 1.002 mm/yr; NMAD = 0.647 mm/yr), and was therefore interpreted as a coverage-precision trade-off rather than a more accurate product. A common-support comparison matched 28,257 merged-PS points within 30 m and yielded an NMAD of velocity differences of 0.334 mm/yr, but weak pointwise association ($R^2 = 0.258$), showing that small robust differences do not imply strong equivalence. Most velocities were near zero; however, these relative single-orbit LOS observations cannot independently resolve vertical and horizontal motion or verify structural safety. Residual atmospheric effects, vegetation decorrelation, and viewing geometry limit physical interpretation. Without collocated field observations, the results therefore provide an internal comparison and remote-sensing screening indicators rather than external validation of dam performance.

Keywords: EZ-InSAR, Merged Approach, PS-InSAR, SBAS-InSAR, Time-Series InSAR

1. Introduction

Interferometric Synthetic Aperture Radar (InSAR) measures phase changes between repeated SAR acquisitions and can resolve millimetre-scale displacement along the satellite line of sight (LOS) under favourable coherence and error-control conditions [1]. Multi-temporal methods reduce decorrelation and atmospheric effects by exploiting image stacks [2]. Persistent Scatterer InSAR (PS-InSAR) identifies pixels with stable phase behaviour through time [3], whereas Small Baseline Subset InSAR (SBAS-InSAR) uses a connected network of short-baseline interferograms [4]. Combined PS-SB processing can increase spatial sampling, but adding points does not automatically improve precision or physical coherence [5][6] and [7]. EZ-InSAR provides a semi-automated interface to the processing chain [8] and [9]; parameter selection, quality control, and interpretation still require analyst

judgement. Inter-comparison studies show that point density and velocity dispersion vary with algorithm and common-support definition [10] and [11]. Recent dam and hydropower applications likewise treat satellite InSAR as complementary screening, particularly where vegetation, steep terrain, atmospheric delay, viewing geometry, and absent field validation constrain interpretation [12][13][14] and [15]. These constraints are especially relevant to humid, mountainous reservoir settings. The specific gap addressed here is a same-stack comparison of PS, SBAS, and merged outputs within one open-source workflow for a Thai roller-compacted-concrete dam. The objectives are to compare spatial sampling and velocity dispersion, quantify agreement on common-support points, and examine sensitivity to quality thresholds. The assessment is restricted to relative ascending-orbit LOS motion and does not claim a

three-dimensional deformation solution or a structural-safety determination.

2. Study Area and Data

Khun Dan Prakarn Chon Dam is a roller-compacted-concrete gravity dam in Nakhon Nayok Province, central Thailand (Figure 1). The dam is 93 m high, has a crest length of 2,594 m, and impounds approximately 224 million m³ [16]. The study domain includes the dam, reservoir margins, downstream areas, built surfaces, forested slopes, and agricultural land, producing heterogeneous scattering and topographic conditions. No documented distress event or site-specific geological, rainfall, seismic, or instrument record was evaluated in this study; consequently, the analysis addresses an observational gap rather than testing a known failure mechanism. The dataset comprises 43 Sentinel-1A/B Interferometric Wide Swath scenes from ascending Path 172 acquired between January 2015 and July 2025. The baseline network shown in Figure 2 used 7 April 2021 as the reference acquisition and contains 138 interferometric pairs. Sparse and irregular sampling over the decadal window limits recovery of seasonal and short-duration processes. Data were obtained through the Alaska Satellite Facility interface implemented in EZ-InSAR [8], and interferogram formation was performed in ISCE [9].

3. Methodology

3.1 Overview of the Processing Workflow

The workflow (Figure 3) used EZ-InSAR to organise Sentinel-1 data, execute ISCE interferometric processing, prepare StaMPS inputs, estimate displacement time series, and export products for statistical and spatial analysis [8] and [9]. MintPy was not used for time-series inversion in this study and is therefore not included in the processing chain. Atmospheric phase components were estimated within the StaMPS workflow. Atmospheric correction reduces, but cannot demonstrate complete removal of, tropospheric artefacts; corrected maps were therefore assessed together with spatial continuity, velocity dispersion, and common-support comparisons rather than treated as ground truth [17]. The workflow consisted of three primary processing paths as follows:

1. PS-InSAR processing to identify highly coherent persistent scatterers (PS points).
2. SBAS-InSAR processing to generate a network of small-baseline interferograms for low-coherence surfaces.
3. Merged processing combined accepted PS and small-baseline candidates within the StaMPS multi-temporal solution to increase spatial sampling [5] and [6]. The merged result was evaluated as a hybrid point population and was not assumed a priori to have higher precision or physical coherence.

