2025 DRAGON 6 SYMPOSIUM

14-18 JULY 2025

PROJECT ID. 95436

DYNAMIC DEFORMATION MONITORING AND HEALTH DIAGNOSIS OF INFRASTRUCTURES AND SURROUNDING GEOLOGIC ENVIRONMENTS WITH MULTI-SOURCE EARTH OBSERVATION DATA







Northeastern University

2025 Dragon 6 Symposium



CSTEC 中国科学技术交流中心 China Science and Technology Exchange Center

esa → THE EUROPEAN SPACE AGENCY

THURSDAY, 17/JULY/2025

ID. 95436

PROJECT TITLE: DYNAMIC DEFORMATION MONITORING AND HEALTH DIAGNOSIS OF INFRASTRUCTURES AND SURROUNDING GEOLOGIC ENVIRONMENTS WITH MULTI-SOURCE EARTH OBSERVATION DATA

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XIAOQIONG QIN (SHENZHEN UNIVERSITY)

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Outline

- Objectives
- EO Data Procurement and Delivery
- Young Scientist's Contribution
- Project Schedule
- Expected Results
- Preliminary results from Year 1 and overview on the European and Chinese young scientists’ research (presented by the YSs attending the symposium)

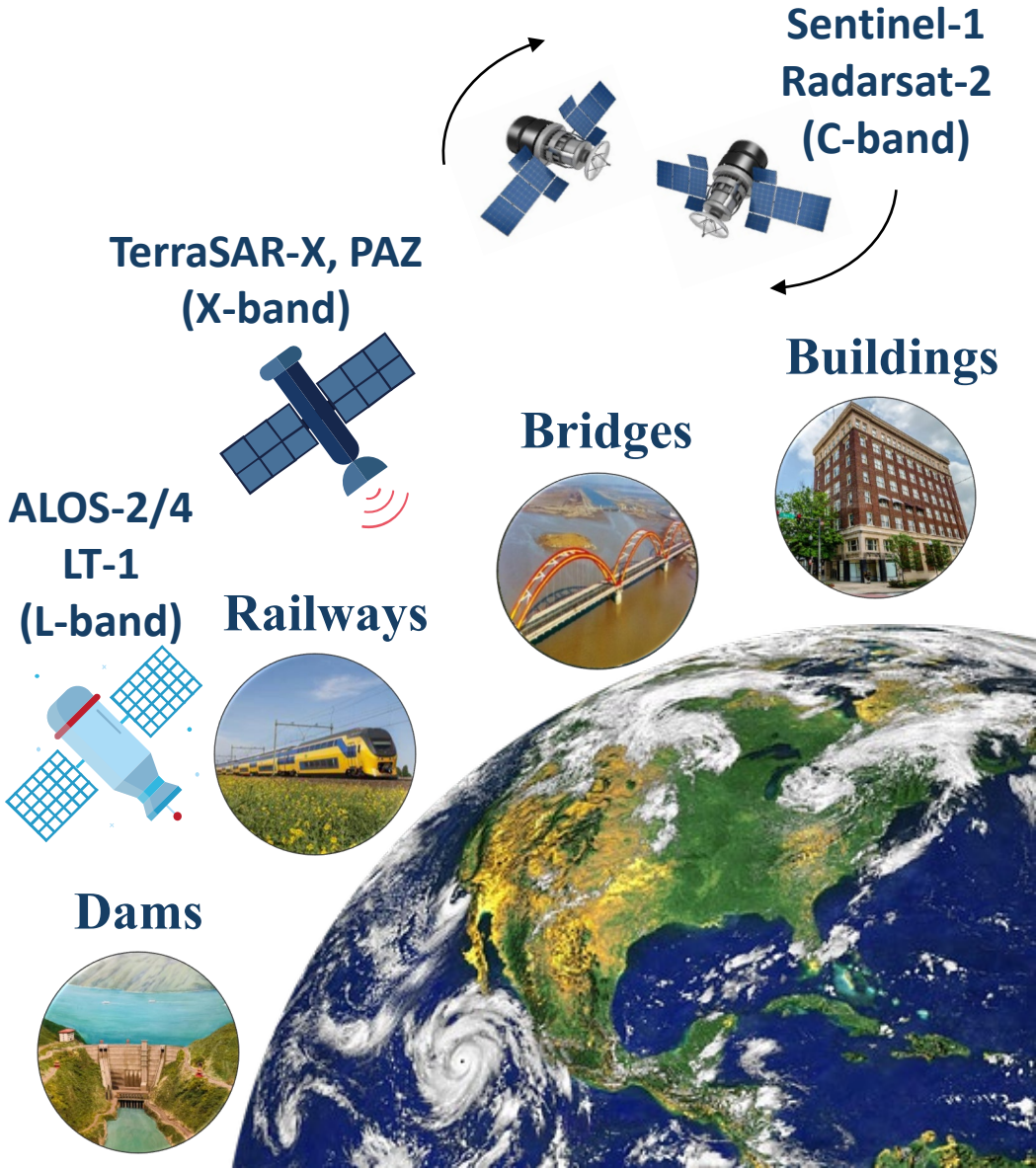
Objectives



- **Use DInSAR technology to develop accurate infrastructure health status monitoring tools.**
  - **Infrastructure itself** and the **surrounding geological environment**.
  - Provide society with **efficient and reliable tools for infrastructure monitoring** with EO data, able to **ensure the safety of people's lives and properties**.
  - Take advantage of as much **diversity of data and ancillary information** as available.
  - **Strengthen the cooperation** and data sharing **between Chinese and European partners**.
  - Facilitate the **formation of Young Scientists** in the field of EO data processing and applications.
- The project involves the following institutions:
  - **Wuhan University** (WHU)
  - **Sun Yat-Sen University** (SYSU)
  - **Southeast University** (SEU)
  - **Shenzhen University** (SZU)
  - **Northeastern University** (NEU)
  - **China University of Mining and Technology** (CUMT)
  - **Universitat Politècnica de Catalunya** (UPC)
- **Dynamic project**: within the original objectives, we are adapting to data availability, new areas of interest, final users' collaboration, YS profiles, etc.

Objectives

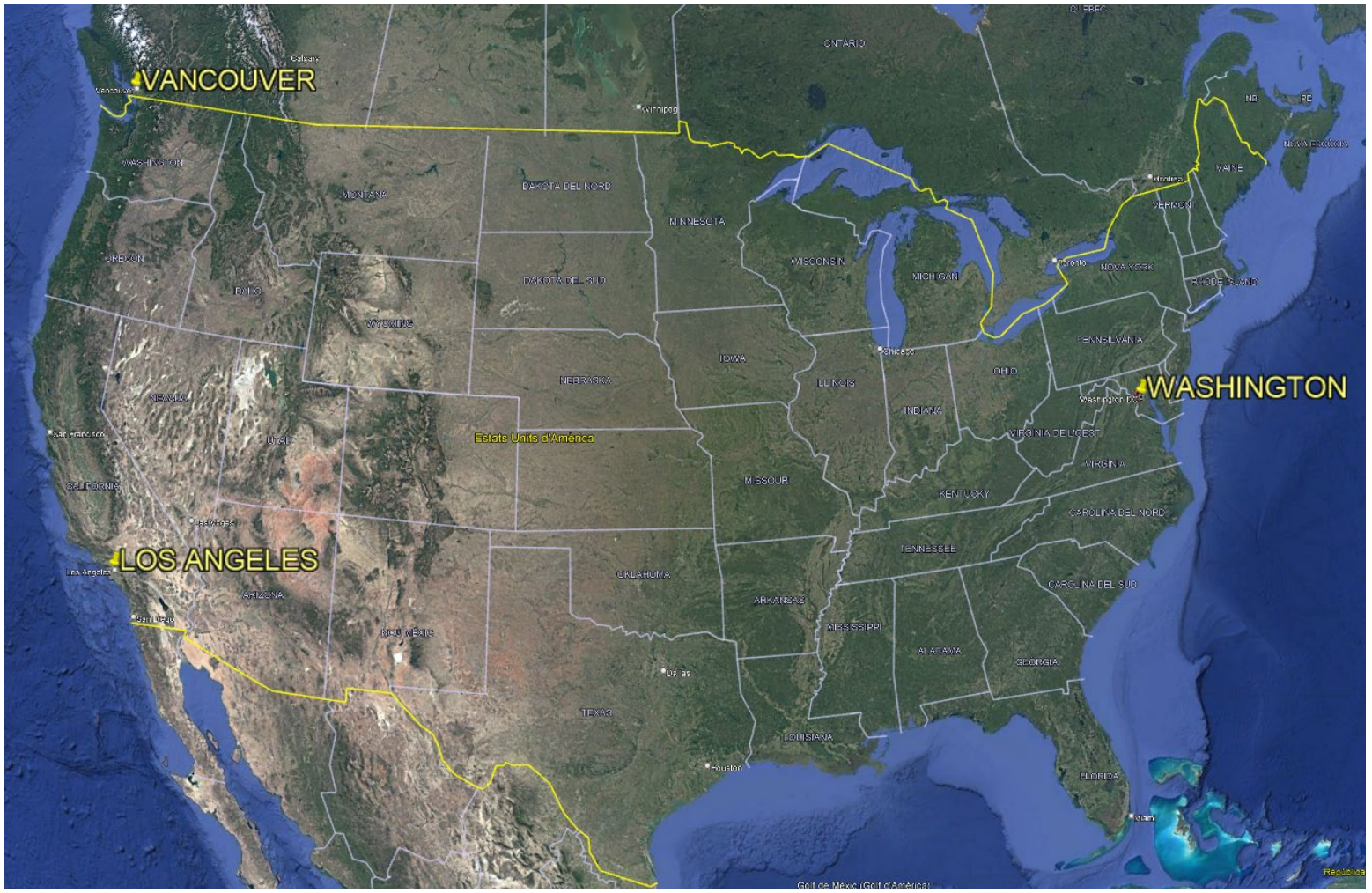
- **Mastering these Research Topics**
  - **PolDInSAR/PSI** deformation monitoring techniques (TS).
  - **Precise geocoding** techniques.
  - **Collaborative analysis** and **deformation modeling**.
  - Application of **Deep Learning and Artificial Intelligence** tools.
  - **Sequential dynamic monitoring** and **health degradation diagnosis** of infrastructure.
- **Data**
  - **Multi-sensor approach**: band, mode, resolution, observation angles, polarimetric diversity (full-, half-, and single-pol), and **ancillary data and/or models**.
  - **Archived and new data** from ESA and third-party missions.
- **Young Scientists**
  - A friendly and challenging environment to **encourage their training and development in EO** engineering and science.
  - With the plus of **international cooperation** and **future opportunities**.



Test-sites

- Test-sites in which the YS have been working with and/or future acquisitions have been agreed with third-party missions.





Test-sites


BEIJING
DA LIAN
Corea del Nord
Sea of Japan (East Sea)
Pyongyang 평양
Dalian 大连市
Pequin 北京
HEBEI
GANSU
Yinchuan 银川市
NINGXIA
SHANXI
QINGHAI
Xining 西宁市
Lanzhou 兰州市
SHAANXI
Jinan 济南市
SHANDONG
Corea del Sud
Mar Groga
Xina
Xi'an 西安市
Fukuoka 福冈
HENAN
JIANGSU
NANJING
Nanquin 南京市
YAIJANG COUNTY
HUBEI
ANHUI
SHANGHAI
Mar de la Xina Oriental
Wuhan 武汉市
Chongqing 重庆
ZHEJIANG
ASSAM
NAGALAND
GUIZHOU
HUNAN
JIANGXI
MANIPUR
FUJIAN
Kunming 昆明市
YUNNAN
Taipei 臺北
GUANGXI
GUANGDONG
Taiwan
Myanmar (Birmània)
ZHU HAI
Mar de les Filipines

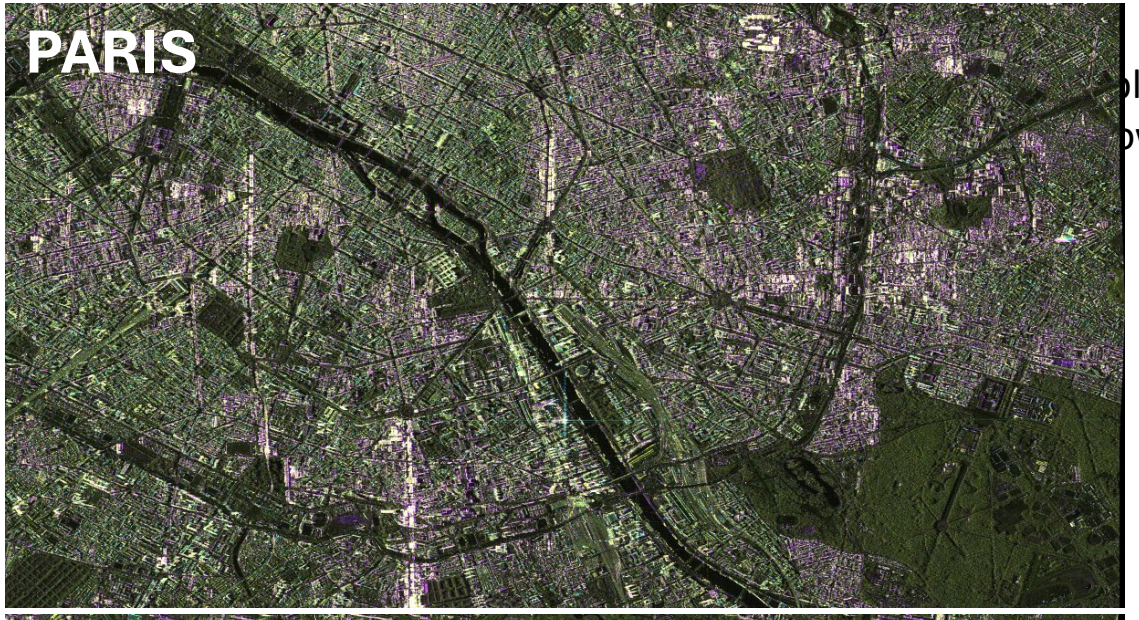
Dragon 6 EO Data Delivery

ESA /Copernicus Missions	No. Scenes
1. Sentinel-1	~360
2. Sentinel-2	~50
3.	
4.	
5.	
6.	
Total:	~410
Issues:	

