

Deformation Monitoring, Prediction, and Quantitative Analysis of Thermal Effects for

Shanghai Lupu Bridge Using PS-InSAR Technology

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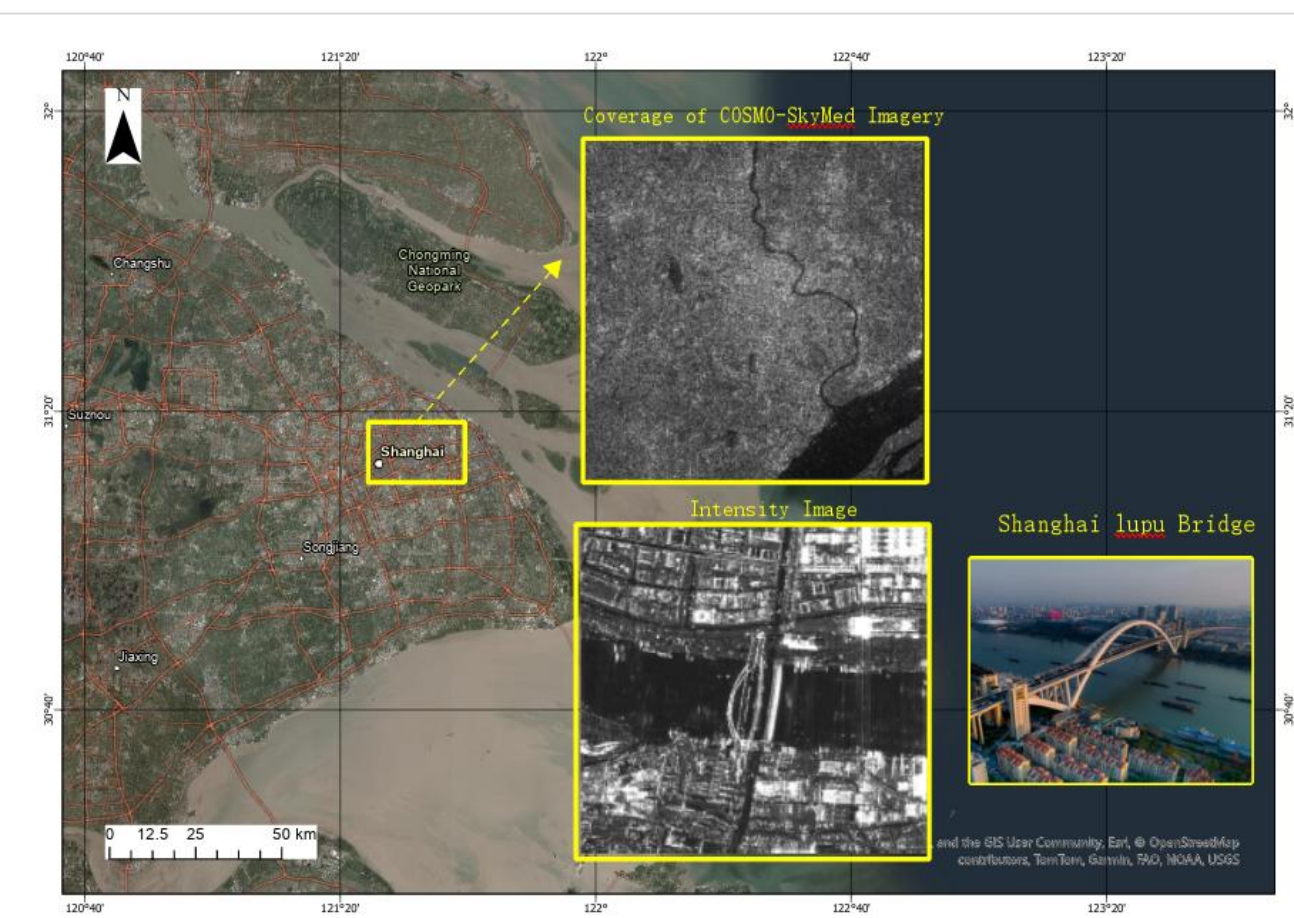
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ABSTRACT