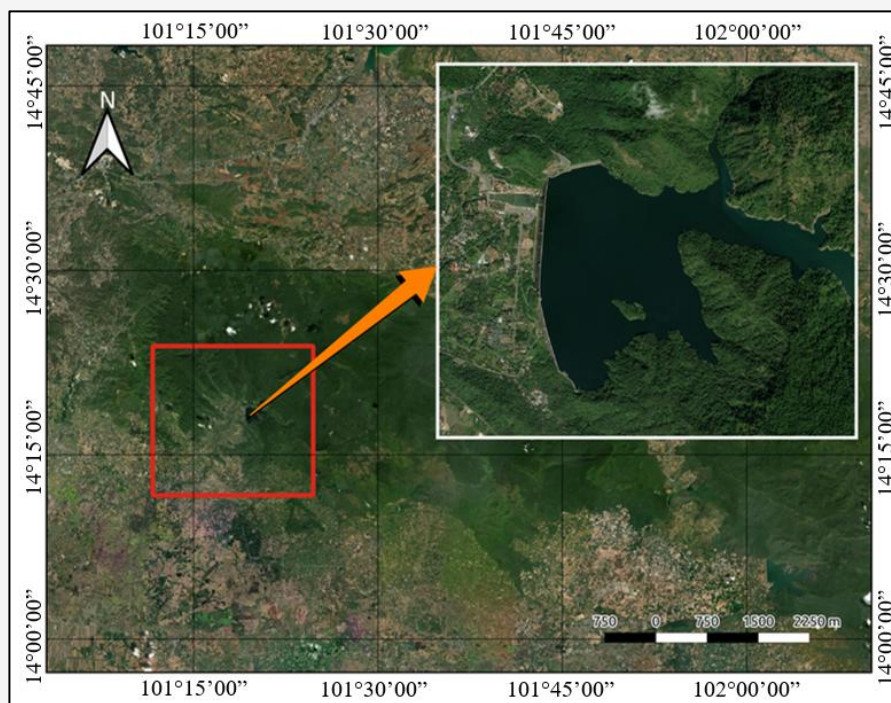


Figure 1: Study area of Khun Dan Prakarn Chon Dam, Nakhon Nayok Province

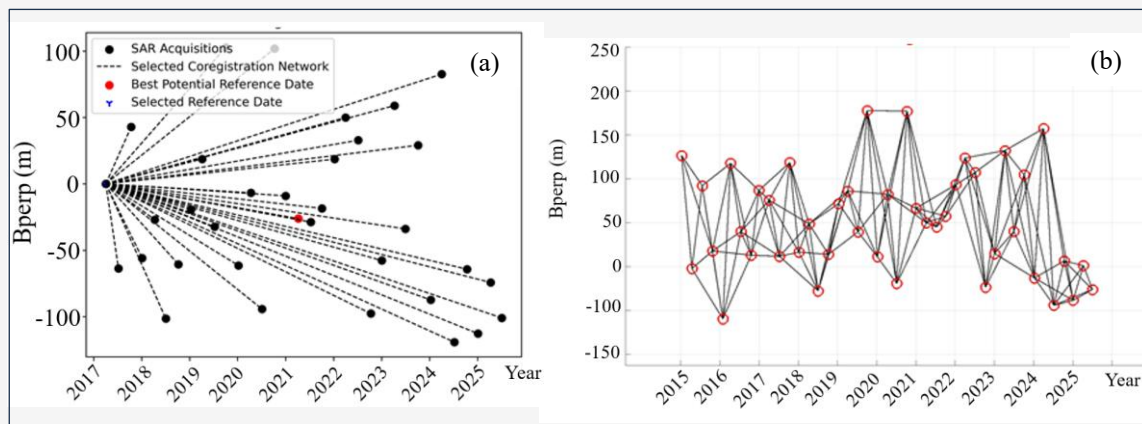


Figure 2: Interferogram baseline networks for (a) PS-InSAR and (b) SBAS-InSAR; the reference acquisition is 7 April 2021 and the plotted network contains 138 pairs