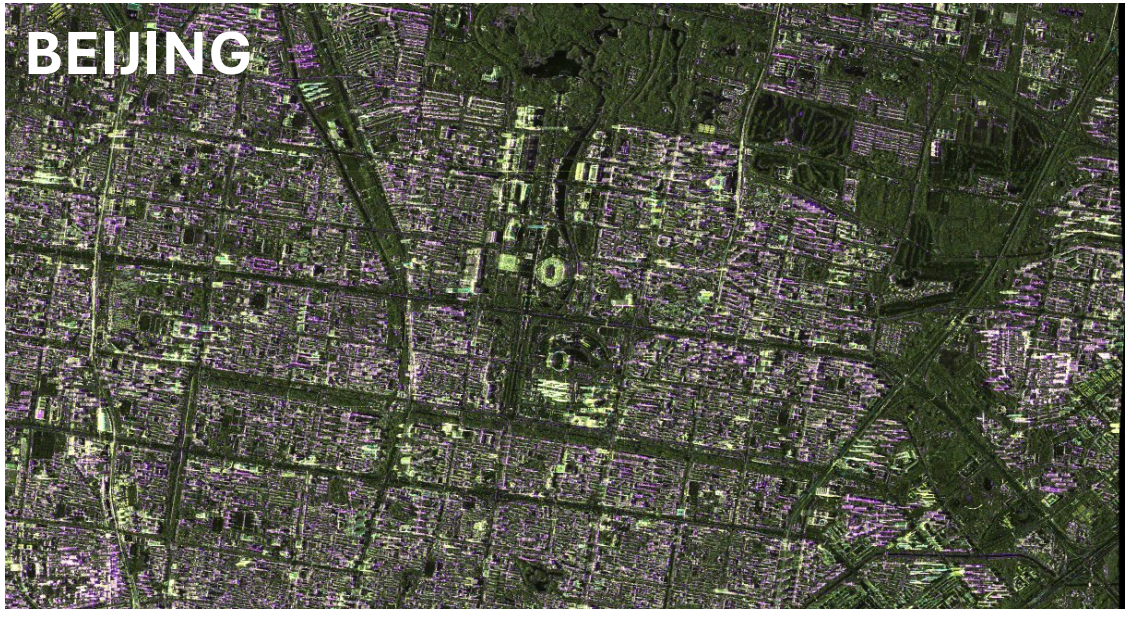
ESA Third Party Missions	No. Scenes
1. PAZ AO-006-016 (Beijing) HS A (HHVV) 20250427-20271210	2/30
2. PAZ AO-006-016 (Nanjing) HS D (HHVV) 20250417-20271230	4/89
3. PAZ AO-006-016 (Paris) HS D (HHVV) 20250423-202712317	1/45
4. PAZ AO-006-016 (Shanghai) ST A & D (HHVV) 20250422-20271216	5/89
5. TSX (Barcelona) STR A (HH) 20080704-20100711	12
5. TSX MTH3964	TBC
6. CSA RCM UPC	TBC
7. CSA RCM CUMT (Vancouver, Washington)	74
Total:	
Issues: **There is the risk that some of the planned acquisitions are not imaged due to conflicts with higher priority users.**	

Chinese EO data	No. Scenes
1.	
2.	
3.	
4.	
5.	
6.	
Total:	
Issues: **Not at this moment, but we will try for the future.**	

Dragon 6 PAZ HS Data (HH+VV A or D)

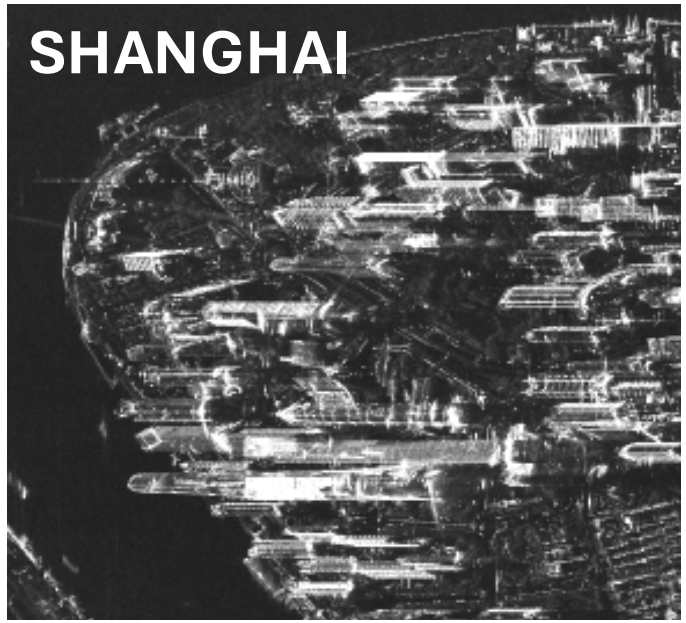




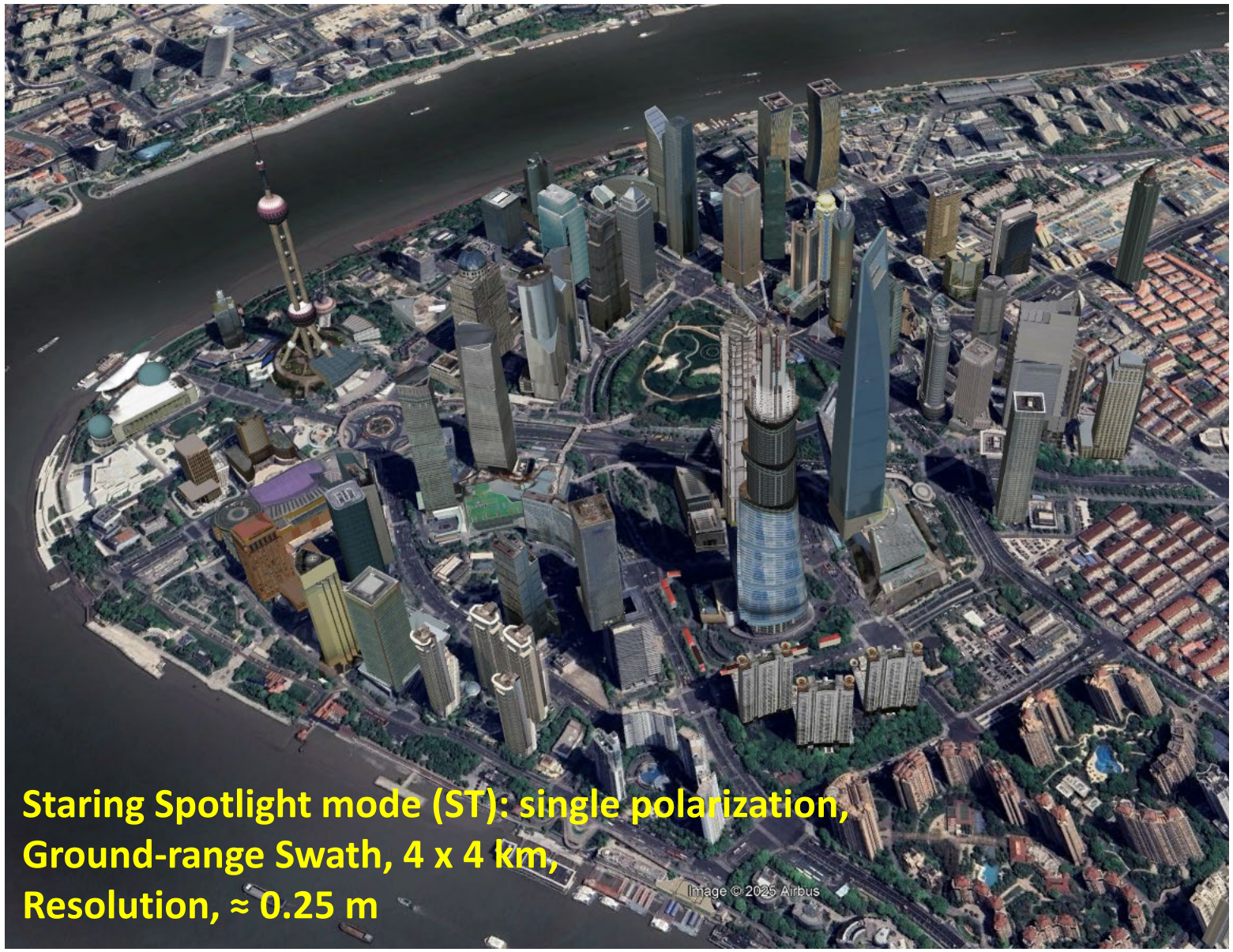


High Resolution Spotlight mode (HS): dual polarization,
Ground-range Swath, 5-10 x 5 km
Resolution (rg x az), 1.17 x 2.16 m

Dragon 6 PAZ ST Data (A & D)







Chinese Young Scientists contributions in Dragon 6

Name	Institution	Poster title	Contribution including period of research
Leixin ZHANG	CUMT	Adaptive Polarimetric Optimization for Ground Deformation Monitoring	Main author
Yuxuan Zhang	CUMT	Adaptive Polarimetric Optimization for Ground Deformation Monitoring	Main author
Zixuan QIN	WHU	Forest Fire Scar Detection From Time-series Sentinel-1 Observations Based On Coherence Prediction Using Recurrent Neural Network	Main author
Xiaohan YANG	SEU	A Two-Stage Method Using SegFormer and Convolutional Networks for Noise-Resistant InSAR Phase Unwrapping	Main author
Yuhan LUO	SZU	Temporal and Spatial Subsidence Monitoring and Prediction of Reclamation Airports Based on Time-series InSAR Measurements	Main author

European Young Scientists contributions in Dragon 6

Name	Institution	Poster title	Contribution including period of research
Yunyue ZHOU	SZU	Effective Quantification of Bridge Temperature Effects in PS-InSAR Time-Series Deformation Analysis	Main author
Yifan ZHANG	UPC (Supported by a CSC grant and UPC funds)	PSSformer: Persistent Scatters Selection Method for SAR Interferometry based on Temporal-Spatial Vision Transformers.	Main author
Peng SHEN	WHU	Research Progress of Phase Linking Method in Time-Series InSAR Data Processing	Main author
Yian WANG	NEU	Sequential polarimetric phase optimization algorithm for dynamic deformation monitoring of landslides	Main author

Project schedule

2024-2025:

- Data procurement: ESA, DLR, HISDESAT, CSA.
- Software preparation
- Development of POL PS-InSAR
- Presentation at Dragon symposium 2025

2025-2026:

- Development of POL PS-InSAR
- Analysis and modeling of TS-InSAR result
- Improvement of InSAR point cloud positioning accuracy.
- Presentation at Dragon symposium 2026
- Preparation of joint journal papers

2026-2027:

- Sequential InSAR algorithm development
- Sequential dynamic monitoring and health diagnostics
- Development of multi-source InSAR fusion algorithms.
- Presentation at Dragon symposium 2027

2027-2028:

- Validation of results
- Presentation at Dragon symposium 2028
- Preparation of joint journal papers

Strengthening collaboration among partners

Expected results



- The **development of validated, efficient, and reliable tools** based on **DInSAR technology**, able to perform **accurate infrastructure health status monitoring**.
- A new generation of **Young Scientists with proven knowledge and practical experience in DInSAR techniques and applications**.
- To do that, we will produce
  - **Improved PSI processing algorithms** that take full **advantage of all the data diversity** possible.
    - ✓ **Polarimetric diversity**: pixel phase quality improvement using all polarimetric channels available (dual-, or full-pol)
    - ✓ **Sensor diversity**: new processing strategies that jointly process data from different bands and resolutions.
    - ✓ **Observation diversity**: processing strategies that combine ascending and descending orbits that fully characterize (3D) infrastructure.
  - **Post-processing algorithms** able to analyze and reveal the **deformation mechanism between infrastructure deformation and environmental factors** using **Artificial Intelligence** (AI) and **Deep Learning** (DL) techniques.
  - **Collaborative peer-reviewed journal papers**.



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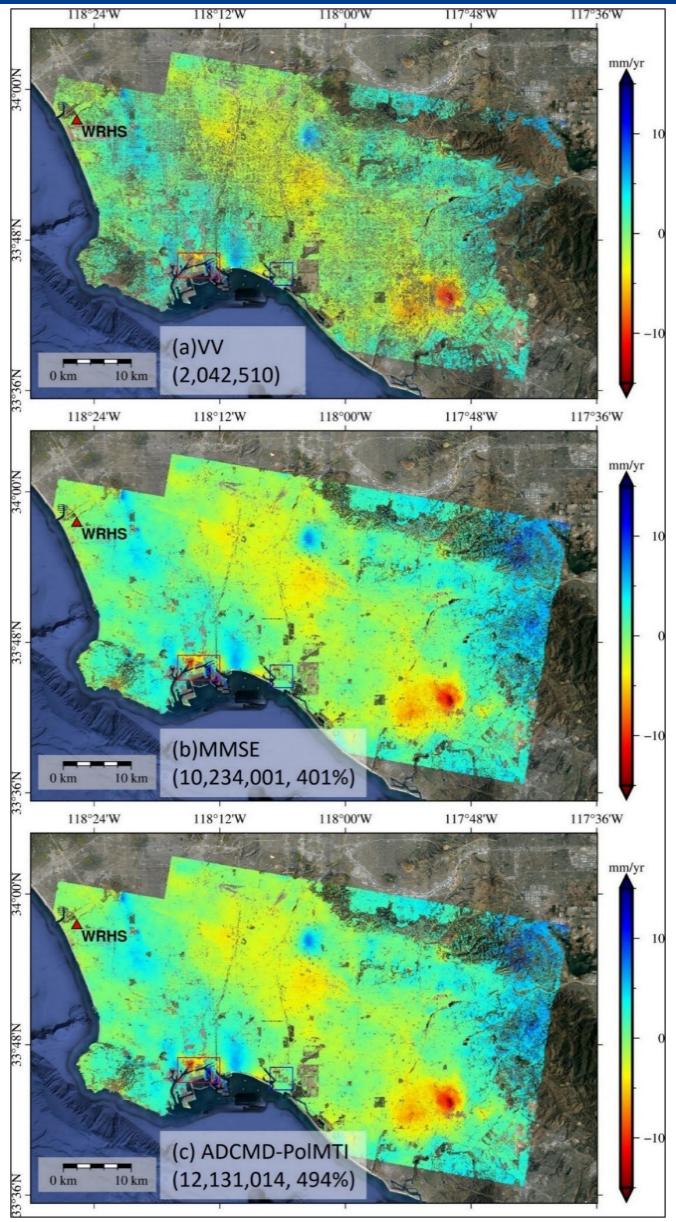
Preliminary results from Year 1 YS Contribution