As critical transportation infrastructure, bridges are subject to deformation and degradation under complex geological, meteorological, and marine conditions. This study investigates the Lupu Bridge in Shanghai using time-series Persistent Scatterer Interferometric Synthetic Aperture Radar (PS-InSAR) technology to extract deformation dynamics from SAR data. We further quantify thermal effects on observed deformation. Additionally, a novel predictive framework integrating K-means Clustering Classification (KCC), Bidirectional Long Short-Term Memory (BiLSTM), and self-attention mechanisms is proposed for short-term bridge deformation forecasting based on InSAR time-series data.

STUDY AREA



(a)

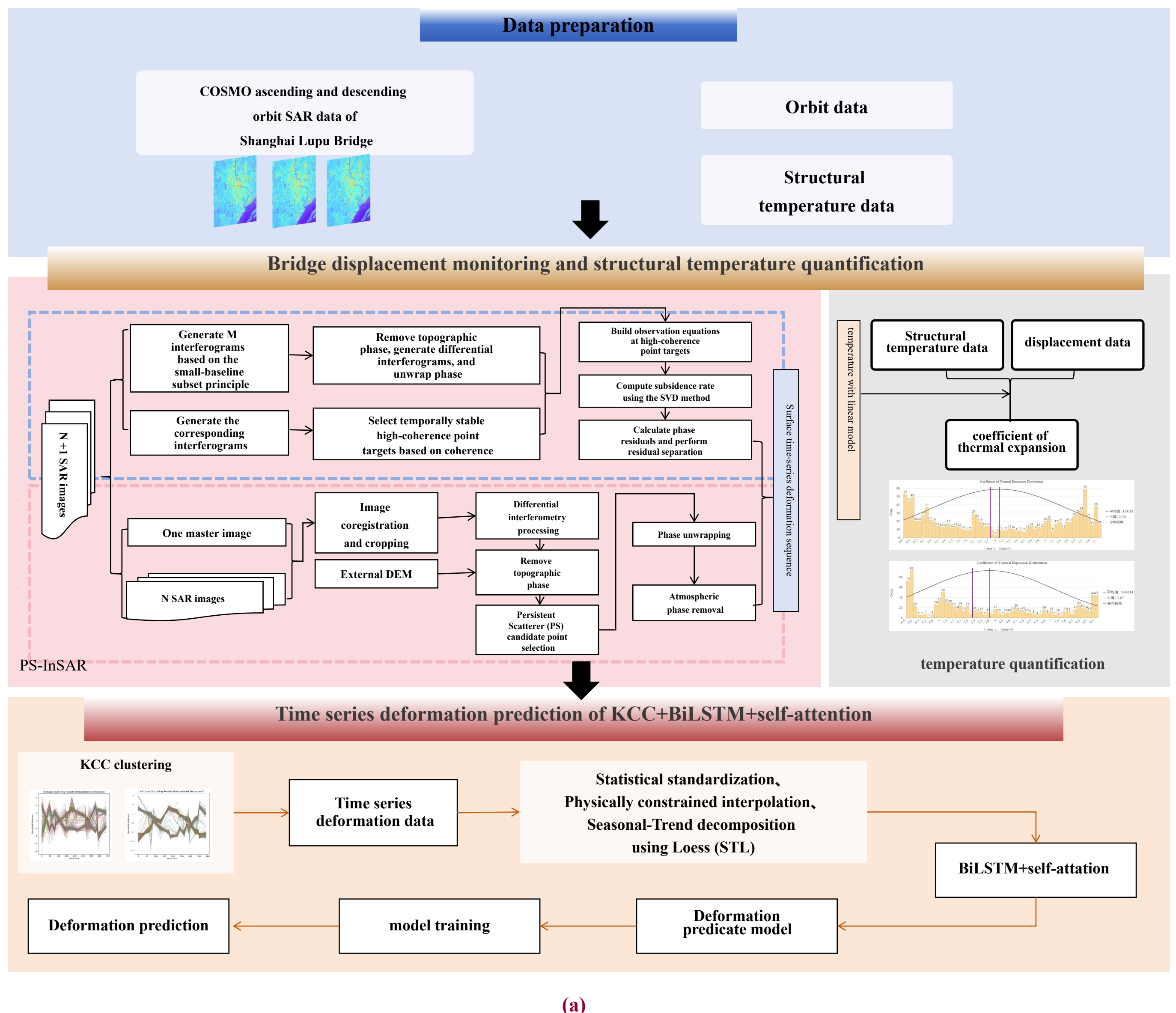
Parameter Name	Parameter Value
Data Type	RSLC
data type	COSMO-SkyMed
Resolution/(m x m)	1.0× 3.0
Revisit Cycle/d	40
Imaging Mode	High-Resolution Image
Band Type	X-band SAR
Band Wavelength (cm)	3.1 cm
Polarisation Pattern	HH
Acquisition Time	20090212-20100207 18 Scene COSMO-SkyMed Ascending Orbit Data of the Lupu Bridge; 20090113-20100201 18 Scene COSMO-SkyMed Descending Orbit Data of the Lupu Bridge