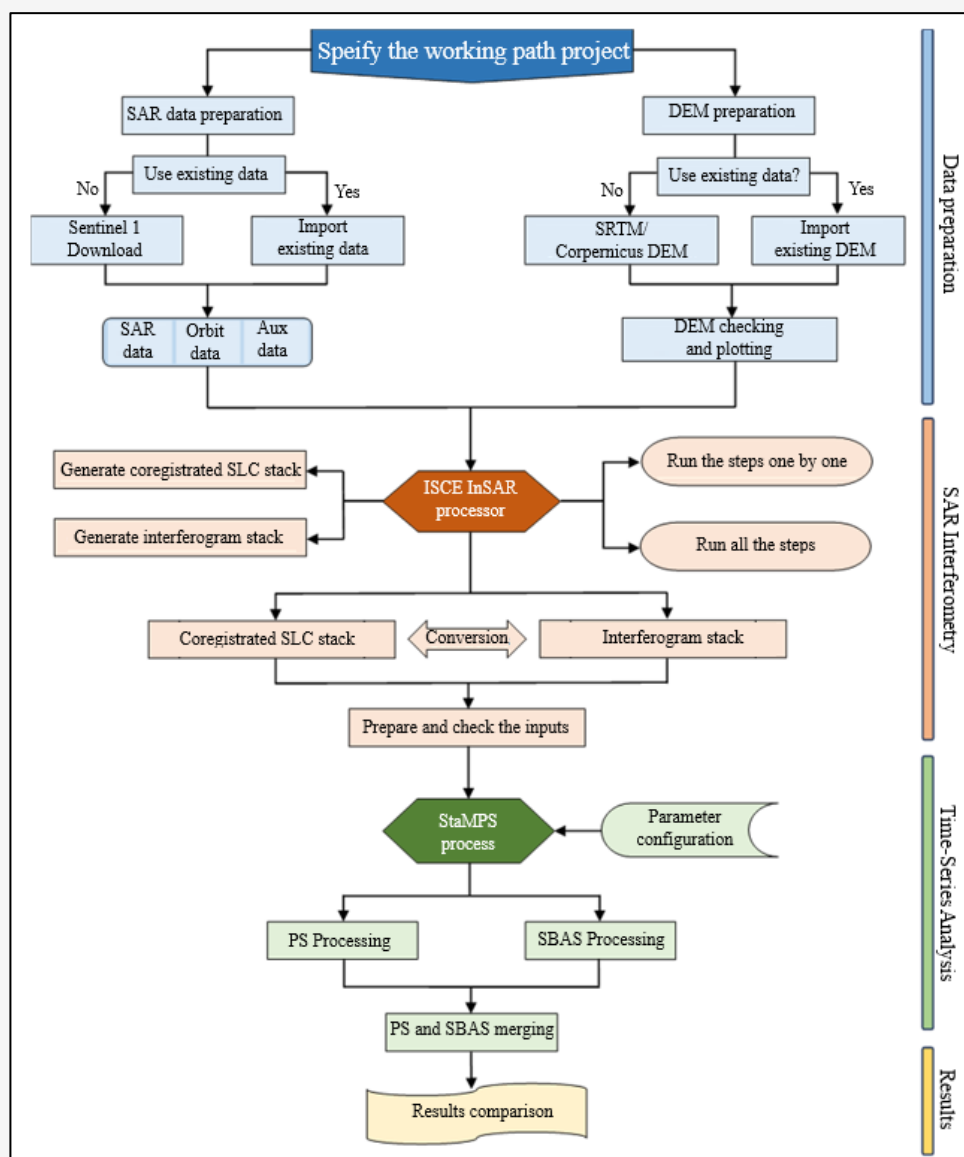


Figure 3: Workflow of Time-Series InSAR analysis using the EZ-InSAR platform [8]

3.2 PS-InSAR, SBAS-InSAR, and Processing Parameters

PS-InSAR selected long-term phase-stable candidates, commonly concentrated on engineered or strongly reflecting surfaces [3]. SBAS-InSAR inverted a connected small-baseline interferogram network to reduce temporal and spatial decorrelation [4]. Sentinel-1 TOPS co-registration and interferogram generation followed the ISCE workflow [9] and [18], while StaMPS was used for scatterer selection, phase unwrapping, atmospheric-phase estimation, and time-series inversion [5] and [19]. Pairwise statistics were computed only after nearest-neighbour matching within 30 m; full-product counts and matched-subset counts are therefore not interchangeable. No weighted averaging or kriging was applied in the pairwise analysis. A matching-radius sensitivity test could not be reconstructed from the retained summary outputs; this limitation is reported rather than presenting the 30 m radius as an optimised value.

3.3 Performance Metrics

Performance was described using point count and density, the reported coherence metric, mean LOS velocity, standard deviation (STD), normalized median absolute deviation (NMAD), common-support pairing rate, and coefficient of determination (R^2). These metrics characterise internal precision, dispersion, sampling, and inter-method agreement; none is an independent measure of engineering safety [2][10] and [11]. The density (D) is the ratio between the total number of deformation points and the total area as defined in Equation 1:

$$D = \frac{N}{A} \quad \text{Equation 1}$$

Where:

- D = The density (pts/km²)
- N = The number of valid deformation points
- A = The total study area (km²).

The coherence values (γ) are mean interferometric coherence values sampled at retained output locations. They are not the StaMPS temporal coherence or *ps_gamma_t* criterion used to identify PS candidates. Consequently, a low mapped median for PS points does not by itself imply that the PS selection failed, and the PS, SBAS, and merged medians should not be interpreted as directly equivalent measures of temporal phase stability. Merging changes the composition and spatial coverage of the point population. The coherence is defined in Equation 2:

$$\gamma = \frac{\left| \sum_{i=1}^n S_{1i} \cdot S_{2i}^* \right|}{\sqrt{\sum_{i=1}^n S_{1i}^2 \cdot \sum_{i=1}^n S_{2i}^2}} \quad \text{Equation 2}$$

Where:

- S_{1i} and S_{2i} = Complex radar samples
- S_{2i}^* = The complex conjugate of S_{2i} .
- n = The number of samples
- γ = Interferometric coherence (0-1)

Standard Deviation (STD) measures the spread of velocity values. It is determined from Equation 3:

$$STD = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (v_i - \bar{v})^2} \quad \text{Equation 3}$$

Where:

- v_i = The LOS velocity at point i
- $\bar{v}$ = The mean velocity
- n = The total number of PS/SBAS points

Normalized Median Absolute Deviation (NMAD) is a robust dispersion metric that is less sensitive to outliers than STD [10]. NMAD is expressed in Equation 4:

$$NMAD = 1.4826 \cdot \text{Median}(|v_i - \text{median}(v)|) \quad \text{Equation 4}$$

Where:

- v_i = The velocity of point i
- $\bar{v}$ = The median velocity

Pairing rate (PR) quantifies spatial matching and robust velocity differences between methods within the specified 30 m radius. Pairing rate describes common support; The pairing rate is determined from Equation 5:

$$PR = \frac{N_{pairs}}{N_{total}} \times 100 \quad \text{Equation 5}$$

Where:

- N_{pairs} = Number of matched PS-SBAS points
- N_{total} = The total number of points

NMAD of delta- v describes the dispersion of the paired differences [10] and [11]. The difference of the NMAD is expressed in Equation 6:

$$\Delta v_{NMAD} = 1.4826 \cdot \text{Median}(|v_{A,i} - v_{B,i}|) \quad \text{Equation 6}$$

Where:

$v_{A,i}$ and $v_{B,i}$ = Velocities from methods A and B
 Δv_{NMAD} = The precision difference.

Time-series completion (*TC*) represents the proportion of valid epochs to total acquisitions. Values close to 100% indicate data availability, but do not by themselves establish temporal coherence or accuracy [11]. The time-series completion is determined from Equation 7:

$$TC = \frac{N_{valid}}{N_{total}} \times 100$$

Equation 7

Where:

N_{valid} = the number of epochs with valid deformation data
 N_{total} = the total number of SAR acquisitions.

Coefficient of determination (R^2) is the squared linear correlation between paired LOS velocities. It is not used as a temporal-trend test or as evidence of dam stability [10]. The R^2 is determined from Equation 8:

$$R^2 = 1 - \frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{\sum_{i=1}^n (y_i - \bar{y})^2}$$

Equation 8

Where:

y_i = Paired LOS velocity from method B
 $\hat{y}_i$ = Velocity predicted by the linear model from method A
 $\bar{y}$ = Mean paired LOS velocity of method B

3.4 Statistical, Spatial, and Sensitivity Analyses

Descriptive statistics were computed for each complete output. Pairwise comparison used a common-support subset defined by nearest-neighbour matching within 30 m. For each pair, delta-v was method B minus method A; bias, NMAD of delta-v, R^2 , and Bland-Altman limits of agreement were then calculated. R^2 measures linear association, whereas Bland-Altman analysis measures agreement and bias; neither establishes equivalence. Conventional pointwise confidence intervals and significance tests were not applied because tens of thousands of spatially autocorrelated points do not meet independence assumptions, and no multiple-testing framework was defined. Sensitivity tests varied method-specific quality thresholds and tracked NMAD and retained-point count. Values of $|v| > 2$ mm/yr were used only as a descriptive screening threshold, not as a regulatory or dam-safety limit.

3.5 LOS Geometry, Referencing, and Validation Scope

Sentinel-1 measures displacement projected onto the radar LOS. For the ascending track used here, positive and negative velocities indicate relative motion toward and away from the satellite, respectively; one viewing geometry cannot uniquely identify uplift, subsidence, eastward motion, or westward motion [20]. Near-zero means are influenced by the selected reference and are not evidence of absolute stability. No collocated GNSS, levelling, extensometer, inclinometer, piezometer, or other dam-instrumentation series was available for this analysis. Agreement among InSAR workflows is therefore internal inter-comparison, not external validation.