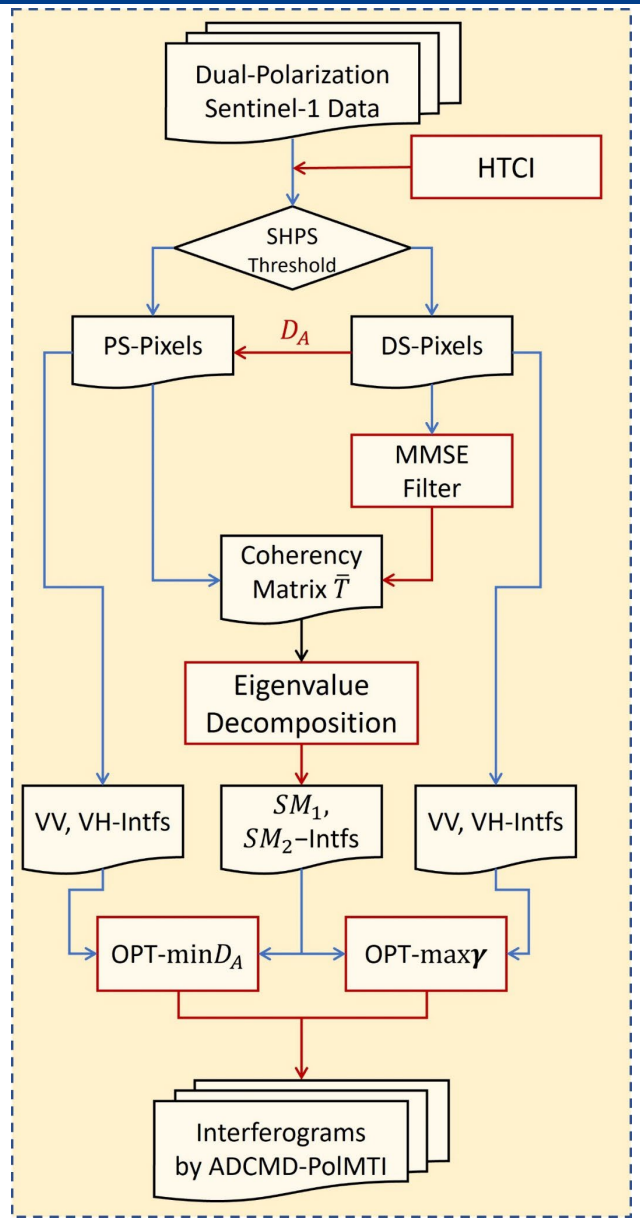


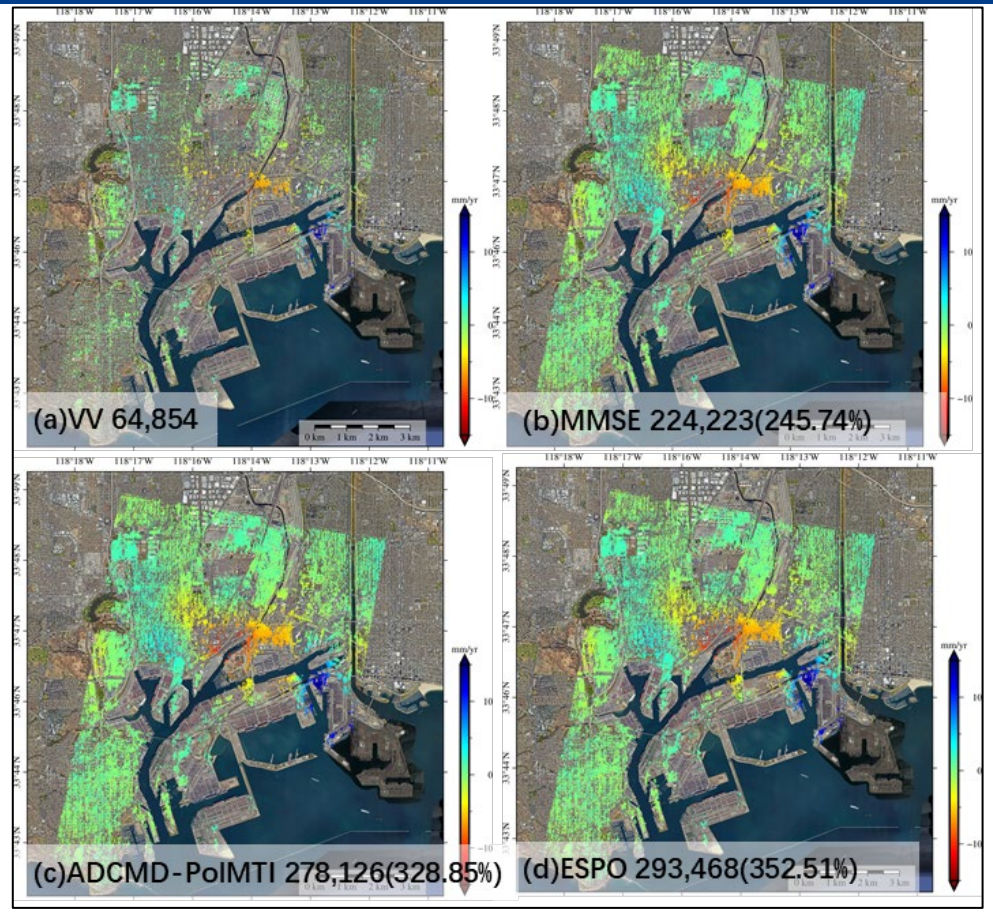
1 and 2. Adaptive Polarimetric Optimization for Ground Deformation Monitoring

Yuxuan Zhang and Leixin Zhang

Adaptive Polarimetric Optimization for Ground Deformation Monitoring

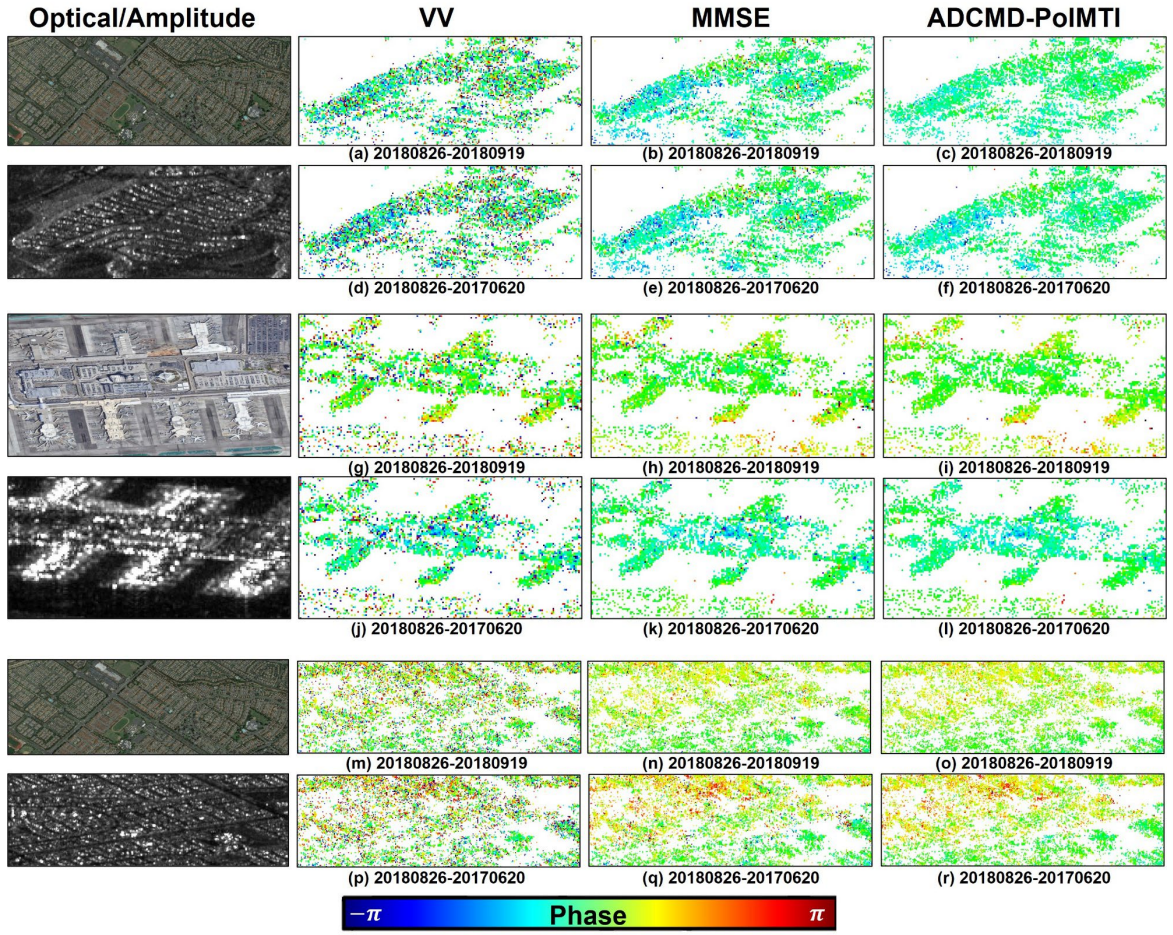






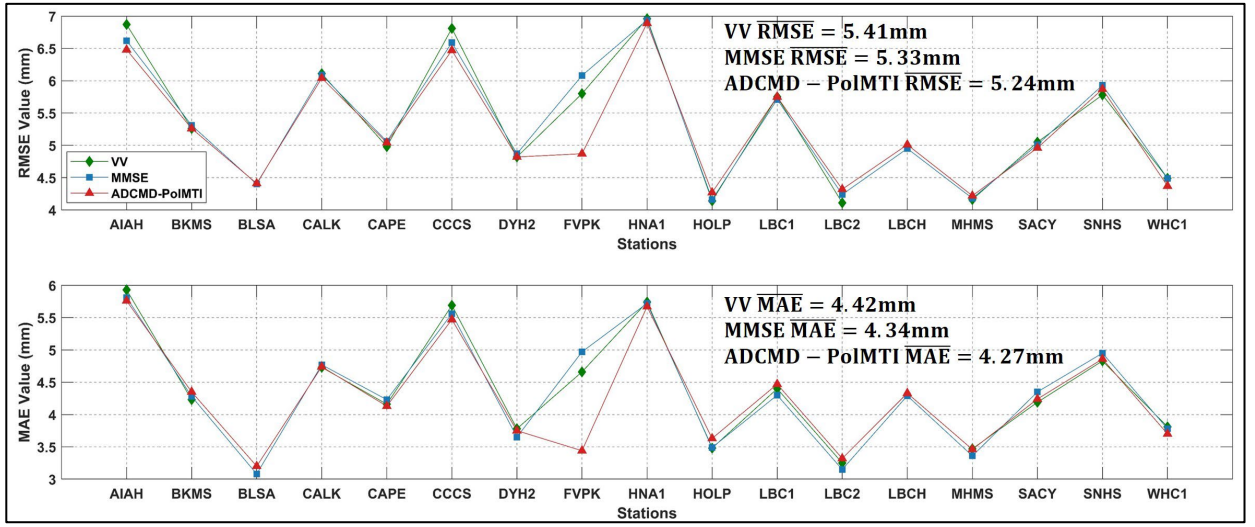
Methods	VV	ADCMD-PolMTI		ESPO	
		PSs-OPT	DSs-OPT	PSs-OPT	DSs-OPT
Times/s	/	10.97 (×1.0)	5,895.68 (×1.0)	2,585.76 (×235.7)	78,839.67 (×13.4)
Pixels Number	64,854	278,126 (328.85%)		293,468 (352.51%)	

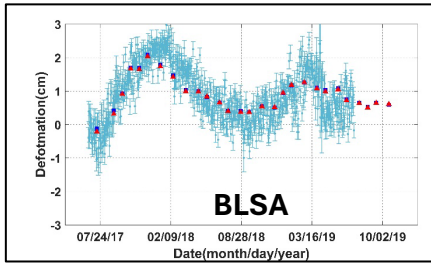
Adaptive Polarimetric Optimization for Ground Deformation Monitoring

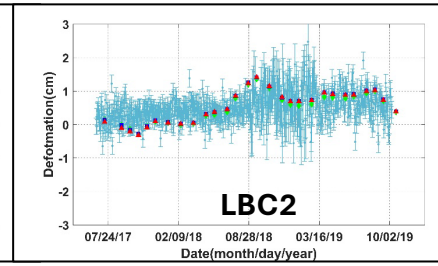


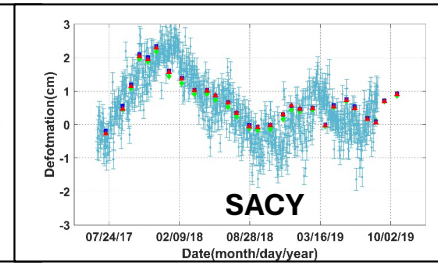
Interferometric results for pixels with TPC > 0.9.

- ADCMD-PolMTI achieves the best performance by optimizing both PSs and DSs.







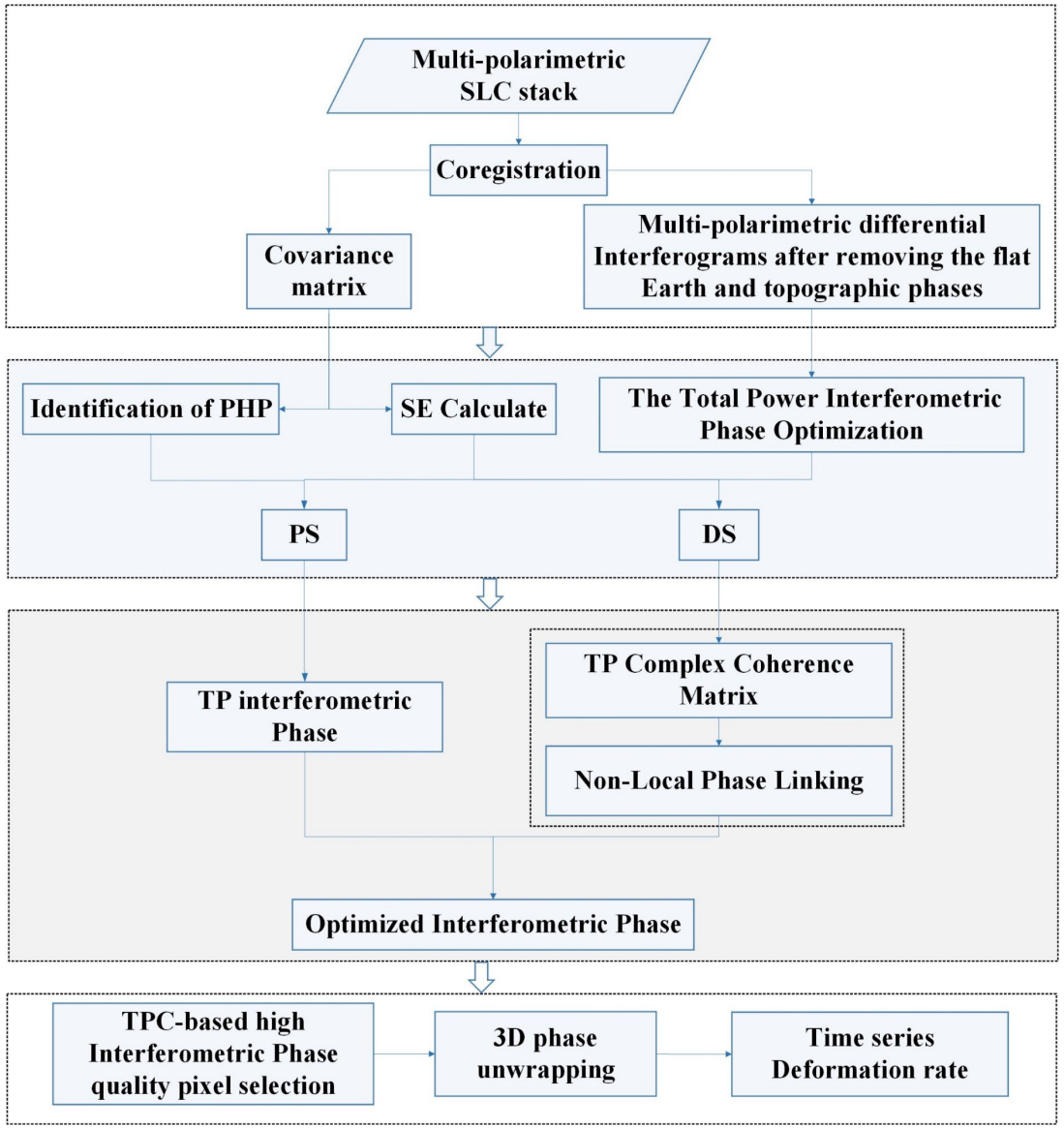


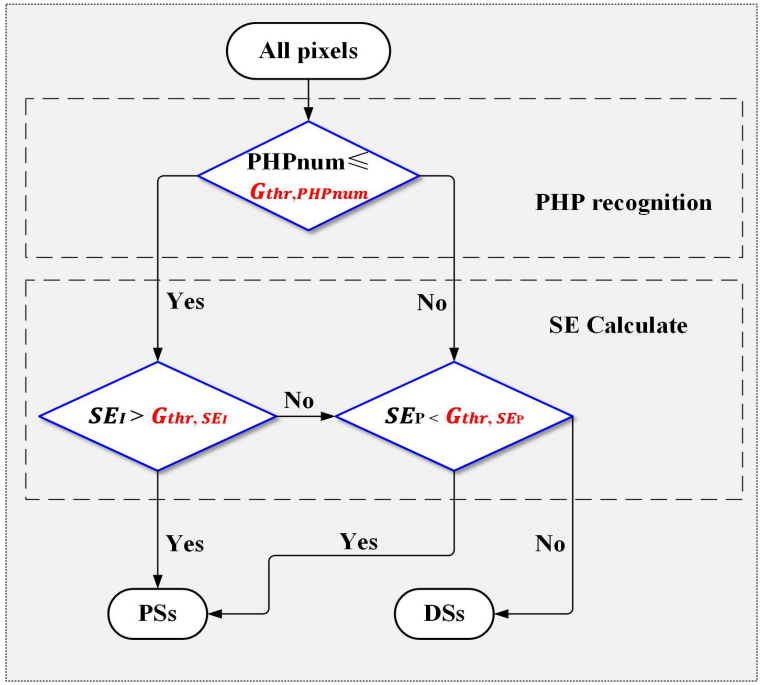
- ADCMD-PolMTI achieves the lowest average RMSE (5.24 mm) and MAE (4.27 mm) among the three methods, confirming the reliability of its optimization performance.