(b)

(a)The coverage of the COSMO-SkyMed imagery, the radar intensity image of the Shanghai Lupu Bridge, and a field photograph of the bridge structure.

(b)The parameter specifications of the COSMO-SkyMed satellite datasets.

METHOD



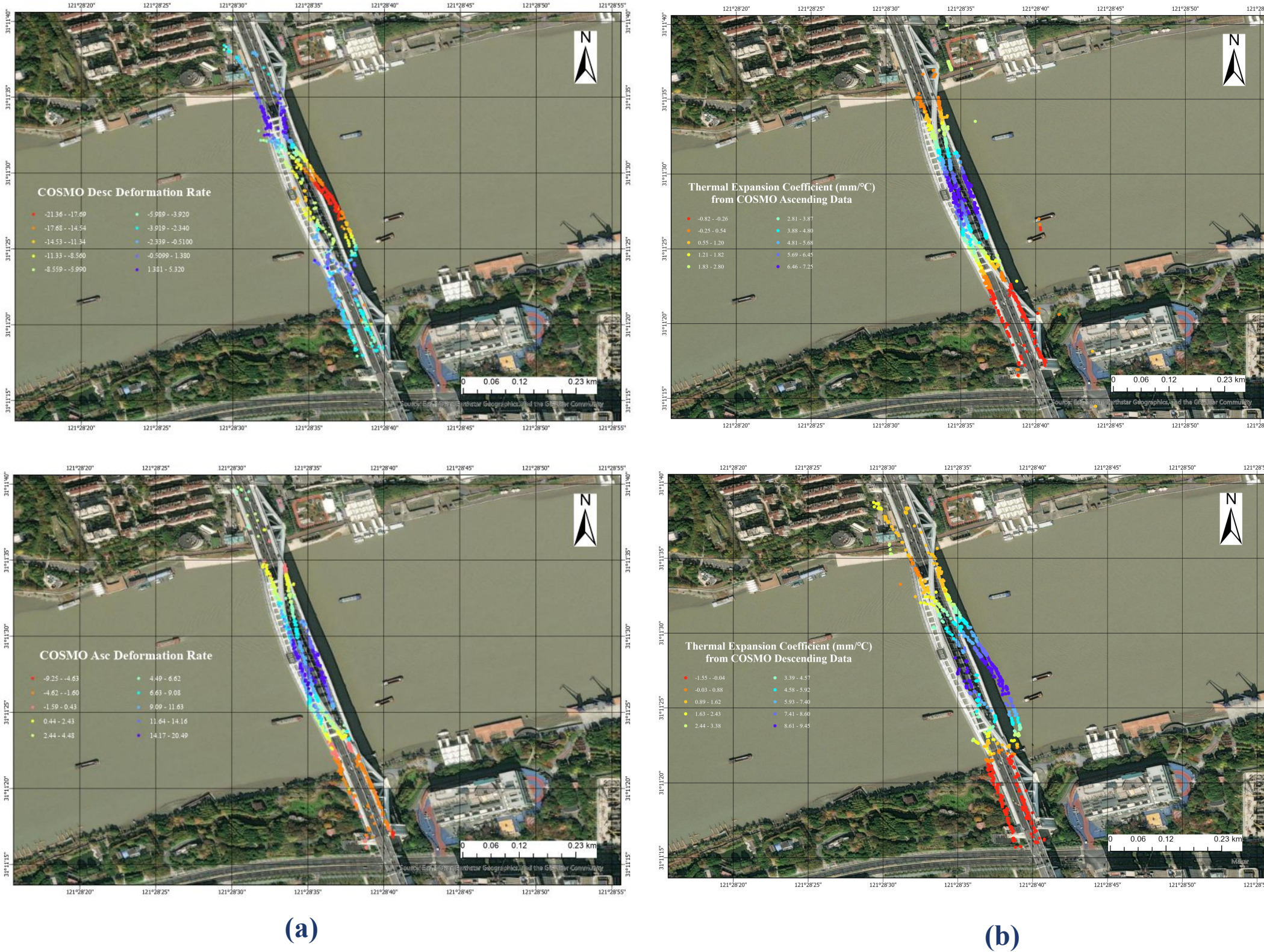
(a)