4. Results and Discussion

4.1 Spatial Coverage and Atmospheric-Phase Correction

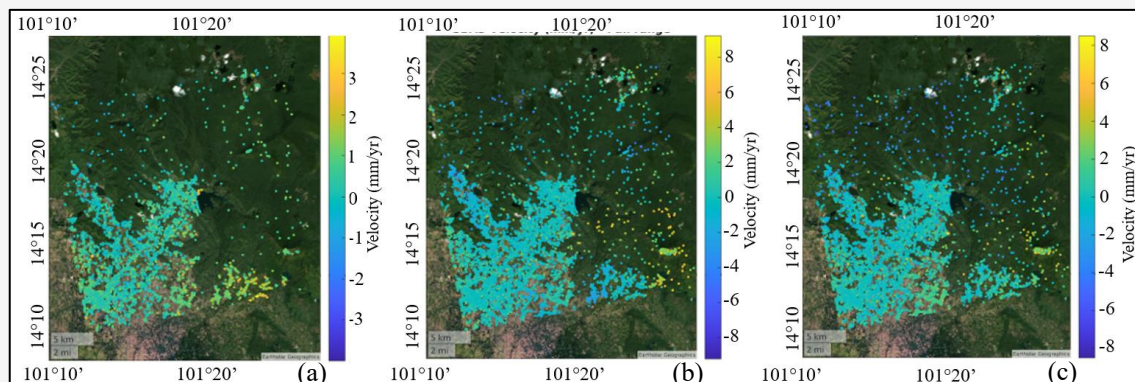
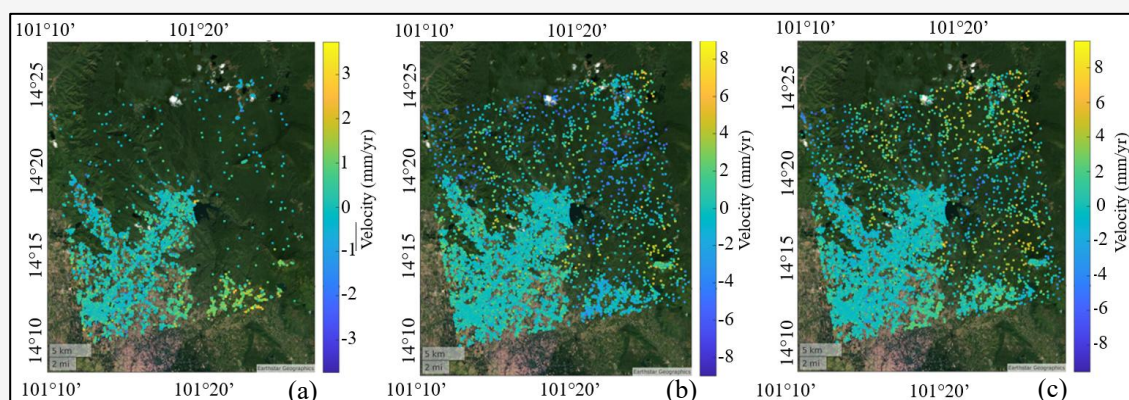
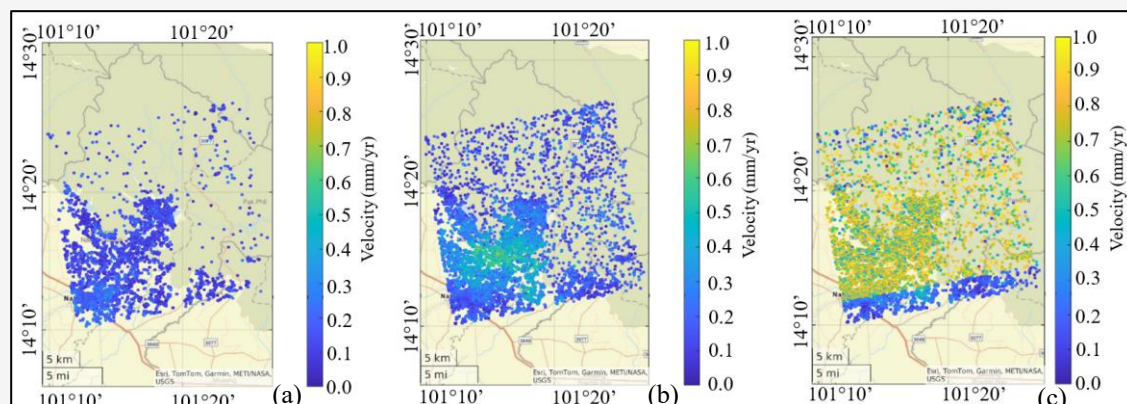
Table 1 summarises the full output populations. PS-InSAR retained 28,555 points (52.88 points/km²), SBAS-InSAR retained 8,919 points (16.52 points/km²), and the merged product retained 35,143 points (65.08 points/km²). The merged count is smaller than the arithmetic sum because overlapping candidates are consolidated. Figures 4 and 5 show the velocity fields before and after atmospheric-phase correction. The smoother corrected field indicates reduced long-wavelength phase structure, but correction does not prove that all residuals are ground motion because topography-correlated delay, vegetation decorrelation, layover, shadow, and unwrapping error may remain [17].

4.2 Coherence Analysis

The mapped median interferometric coherence values were 0.153 for PS locations, 0.259 for SBAS locations, and 0.289 for the merged population (Table 1 and Figure 6). These values are mean interferometric coherence sampled at retained locations, not StaMPS temporal coherence or ps_gamma_t . Therefore, they should not be compared directly with conventional PS temporal-coherence thresholds. The higher merged median primarily reflects a different point population and spatial sampling; merging does not physically increase coherence. The merged velocity STD (1.002 mm/yr) exceeds the PS STD (0.601 mm/yr), so its higher mapped median coherence did not correspond to lower velocity dispersion. No inferential test was applied to the medians because the method-specific point populations are unequal and spatially autocorrelated.

Table 1: Statistical summary of PS-InSAR, SBAS-InSAR, and merged results

Method	N (points)	Density (pts/km ²)	Median Coherence	Mean (mm/yr)	STD (mm/yr)	NMAD (mm/yr)
PS-InSAR	28,555	52.88	0.153	-0.122	0.601	0.513
SBAS-InSAR	8,919	16.52	0.259	-0.183	1.417	0.882
Merged	35,143	65.08	0.289	-0.137	1.002	0.647

**Figure 4:** LOS-velocity maps before atmospheric-phase correction
(a) PS-InSAR, (b) SBAS-InSAR, and (c) merged product**Figure 5:** LOS-velocity maps after atmospheric-phase correction
(a) PS-InSAR, (b) SBAS-InSAR, and (c) merged product**Figure 6:** Mean interferometric coherence sampled (a) PS, (b) SBAS, and (c) merged product