Adaptive Polarimetric Optimization for Ground Deformation Monitoring

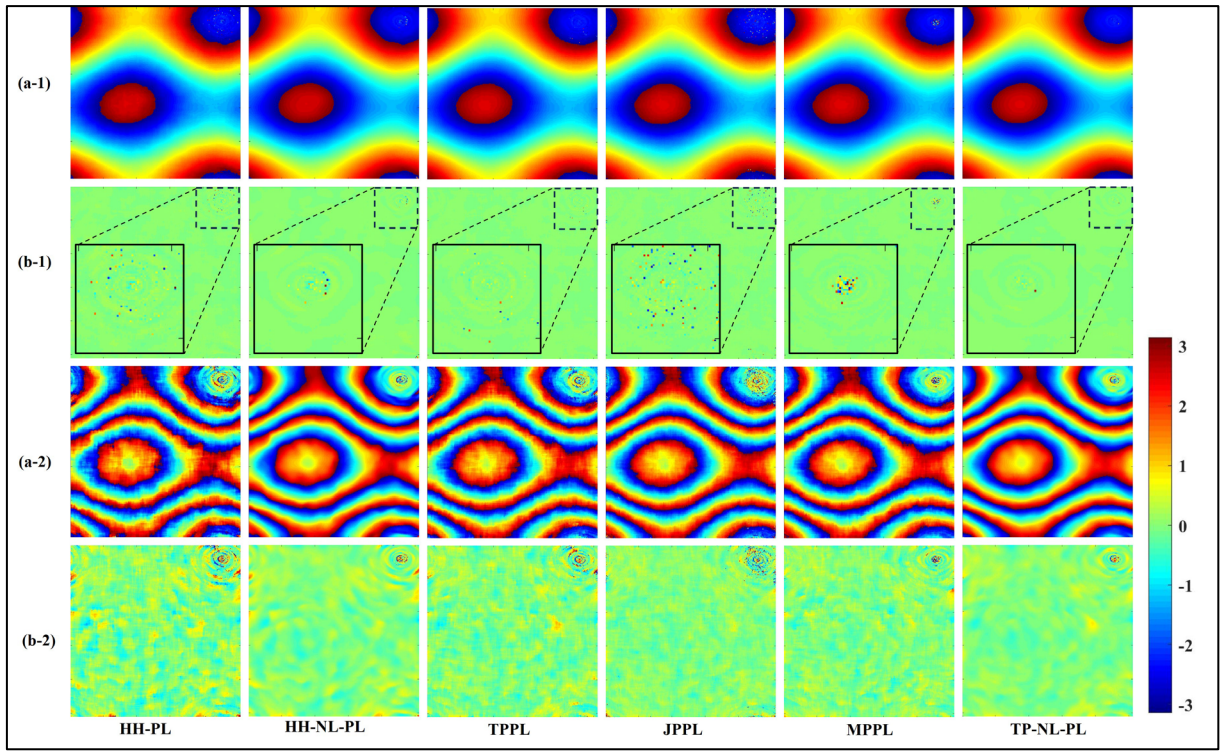
- The multipolarimetric scattering information of ground objects can be utilized to optimize the interferometric phase, thus addressing the challenges of deformation monitoring in low-coherence scenarios.

- Most existing methods for selecting DS candidate pixels primarily rely on a threshold of SHPs (e.g., SHPs ≥ 20), without explicitly accounting for scattering mechanisms.



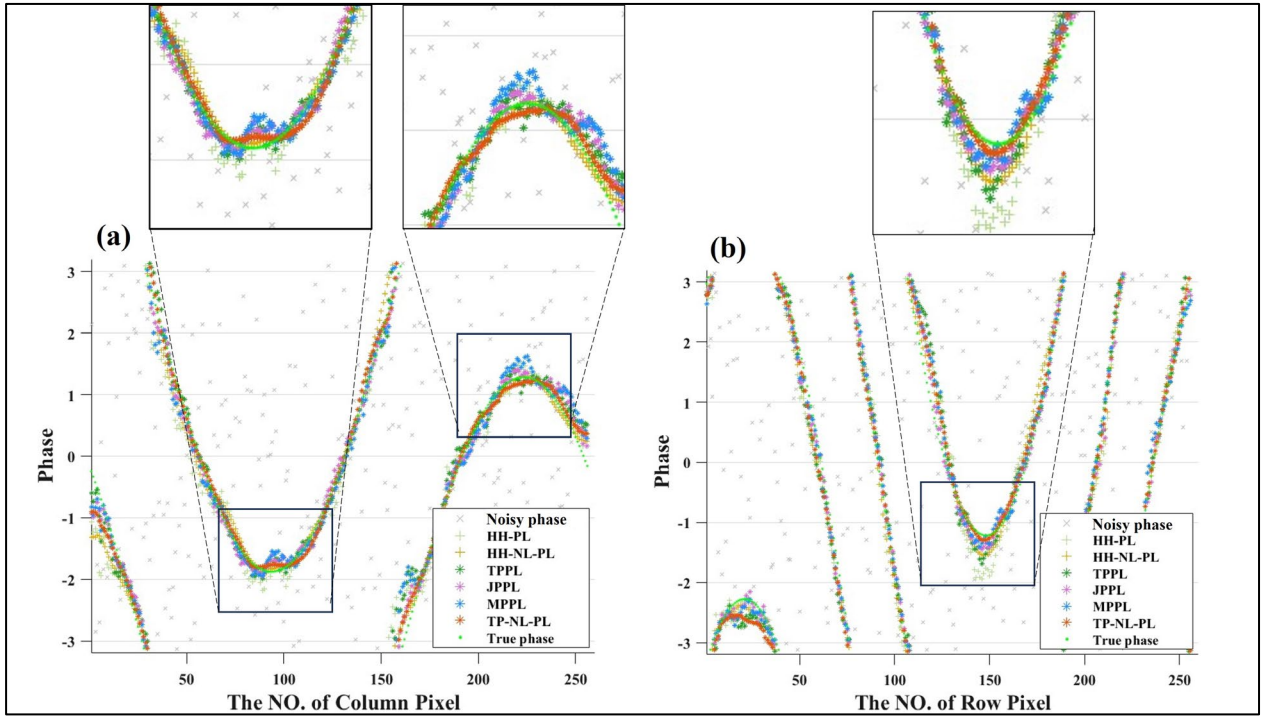


Adaptive Polarimetric Optimization for Ground Deformation Monitoring



Interferometric phases and residual phases obtained by different methods with simulated data
(a-1/2) Optimized phase for the 10th/30th interferogram
(b-1/2) Residual phase for the 10th/30th interferogram

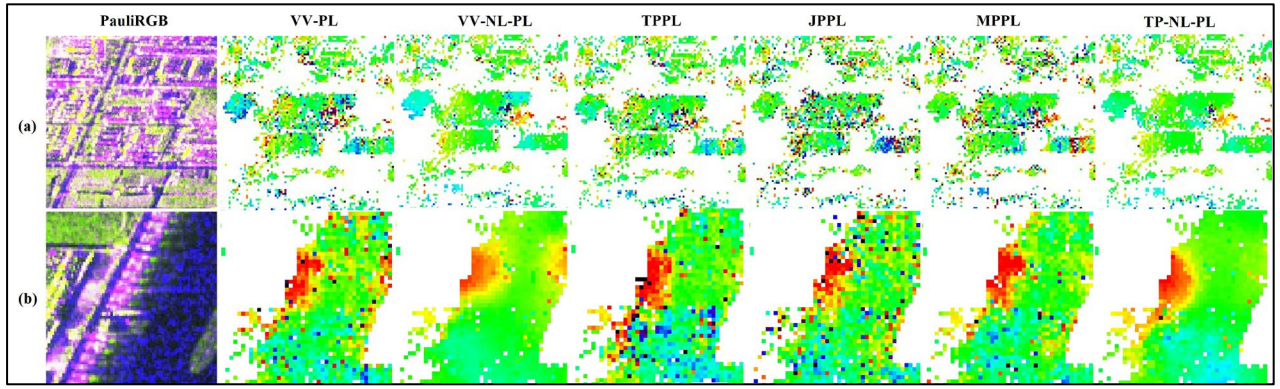
	HH-PL	TP-PL	JPPL	MPPL	HH-NLPL	TP-NL-PL
Mean-RMSE	0.1552	0.1085	0.1189	0.0989	0.1117	0.0843
Max-RMSE	0.3812	0.2950	0.2592	0.2455	0.2544	0.2002
Residual Points $(\times 10^3)$	1.9867	1.7019	1.8455	1.5905	1.4214	1.3722
Time	35s	35s	3805s	832s	522s	633s

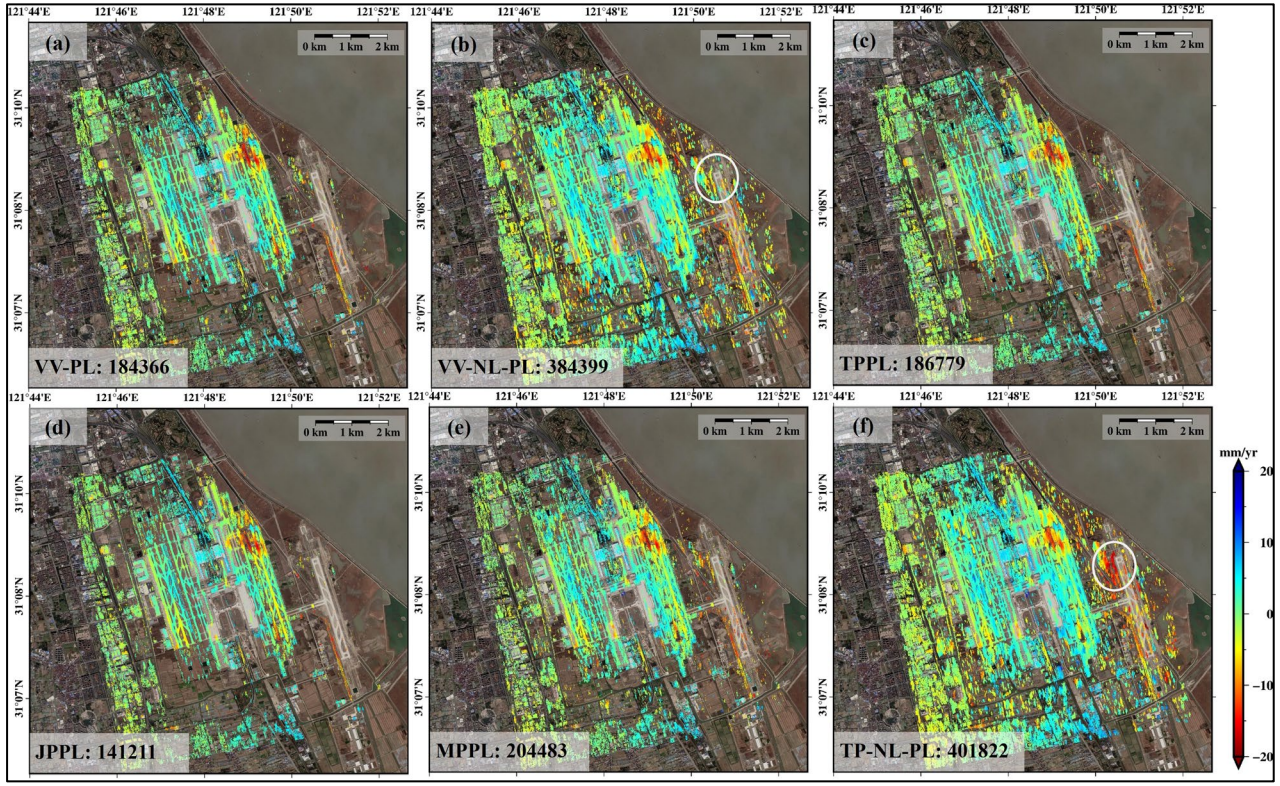


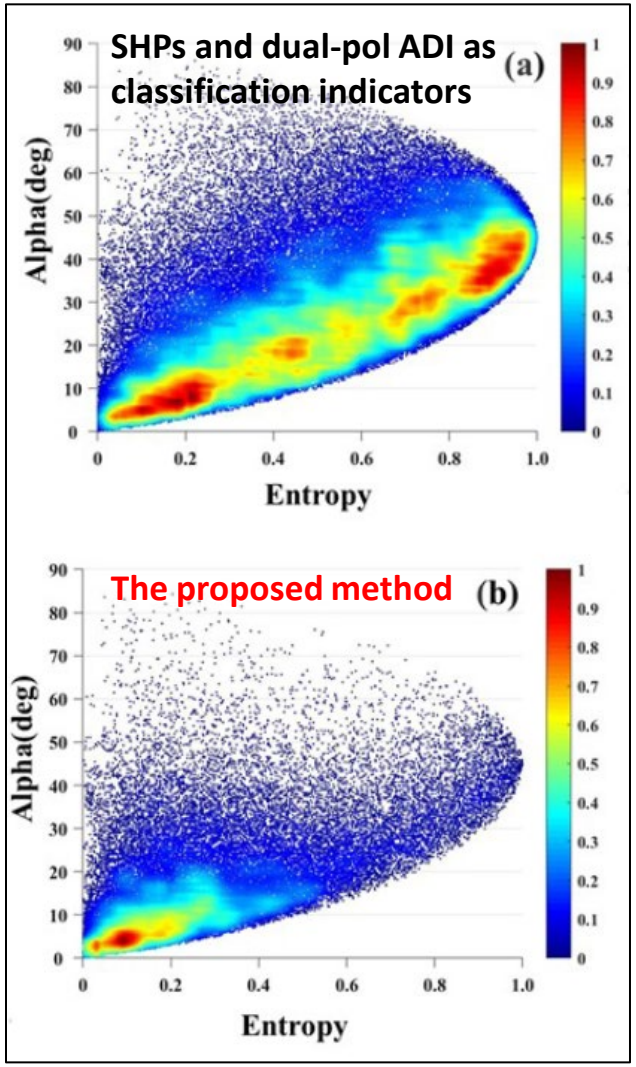
Phase profiles for the 30th interferogram (100th row/17th column)

Adaptive Polarimetric Optimization for Ground Deformation Monitoring

- Interferometric results for pixels with TPC > 0.9 of the first interferogram
- Adaptive phase optimization algorithm for both PSs and DSs based on TP and NLPL.
- DS/PS classification using PolSAR scattering mechanisms.
- Improves coherence matrix estimation and phase reliability.