(a)Workflows of PS-InSAR processing, bridge thermal dilation quantification, and bridge displacement prediction.

ACKNOWLEDGEMENT

This work is supported by the Sino-EU Dragon 6 Project (id 95436).Gratitude to the ESA-MOST Dragon Project Phase 6 (2025) organizers for the presentation platform. Special acknowledgment to the COSMO-SkyMed data provided by the COSMO-SkyMed Radar Satellite,developed by the ASI.

RESULTS AND DISCUSSION

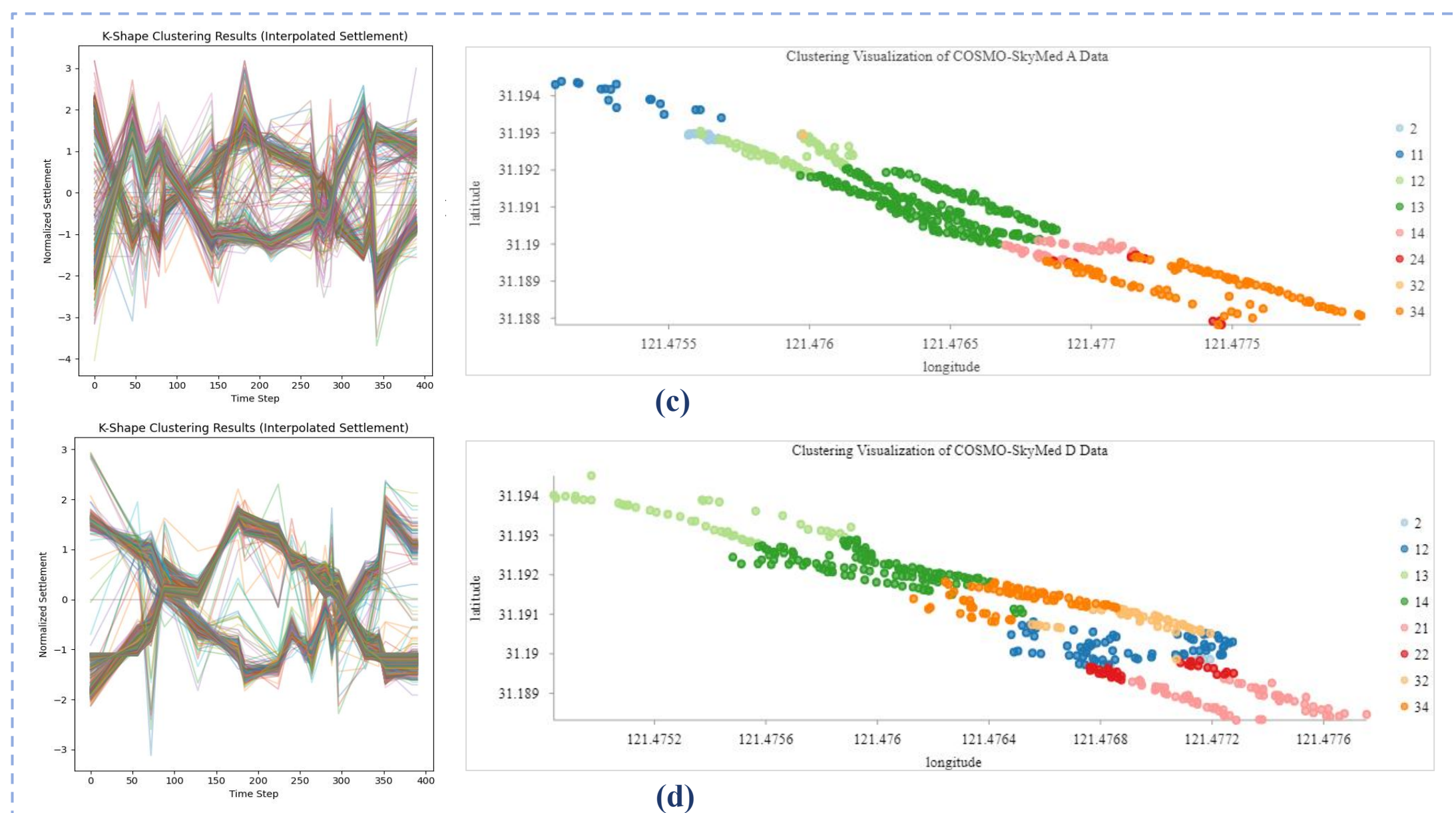


(a)

(b)

(a) During Jan 2009-Feb 2010, deformation rates of Lupu Bridge ranged from **-21.36 mm/yr to 20.49 mm/yr**;

(b)Joint analysis of deformation-temperature series revealed significant spatial heterogeneity in thermal expansion coefficients (α) across bridge segments, with α values spanning **-0.53 mm/°C to 1.98 mm/°C**.