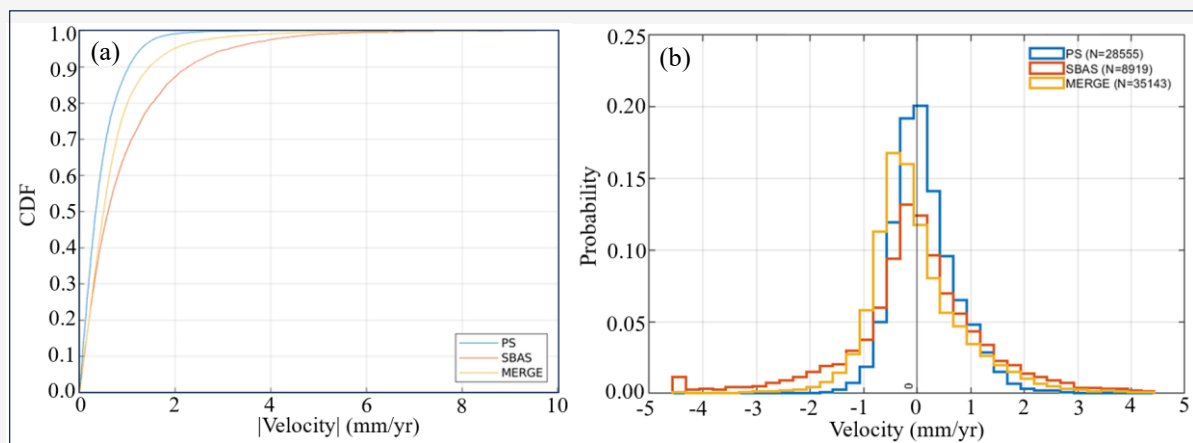


Figure 7: (a) Empirical CDF of absolute LOS velocity and (b) normalized LOS-velocity distributions for the three methods

4.3 Deformation Statistics

Table 1 shows that PS-InSAR has the narrowest velocity distribution (STD = 0.601 mm/yr; NMAD = 0.513 mm/yr), SBAS-InSAR the broadest (STD = 1.417 mm/yr; NMAD = 0.882 mm/yr), and the merged product an intermediate distribution (STD = 1.002 mm/yr; NMAD = 0.647 mm/yr). Thus, PS provides the greatest internal precision in this dataset; merging gains coverage at the cost of greater dispersion than PS alone. Similar algorithm-dependent trade-offs in common-support density and velocity dispersion have been reported in inter-comparison studies [10] and [11]. The near-zero means are relative to a reference and should not be interpreted as absolute stability. Figure 7(a) is the empirical cumulative distribution of absolute velocity: at each x value, the ordinate is the proportion of points with $|v| \leq x$. The curves approach 1 by approximately 6 mm/yr because nearly all retained observations fall below that magnitude. Figure 7(b) shows heavier SBAS tails and a narrower PS distribution. Positive and negative values indicate relative LOS motion toward and away from the satellite, not dam oscillation.

4.4 Pairwise Comparison

Pairwise statistics must be interpreted on the same matched subset (Table 2). According to Figure 8, for merged versus PS, 28,257 of 28,555 PS points were matched within 30 m, giving a pairing rate of 98.96%. The mean difference (merged minus PS) was -0.216 mm/yr and NMAD (Δv) was 0.334 mm/yr. The negative bias may reflect reference choice, contributions from small-baseline candidates, and local velocity gradients within the matching radius. The Bland-Altman plot shows that

most differences lie within the limits of agreement, but the scatter plot gives $R^2 = 0.258$, indicating weak pointwise linear association. Thus, small robust differences for many points coexist with substantial point-to-point scatter. The overlap is consistent with PS dominance in the merged population, not strong equivalence or proof that the merged product is superior. The value 0.334 is NMAD of the paired Δv distribution and represents robust dispersion of inter-method differences, not R^2 or external accuracy.