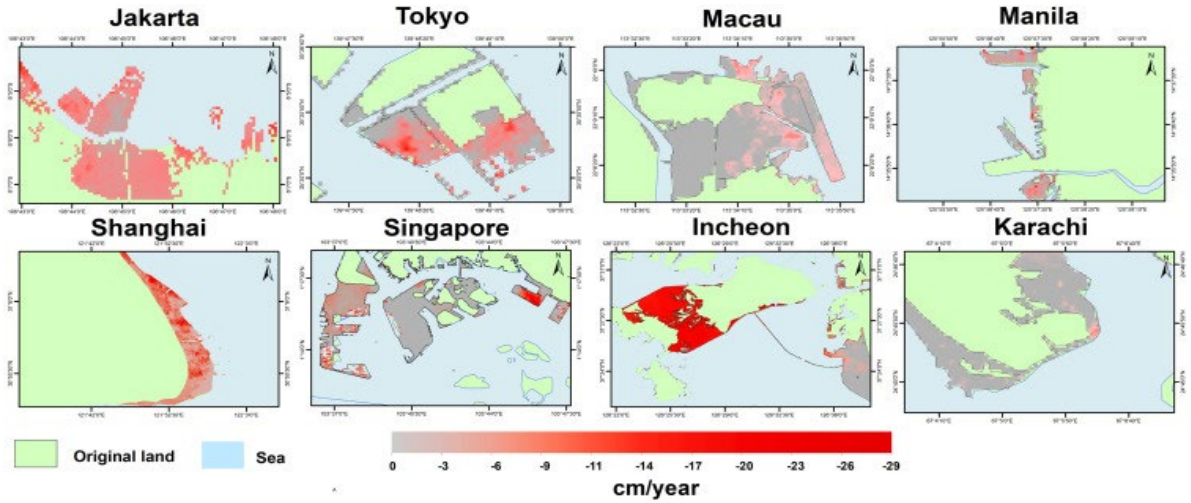


The H/Alpha distribution density of PS candidates

3. Temporal and spatial subsidence monitoring and prediction of Reclamation Airports based on time-series InSAR Measurements

Yuhan Luo

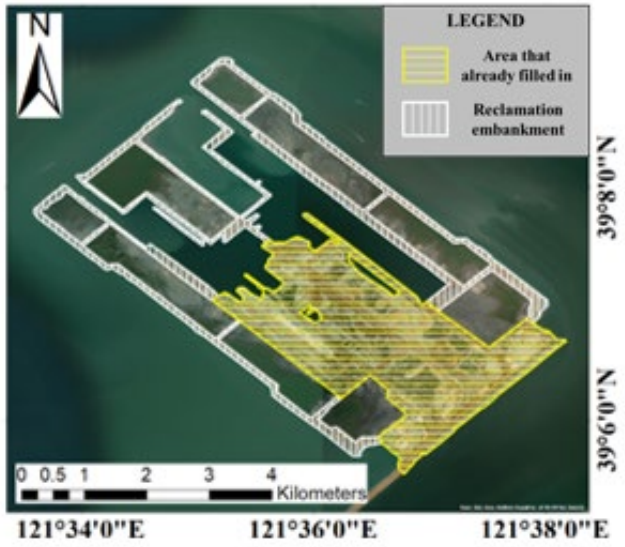
Temporal and spatial subsidence monitoring and prediction of Reclamation Airports based on time-series InSAR Measurements



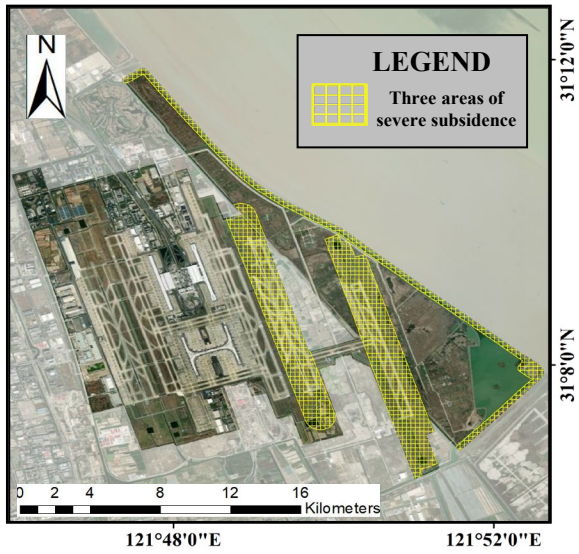
To support the operation and maintenance of airports in the reclamation area, we monitor deformation and predict future changes.

- **Significant ground subsidence has occurred in areas of land reclamation in many cities.**
- **The airport in the reclaimed area has become an important facility for enhancing regional transportation services in coastal metropolitan areas.**





Dalian Jinzhou Bay International Airport (DJBIA)



Shanghai Pudong International Airport (SPIA)

Temporal and spatial subsidence monitoring and prediction of Reclamation Airports based on time-series InSAR Measurements

Deformation extraction by PS-InSAR

InSAR data

Sentinel-1A | TerrSAR-X | POE Orbit | NASA DEM

Multi segment image datasets

Extract master image

Connection, Co-registration, Interference…

Differential interferogram, Coherence map

Coherence assessment

PS point extraction

Terrain phase removal, phase unwrapping, APS removeal…

Pixel Temporal Analysis, Geocoding…

Deformation time-series dataset of PS

Multi strategy optimized machine learning prediction

PS space matching & time-series connection

Divide the forecast unit area



Dataset processing: sliding time window strategy

Series of deformation time-series sub datasets

LSTM

CNN

Optimal prediction model set

Multimodal settlement prediction values

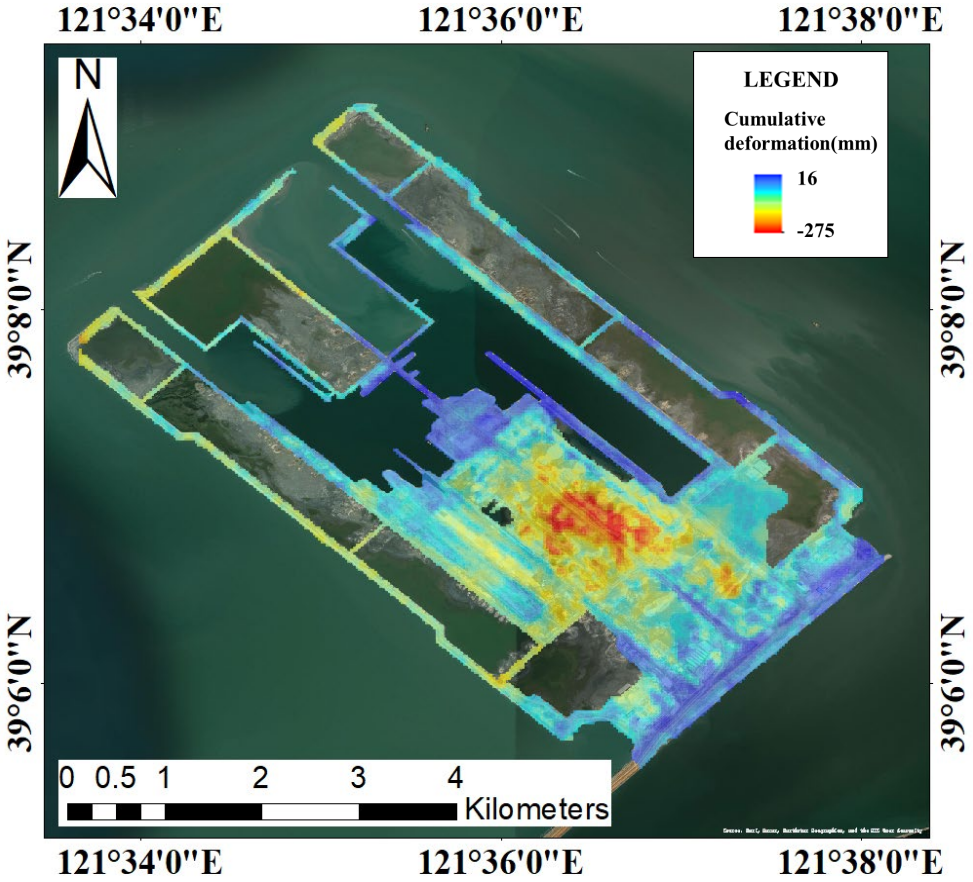
Merge

Final deformation prediction value

Accuracy comparison

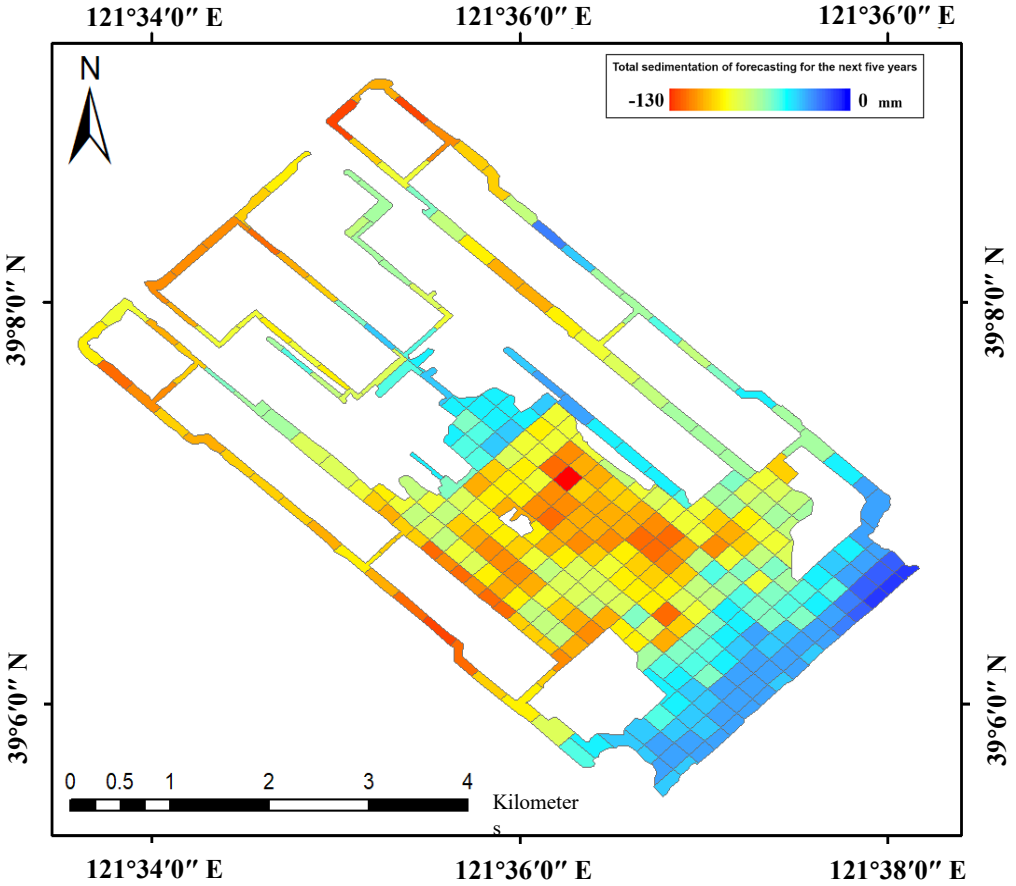
Temporal and spatial subsidence monitoring and prediction of Reclamation Airports based on time-series InSAR Measurements

Accumulated settlement amount



The most serious subsidence area in DJBIA is located in the center of the reclamation area, and the soil layer is relatively new.the closer the reclamation time, the more significant the subsidence.

Total sedimentation of forecasting for the next five years



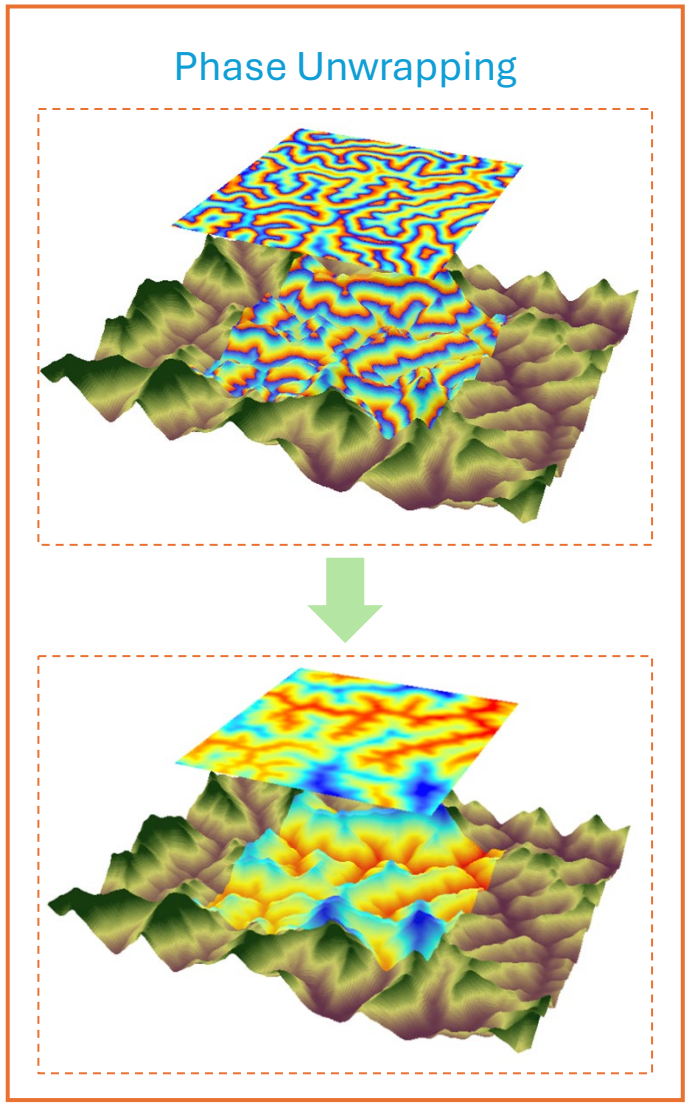
The airport is under construction, yet a land subsidence trend is already evident.

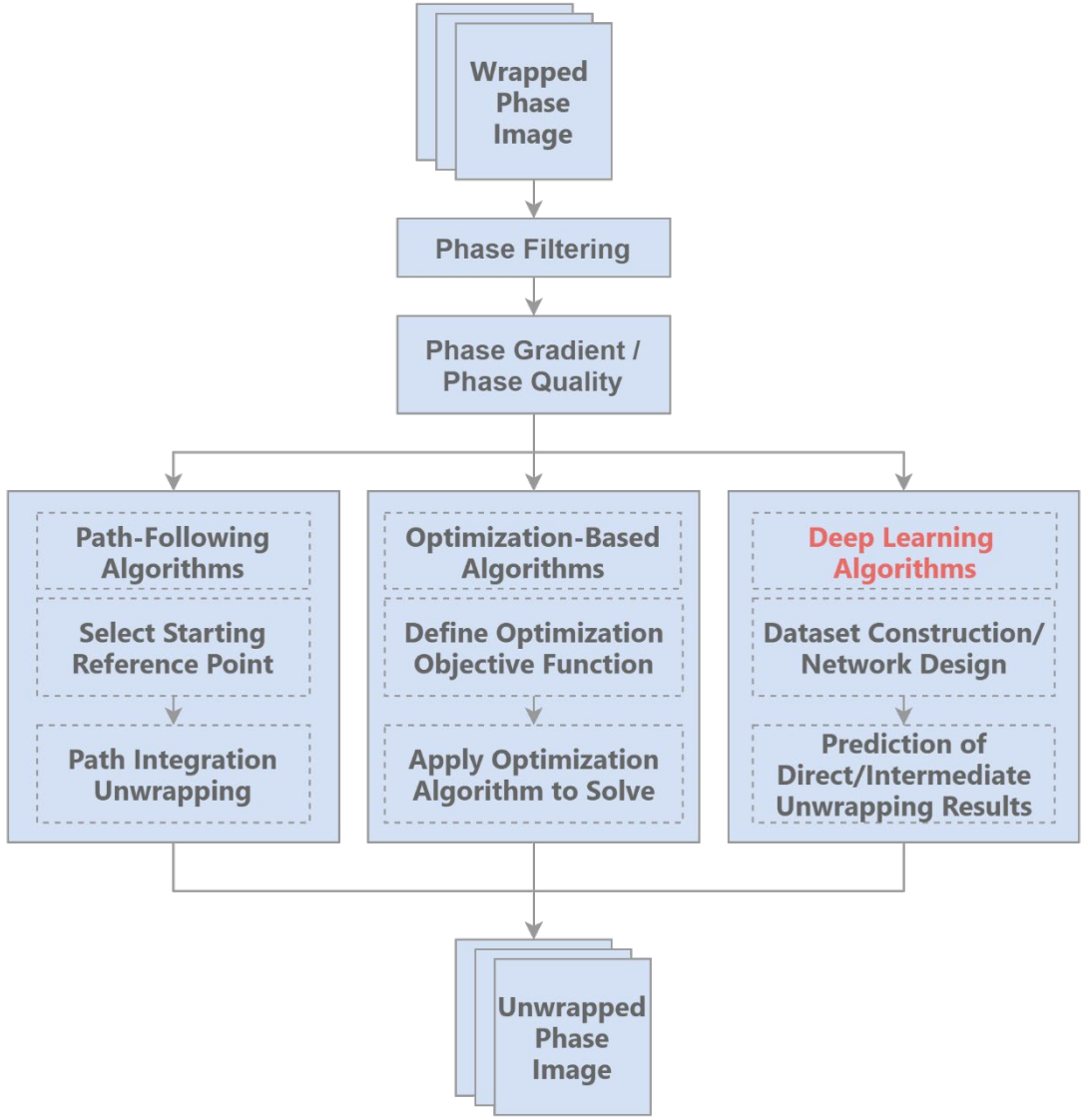
4. A Two-Stage Method Using SegFormer and Convolutional Networks for Noise-Resistant InSAR Phase Unwrapping