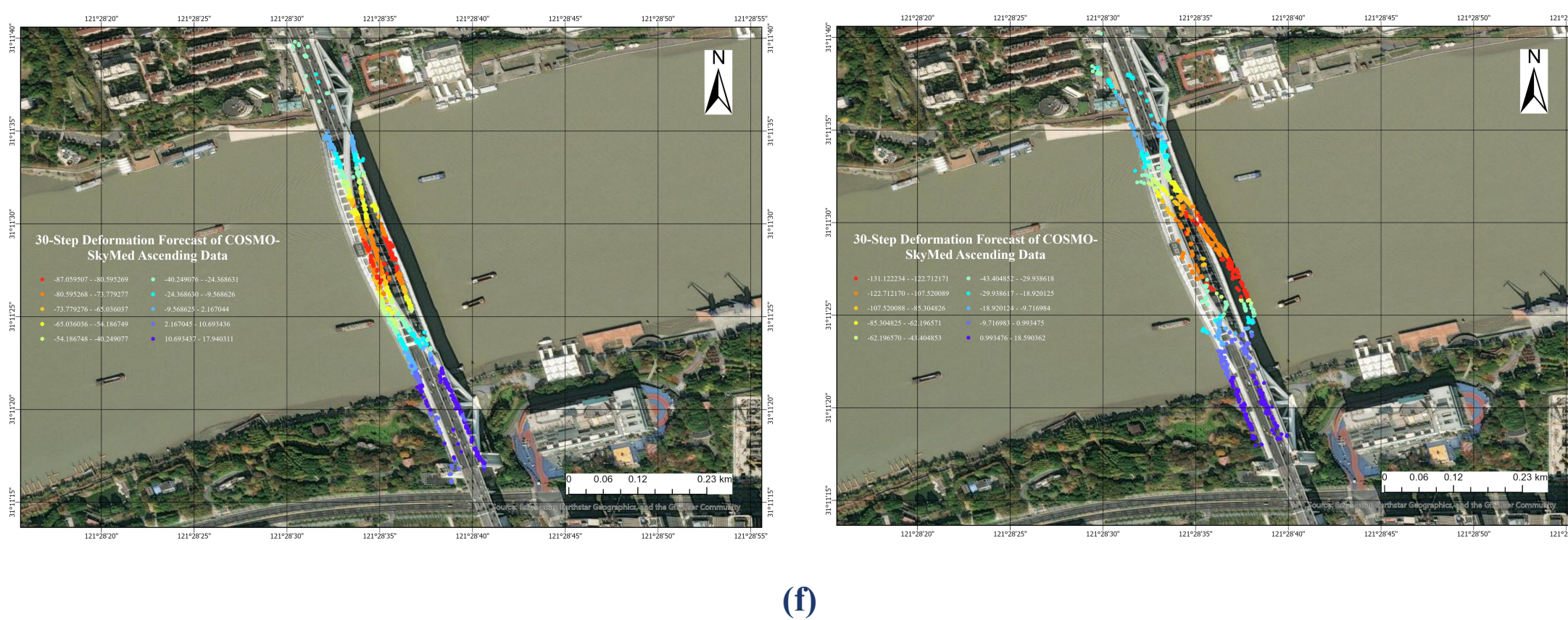
(c) K-Shape clustering reveals high morphological similarity within clusters, exhibiting periodic oscillations.

(d) Spatiotemporal visualization demonstrates spatial autocorrelation of co-clustered points.

Clusters 2 and 24 (COSMO Asc) / Clusters 2, 12, 22 (COSMO Desc) concentrate in low-deformation zones at bridge approaches, indicating minimal displacement . In contrast, Cluster 13 (COSMO Asc) and Clusters 14, 34 (COSMO Desc) localize in high-deformation zones with variable rates over the main span. Despite spatial proximity, distinct deformation patterns highlight the necessity of incorporating spatial heterogeneity in segmentation

RMSE Comparison: Proposed vs. Baseline Models				
RMSE at Representative Points	BiLSTM-SelfAttention Model		KCC-BiLSTM-SelfAttention Model	
	point 1	2.84	point 1	0.01
	point2	4.06	point2	0.29
	point 3	1.13	point 3	0.27
	point 4	6.16	point 4	0.27
	point 5	5.26	point 5	0.33
	point 6	5.13	point 6	0.31
	point 7	7.16	point 7	0.27
	point 8	5.18	point 8	0.61
	point 9	5.39	point 9	0.65
	point 10	8.61	point 10	0.51
	point11	1.88	point11	0.62
	point 12	5.29	point 12	0.73

(e)



(f)

(e) Comparing the 12 representative bridge points, the proposed model significantly reduces RMSE to **0.01-0.73 mm** (baseline: 1.13-8.61 mm)

(d) Fig. d shows the 30-step deformation forecast for Lupu Bridge using the KCC-BiLSTM-SelfAttention model. Forecasted magnitudes range from **-87 to 17 mm/yr** (COSMO Asc) and **-131 to 18 mm/yr** (COSMO Desc).

CONCLUSION

- (1) Time-series InSAR-based deformation monitoring systematically characterizes deformation patterns of Shanghai Lupu Bridge;
- (2) Integrated deformation-thermal analysis quantifies the mechanistic effects of thermal expansion on structural deformation;
- (3) STL decomposition extracts trend, seasonal, and residual components. An innovative BiLSTM model integrating temperature-seasonal data couples K-Shape clustering to capture spatiotemporal correlations, reducing short-term prediction RMSE by **79-99%** and accurately characterizing bridge deformation dynamics.