4.5 Spatial Deformation Patterns

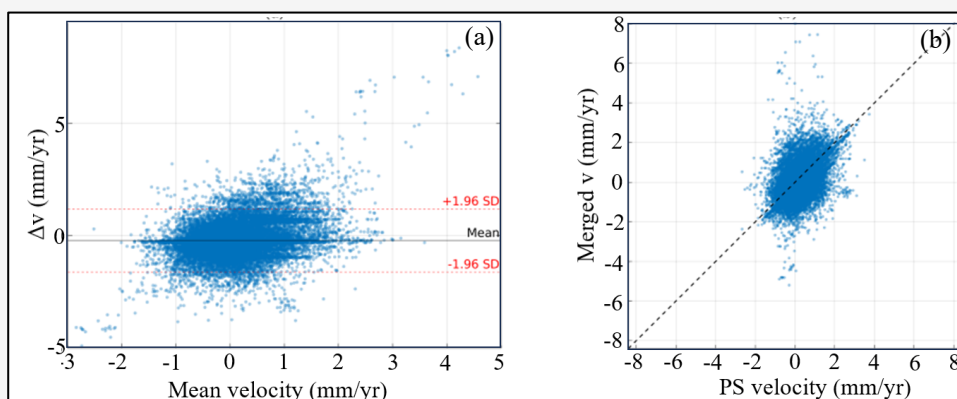
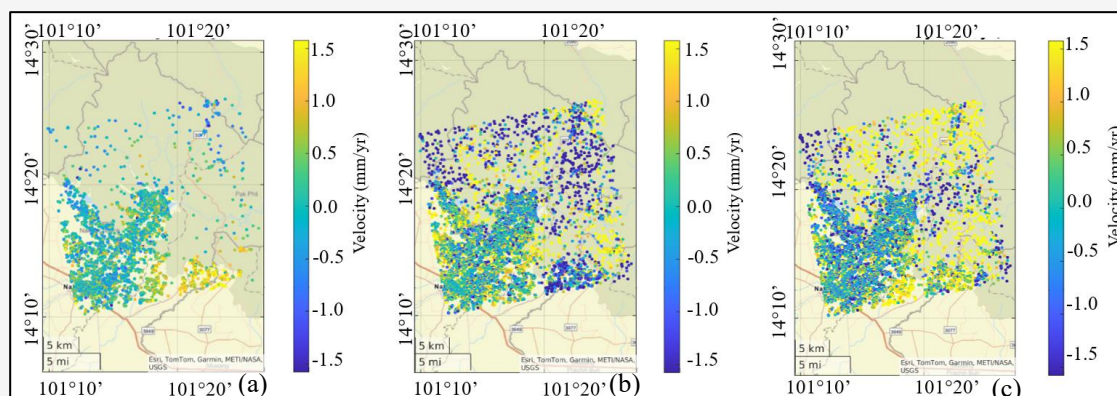
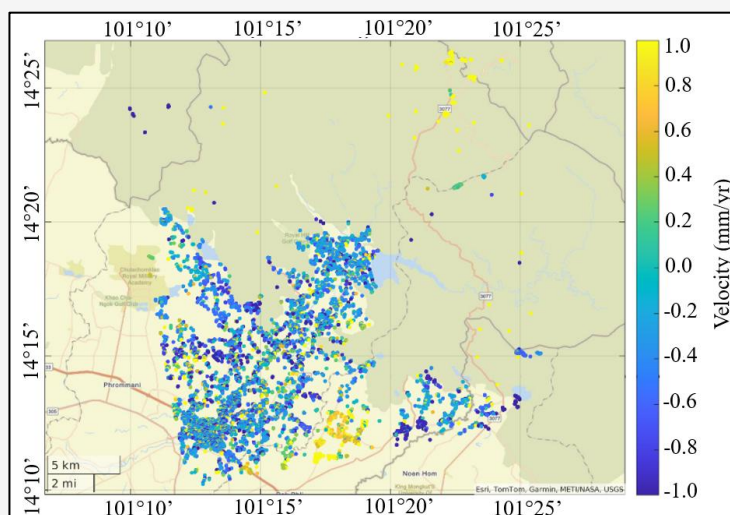
Figure 9 maps LOS velocity using a common display range. The spatially mixed positive and negative values describe relative motion toward and away from the ascending satellite. Because only one LOS geometry was used, apparent anomalies at abutments, spillways, reservoir margins, or slopes cannot be uniquely decomposed into vertical settlement and horizontal displacement. Moreover, layover, shadow, vegetation decorrelation, and residual atmospheric phase are plausible in the mountainous reservoir setting. The maps are therefore used to prioritise locations for field inspection rather than to apply an engineering allowable-deformation criterion.

4.6 Threshold-Exceedance and Sensitivity Analyses

The term hotspot is not used because no formal spatial hot-spot statistic was applied. Figure 10 maps merged-minus-PS velocity differences, and Figure 11 shows the relationship between the reported coherence metric and $|v|$. The 2 mm/yr value is not treated as an allowable dam deformation limit.

Table 2: Pairwise comparison on method-specific common-support subsets. Δv is method B minus method A

Comparison	Pairing Rate (%)	Mean Δv (mm/yr)	NMAD (mm/yr)	N pairs
PS vs SBAS	74.10	0.368	0.439	6,239
Merged vs PS	98.96	-0.216	0.334	28,257
Merged vs SBAS	80.00	0.175	0.466	10,230

**Figure 8:** Agreement between merged and PS LOS velocities on the same 28,257 matched points: (a) Bland-Altman differences and (b) pointwise scatter ($R^2 = 0.258$; NMAD (Δv) = 0.334 mm/yr)**Figure 9:** Spatial distribution of relative ascending-orbit LOS velocity (a) PS-InSAR, (b) SBAS-InSAR, and (c) merged product**Figure 10:** Spatial distribution of merged-minus-PS LOS-velocity differences

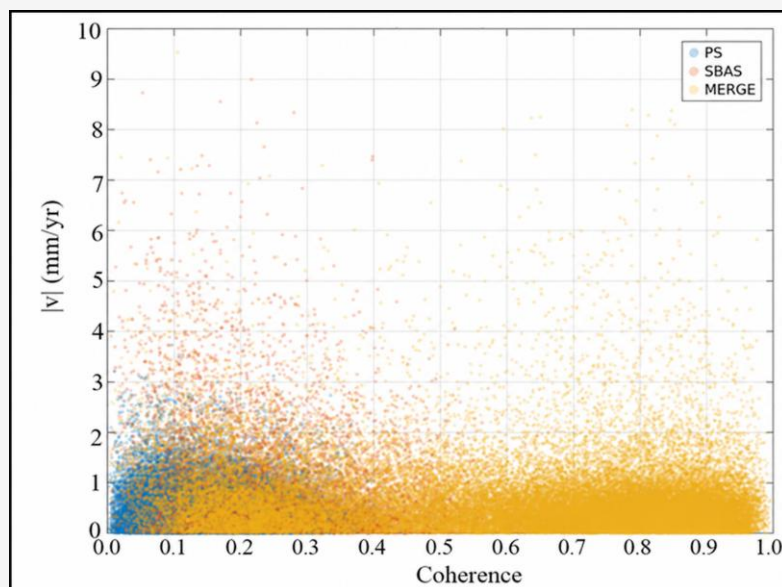


Figure 11: Reported coherence metric versus absolute LOS velocity for PS, SBAS, and merged output populations