Xiaohan Yang

A Two-Stage Method Using SegFormer and Convolutional Networks for Noise-Resistant InSAR Phase Unwrapping

Phase Unwrapping





Path-Following Algorithms:

- Assume phase continuity

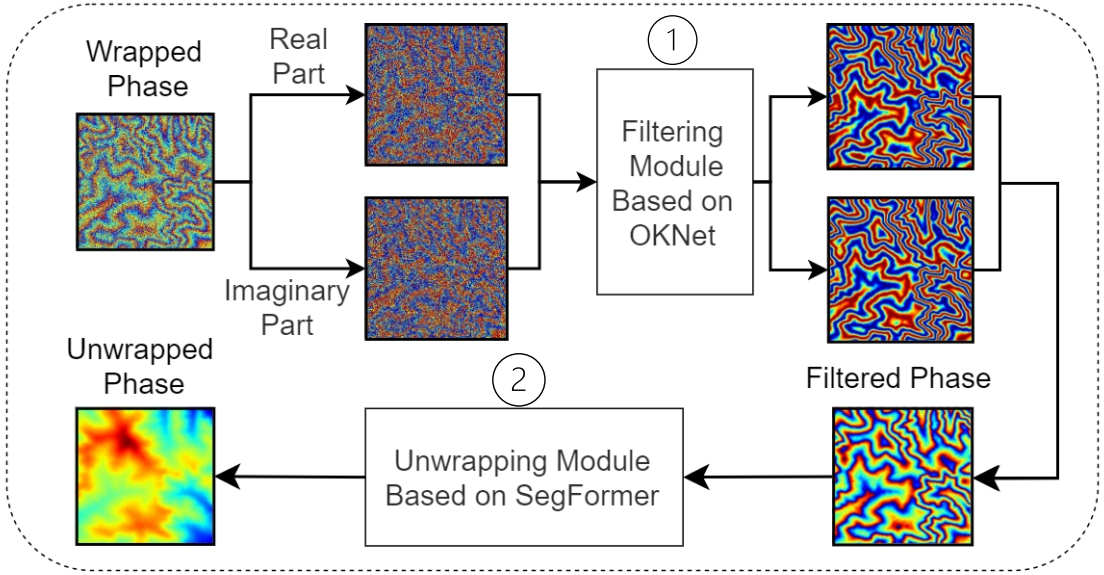
Optimization Algorithms:

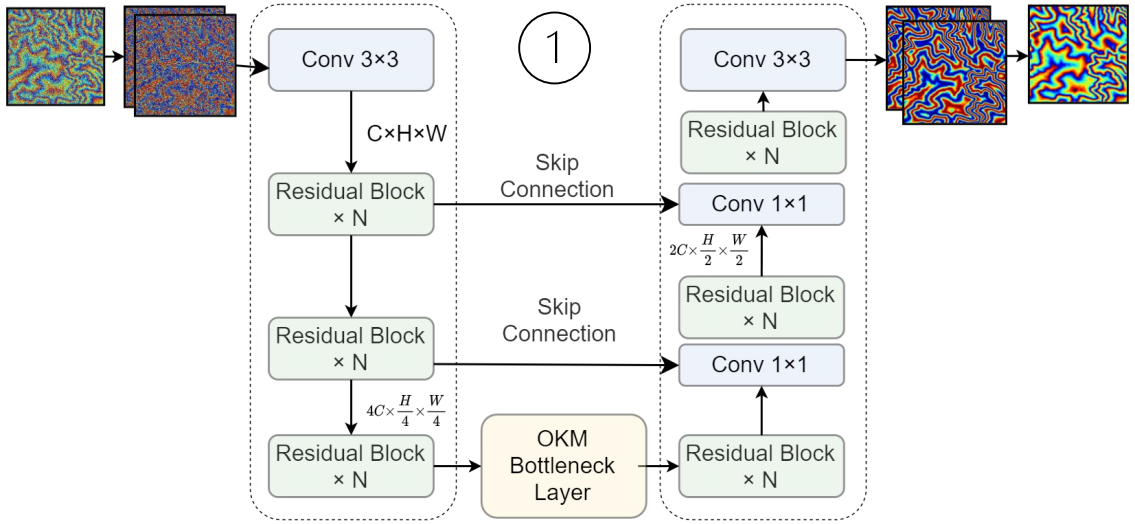
- Noise may be propagated

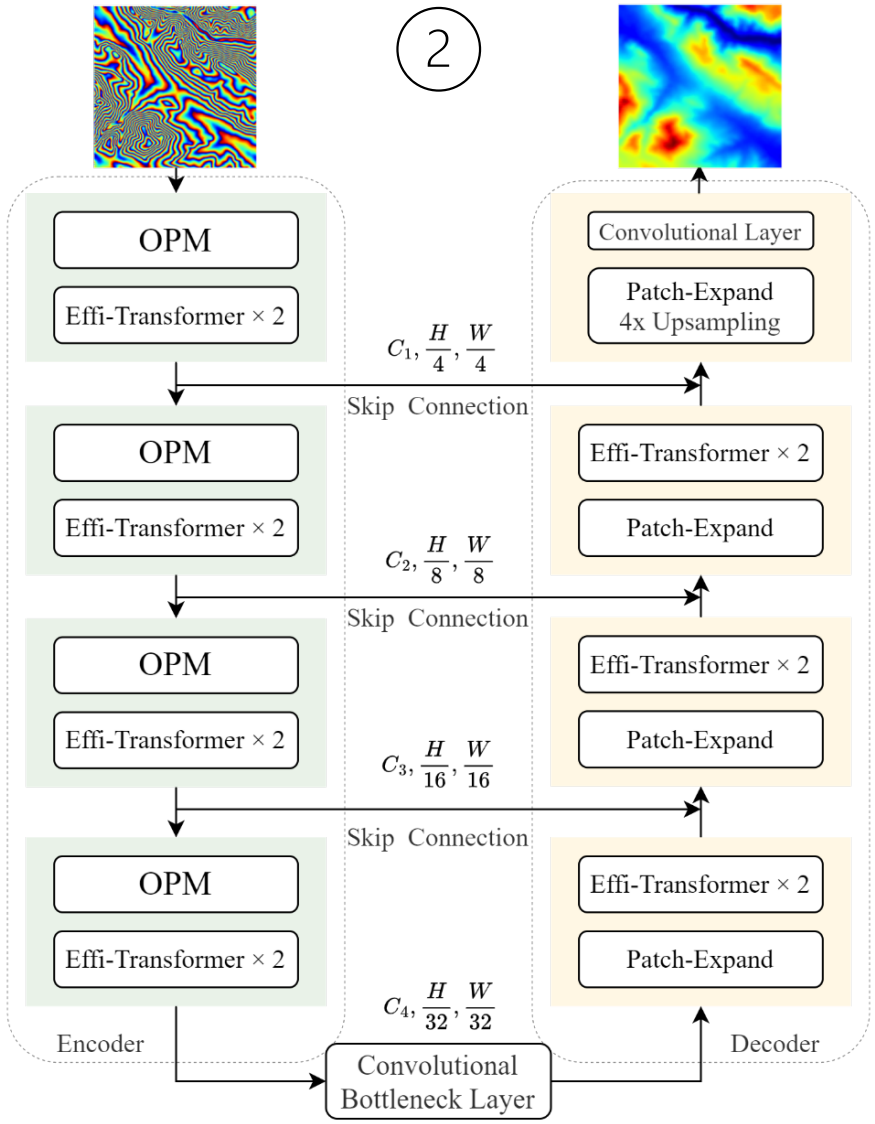
Deep Learning Algorithms:

- Data-driven
- Excels with optical images
- May solves unwrapping issues

A Two-Stage Method Using SegFormer and Convolutional Networks for Noise-Resistant InSAR Phase Unwrapping

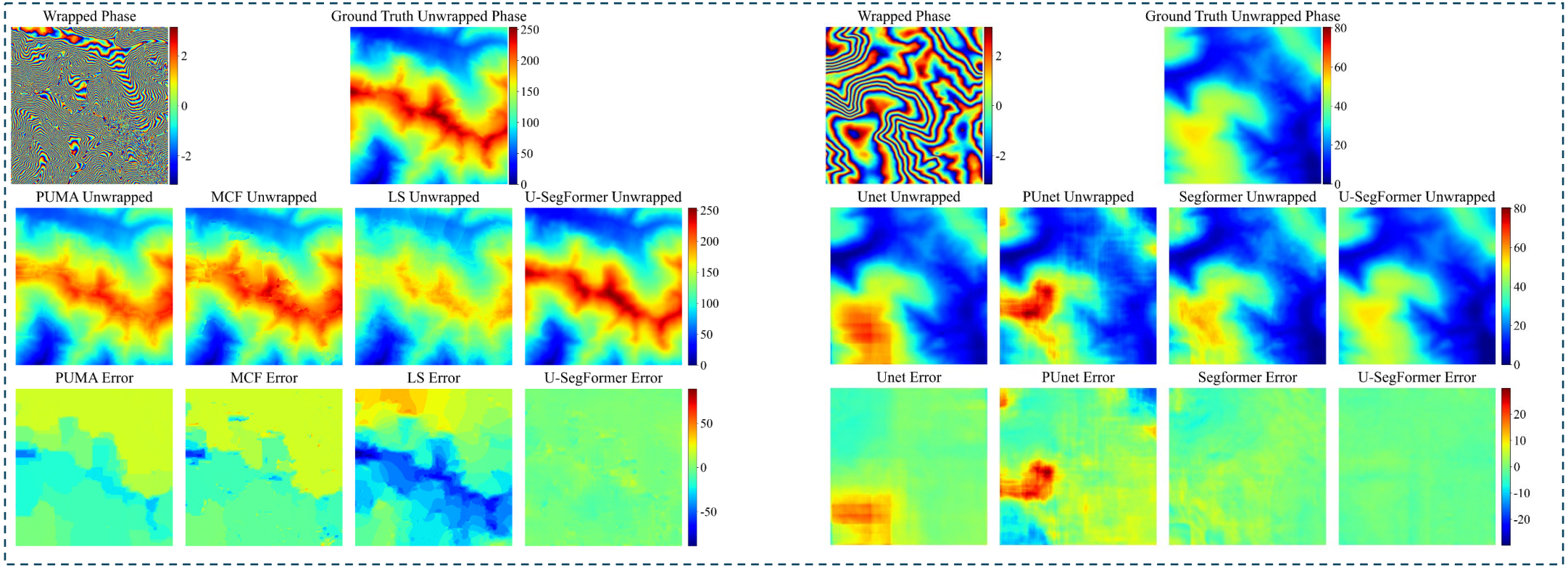




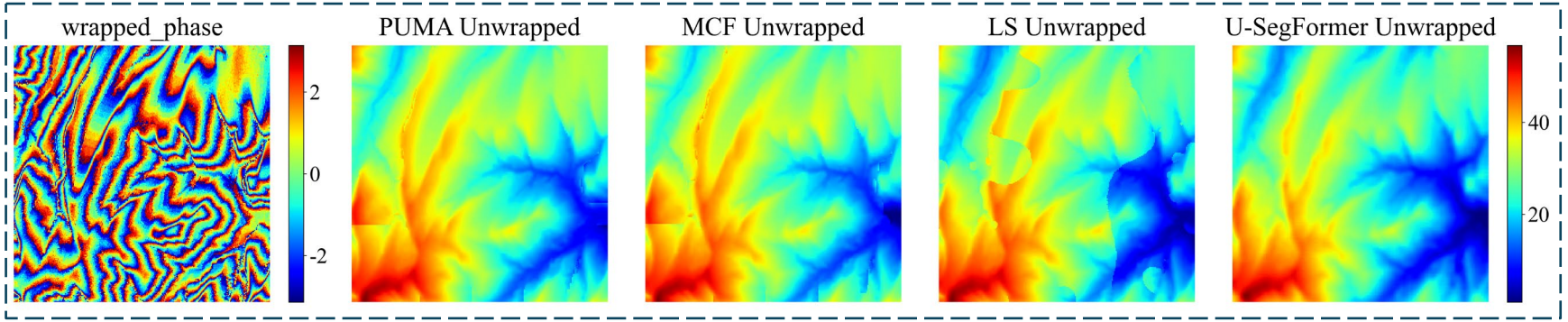


A Two-Stage Method Using SegFormer and Convolutional Networks for Noise-Resistant InSAR Phase Unwrapping

Result on Simulated Data



Result on Real Data





5. Forest Fire Scar Detection From Time-series Sentinel-1 Observations Based On Coherence Prediction Using Recurrent Neural Network

Zixuan Qin

Forest Fire Scar Detection From Time-series Sentinel-1 Observations Based On Coherence Prediction Using Recurrent Neural Network

- Limited by adverse conditions like smoke/cloud cover.

  High-quality post-fire optical imagery is usually unavailable.

  The acquisition of SAR data is independent of weather condition and solar illumination.

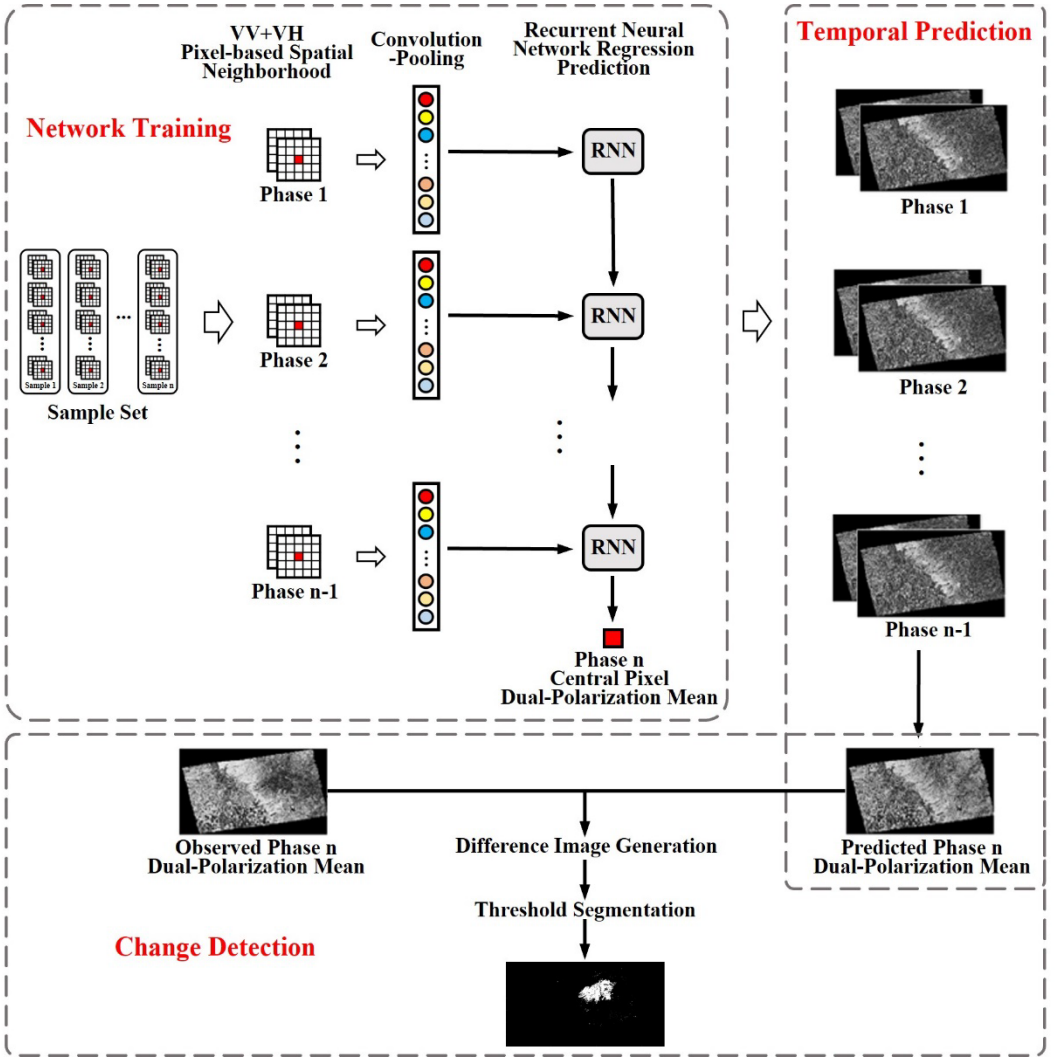
- SAR imagery exhibits complex scattering mechanisms and geometric distortions.

  Using SAR backscatter intensity for multi-temporal change detection may lead to false positives in mountainous terrain with significant undulation.

- The coherence feature derived by InSAR has also been employed for change detection.

  Coherence exhibits uncertainty due to the non-stationary properties of forest vegetation. ⟶ false alarms.

- we proposes a semi-supervised deep learning framework based on time-series SAR coherence analysis.

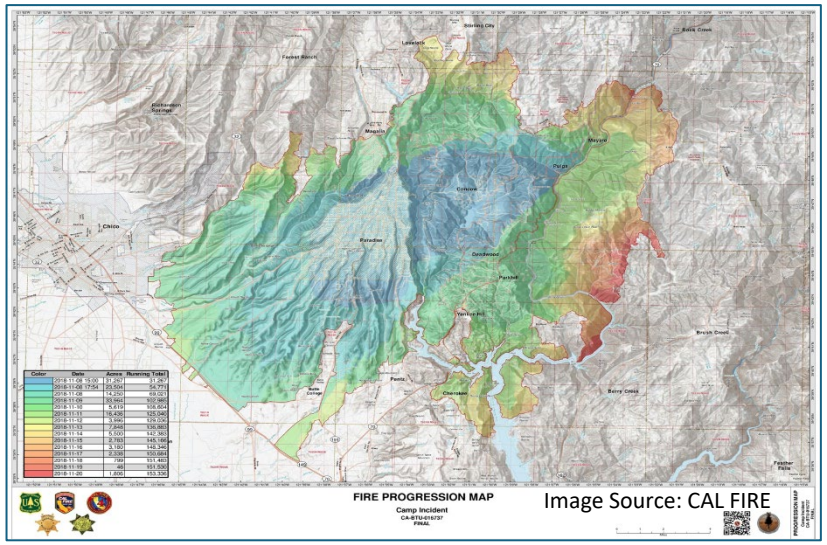


Forest Fire Scar Detection From Time-series Sentinel-1 Observations Based On Coherence Prediction Using Recurrent Neural Network

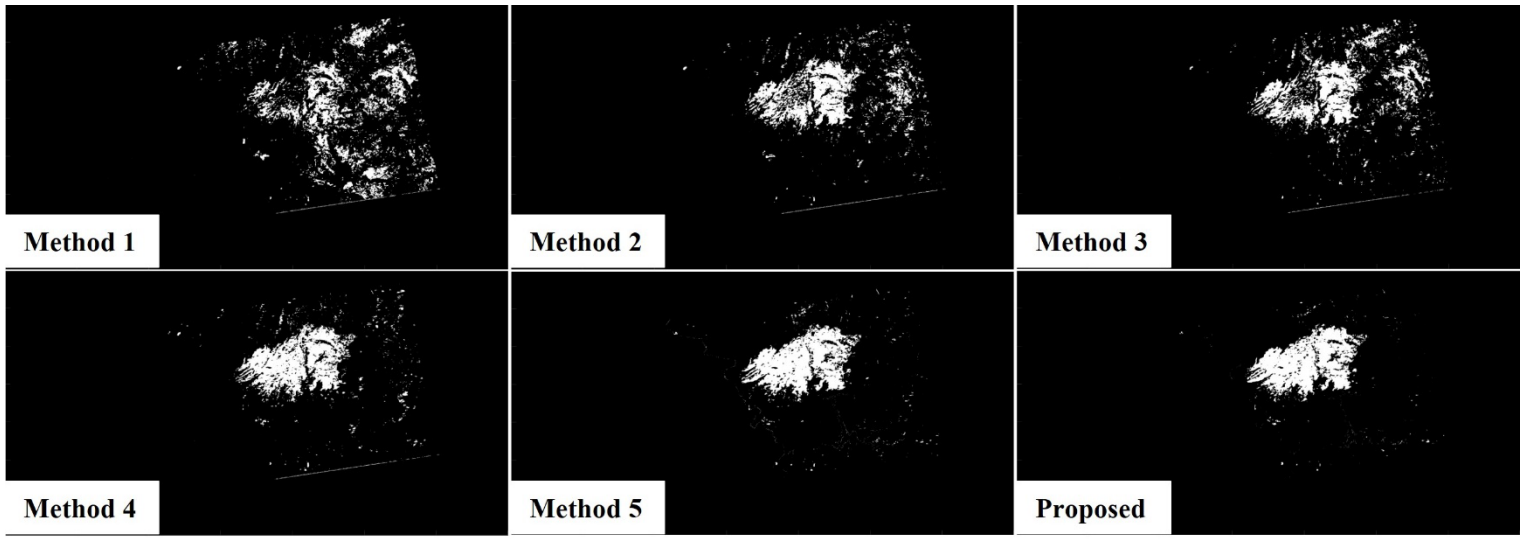
■ Two sets of comparative experiments were conducted:

Comparative Experiments	Method	Method Description
Based on Observed Datasets	Method 1: Variance Operator	Dual-polarization + Time-series variance operator + Threshold segmentation
	Method 2: Optimal Image Selection	Selection of pre-fire optimal coherence image (Phase 4) + Dual-polarization + Difference operator + Threshold segmentation
Based on Multi-Modal Image Features	Method 3: Linear Regression	Dual-Polarization + Linear Regression Prediction + Difference Operator + Threshold Segmentation
	Method 4: Pixel-based BiLSTM (VV)	Single pixel + Single-polarization (VV) + BiLSTM + Difference operator + Threshold segmentation
	Method 5: Spatially-neighbored Pixel-based BiLSTM (VV)	5×5 spatial neighborhood + Single-polarization (VV) + BiLSTM + Difference operator + Threshold segmentation

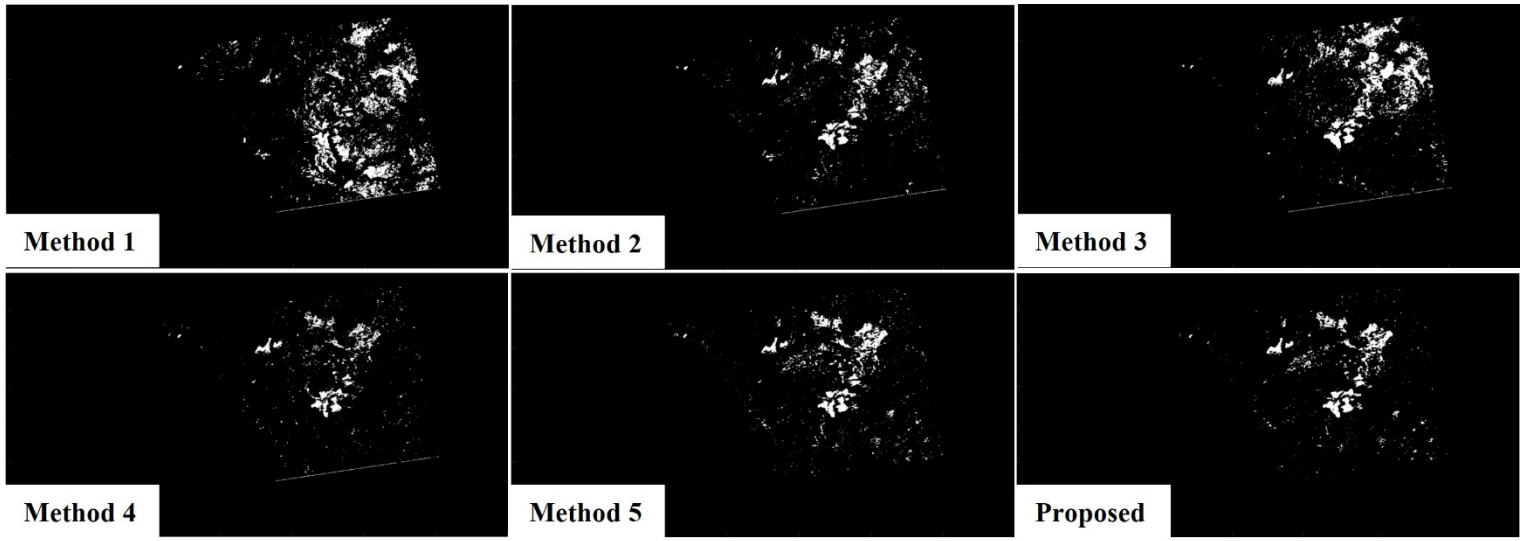
Forest Fire Scar Detection From Time-series Sentinel-1 Observations Based On Coherence Prediction Using Recurrent Neural Network



- Phase 6 outperforms Phase 7 in evaluation results. Phase 7 corresponds to the mid-to-late stage of the wildfire event. During this phase, spatial changes exhibit greater dispersion and smaller scales, while also being subject to uncertainties such as potential human intervention.
- In comparison to Methods 1-3, the change patches extracted using deep learning-based time series prediction methods exhibit more complete shapes, reduced noise levels, and a clearer representation of the wildfire-affected areas and their evolutionary trends.



Change Detection Results for Phase 6(2018.11.05-2018.11.11) of the Camp Fire.



Change Detection Results for Phase 7(2018.11.11-2018.11.17) of the Camp Fire.

Forest Fire Scar Detection From Time-series Sentinel-1 Observations Based On Coherence Prediction Using Recurrent Neural Network

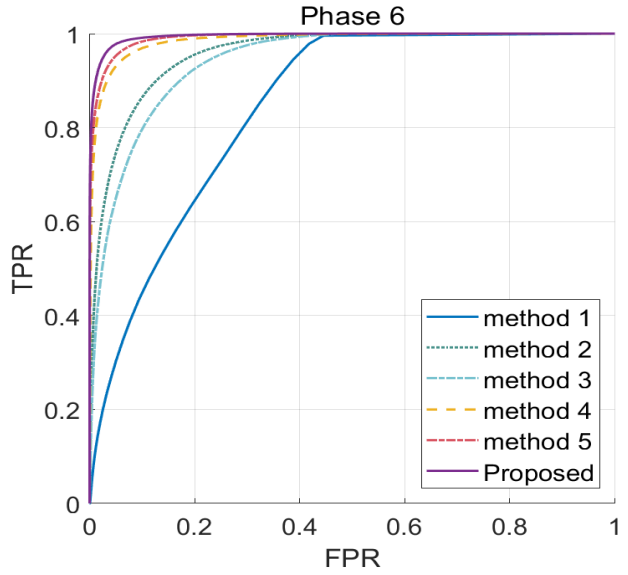
■ Quantitative Evaluation Table of Camp Wildfire Change Detection Results.

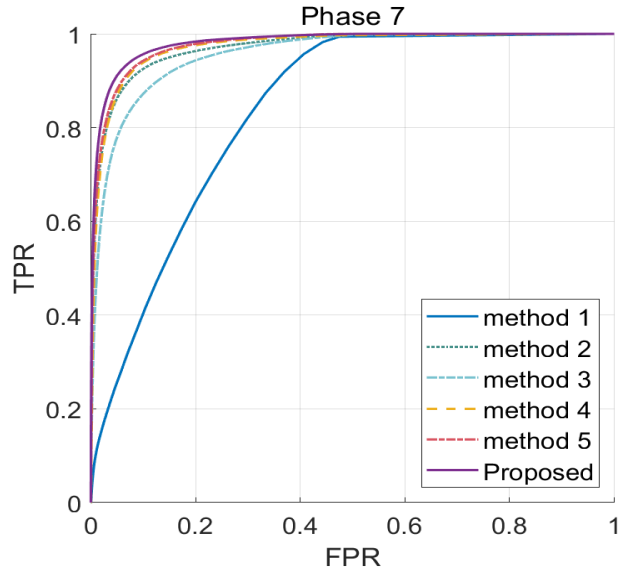
Phase	Metric	Method 1	Method 2	Method 3	Method 4	Method 5	Proposed Method
Phase 6	Pr	0.3444	0.7120	0.6072	0.9065	0.9500	**0.9774**
	Re	0.3448	0.6061	0.5840	0.7300	0.7441	**0.7604**
	Acc	0.8858	0.9444	0.9309	0.9699	0.9743	**0.9774**
	Kappa	0.2820	0.6247	0.5576	0.7926	0.8208	**0.8422**
Phase 7	Pr	0.1246	0.6135	0.4701	0.7044	0.6293	**0.7152**
	Re	0.3209	0.6765	0.6307	0.5059	0.6916	**0.6917**
	Acc	0.9106	0.9771	0.9671	0.9785	0.9782	**0.9822**
	Kappa	0.1418	0.6317	0.5220	0.5781	0.6477	**0.6941**

■ The quantitative index of the proposed method is obviously superior to other methods.

■ The curve of the proposed method is closer to the top-left corner (0,1), indicating its effectiveness in reducing false alarms and missed detections, and demonstrating superior overall performance.

➢ ROC Curves of Comparative Methods.