Table 3: Summary of method-specific threshold sensitivity

Method / metric	Tested range	Observed NMAD behaviour	Point-retention implication
PS / ps_gamma_t	0.30-0.95	Decreased from about 0.38 to 0.10 mm/yr by 0.45; unavailable above 0.45	Very sharp loss; insufficient sample at stricter thresholds
SBAS / coherence	0.30-0.90	Decreased from about 0.68 to 0.32 mm/yr by 0.70	Progressive loss of spatial coverage
Merged / coherence	0.30-0.90	Approximately stable at 0.55-0.59 mm/yr	Large decline in N despite limited NMAD change

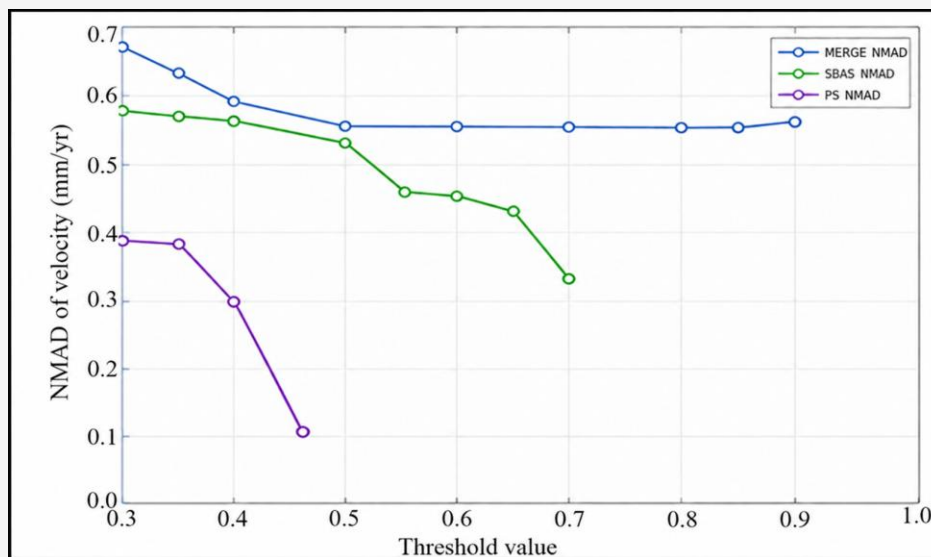


Figure 12: Sensitivity of velocity NMAD to the method-specific quality threshold. Missing PS NMAD values above 0.45 indicate an inadequate retained sample, not zero dispersion

No seasonal-soil-creep attribution is made because displacement was not correlated with rainfall, reservoir level, or geotechnical observations. Earlier candidate time series containing abrupt centimetre-scale jumps were excluded from physical interpretation because their non-progressive form is consistent with phase-unwrapping or sparse-network artefacts [17]. Table 3 and Figure 12 show method-specific sensitivity: SBAS NMAD decreases under stricter coherence screening, whereas merged NMAD remains approximately 0.55-0.59 mm/yr as the retained population changes. The PS NMAD curve ends at $ps_gamma_t = 0.45$ because no adequate retained sample exists at higher tested thresholds; missing values are not zeros. No universal optimum threshold is claimed. Threshold selection must balance dispersion, spatial representation, and sufficient retained points.

5. Conclusion

This study provides a structured internal comparison of PS-InSAR, SBAS-InSAR, and merged EZ-InSAR outputs for Khun Dan Prakarn Chon Dam. PS-InSAR produced the smallest velocity dispersion, SBAS-InSAR produced the largest, and the merged product provided the greatest spatial sampling with intermediate dispersion. The merged result may be useful when additional spatial coverage is needed, while PS is preferable where coherent infrastructure targets and lower dispersion are the priority. Common-support analysis shows a small robust difference for many merged-PS pairs but weak pointwise linear association ($R^2 = 0.258$), so the methods should not be described as strongly equivalent. The observations are relative ascending-orbit LOS estimates and cannot resolve three-dimensional dam movement. Internal agreement among InSAR methods is not external validation. Without collocated GNSS, levelling, inclinometer, piezometer, reservoir-level, or rainfall data, the results cannot confirm structural stability or exclude local deformation. EZ-InSAR is demonstrated here as a screening workflow rather than a validated standard for dam-safety decisions. Future work should use denser acquisitions, ascending and descending geometry, documented reference and processing parameters, robust unwrapping diagnostics, and co-located field observations to separate vertical and horizontal motion, evaluate hydrological forcing, and establish site-specific engineering thresholds.

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