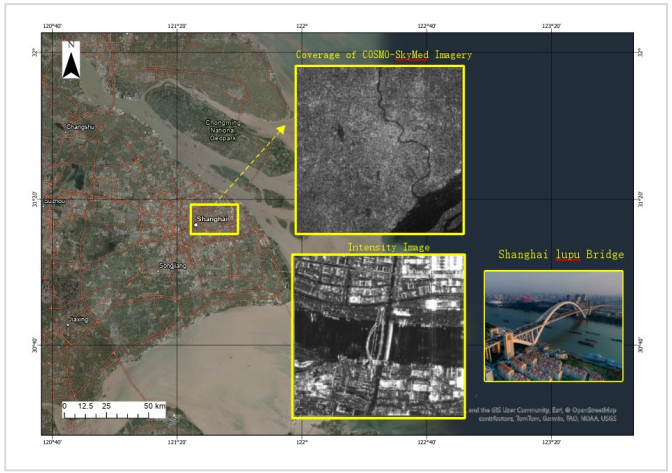
6. InSAR Deformation Monitoring and Prediction of Shanghai Lupu Bridge

Yunyue Zhou

InSAR Deformation Monitoring and Prediction of Shanghai Lupu Bridge

➢ **Bridges are critical hubs in China's transportation network, ensuring road safety and traffic flow. By the end of 2023, China had 1,079,300 highway bridges, including 10,239 extra-large bridges (0.95%) and 177,700 large bridges (16.5%). However, prolonged overloading and structural aging have caused frequent safety failures, posing severe threats to public safety.**

STUDY AREA



(a)

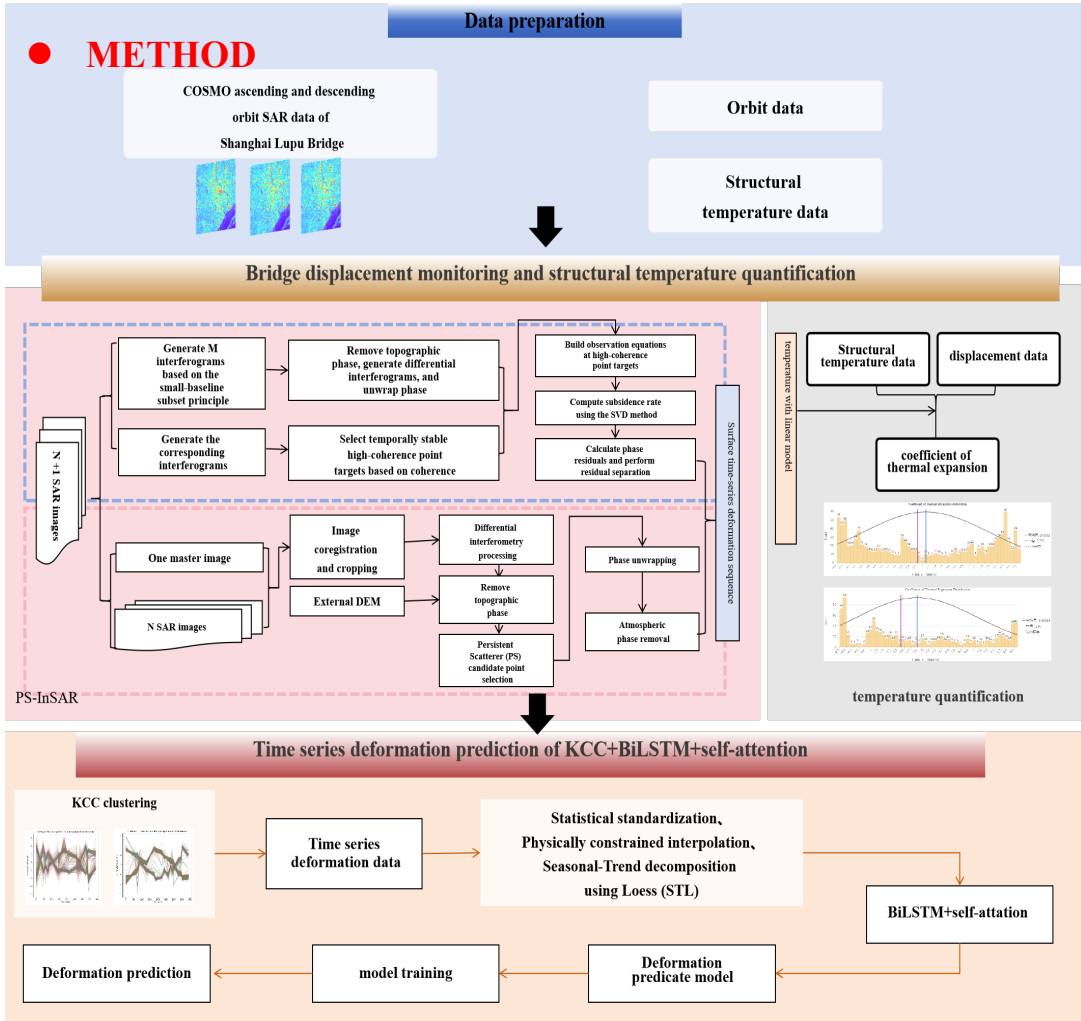
Parameter Name	Parameter Value
data type	COSMO-SkyMed
Resolution/(m x m)	1.0× 3.0
Revisit Cycle/d	16
Imaging Mode	High-Resolution Image
Band Type	X-band SAR
Band Wavelength (cm)	3.1 cm
Polarisation Pattern	HH
Acquisition Time	20090212-20100207 18 Scene COSMO-SkyMed Ascending Orbit Data of the Lupu Bridge; 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.

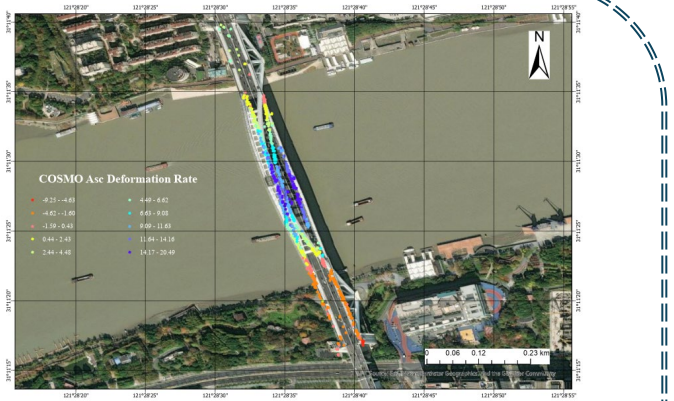
METHOD

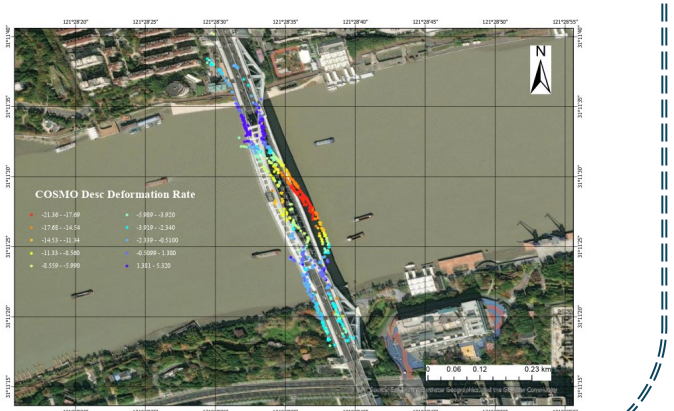


InSAR Deformation Monitoring and Prediction of Shanghai Lupu Bridge

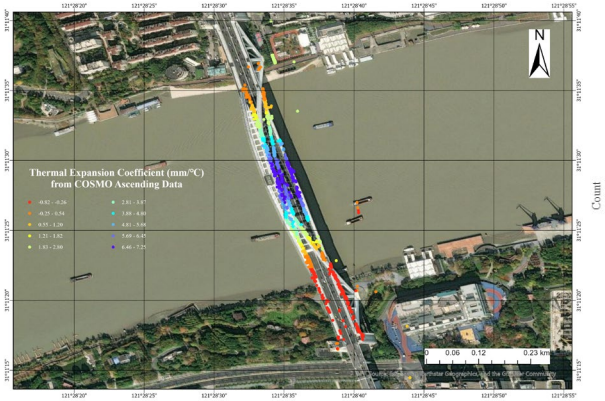
➢ Bridge Deformation Monitoring Results Based on Time-Series InSAR Technology

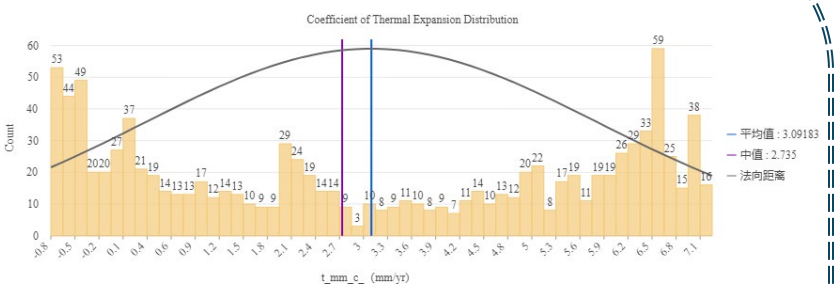
Deformation Monitoring

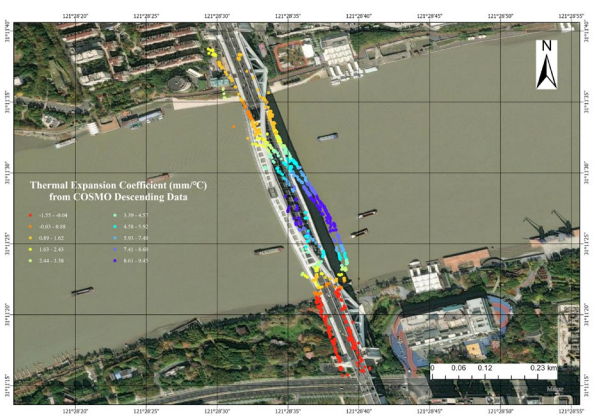


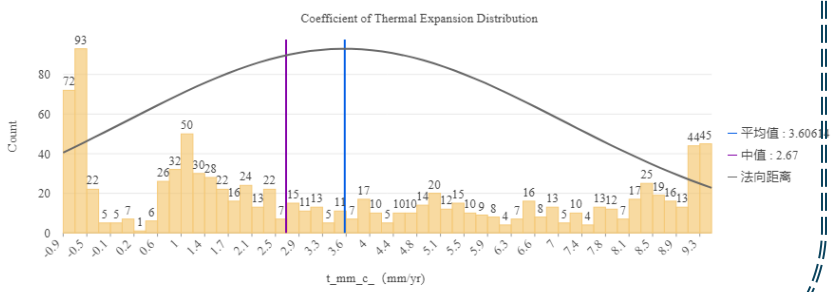


Coefficient of Thermal Expansion









- Ascending orbit: >75% of PS points had deformation rates concentrated at 11.64–20.49 mm/yr
- Descending orbit: >82% of PS points exhibited deformation rates within -9.25–4.63 mm/yr

- Integrated analysis of deformation-temperature sequences for Lupu Bridge revealed significant spatial heterogeneity in thermal expansion coefficients, demonstrating distinct thermoelastic responses between side spans and the central span.

InSAR Deformation Monitoring and Prediction of Shanghai Lupu Bridge

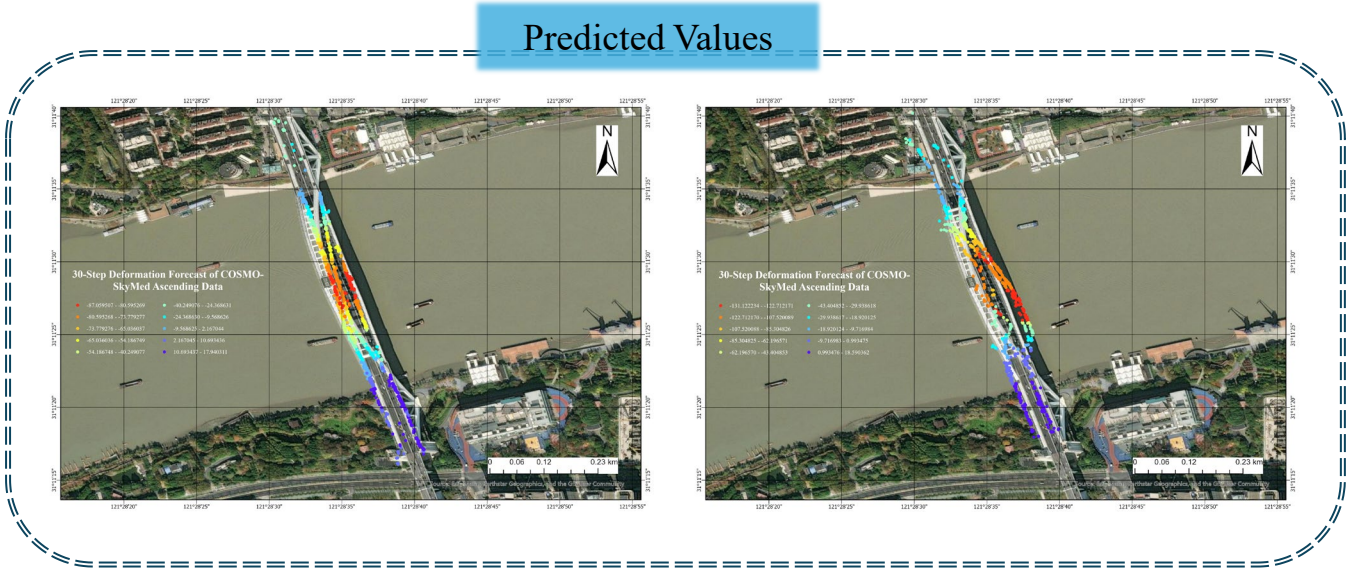
➢ Deformation Prediction of Cable-Stayed Bridges Using Integrated KCC+BiLSTM+Self-Attention

A novel KCC+BiLSTM+Self-Attention integrated framework is proposed for high-precision short-term bridge deformation forecasting. The framework demonstrates statistically significant RMSE reduction compared to the BiLSTM-Self-Attention baseline.

RMSE Comparison: Proposed vs. Baseline Models

	BiLSTM-SelfAttention Model		KCC-BiLSTM-SelfAttention Model	
RMSE at Representative Points	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

- **Comparing the 12 representative bridge points, the proposed model significantly reduces RMSE to 0.01-0.73 mm**



- **Integrating temperature-seasonal data, a BiLSTM model combined with K-Shape clustering captures spatiotemporal correlations, reducing short-term prediction RMSE by 79-99% and characterizing bridge deformation dynamics.**



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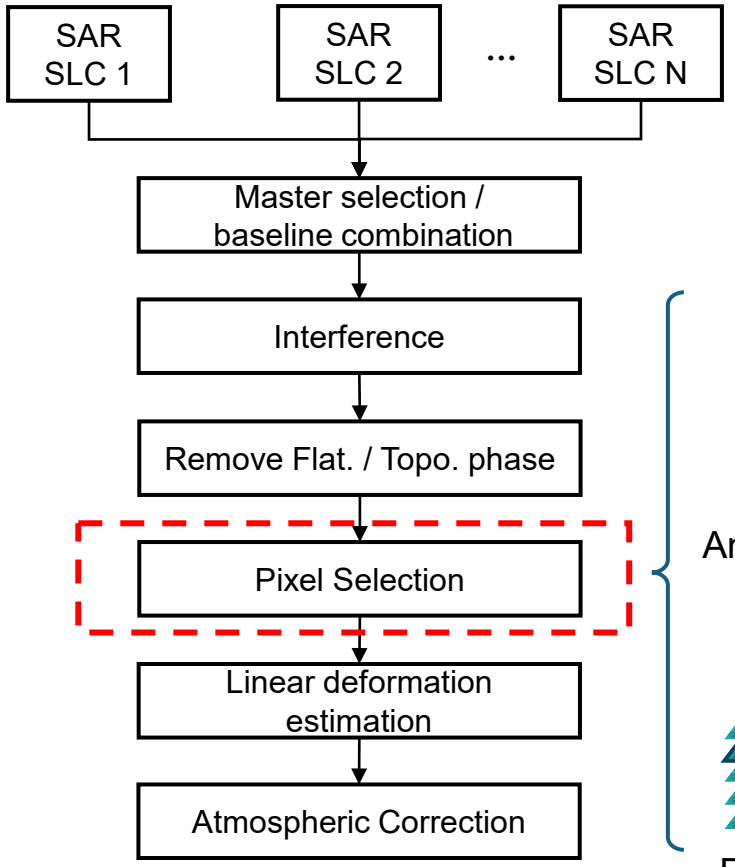
7. Persistent Scatters Selection based on Temporal-Spatial Vision Transformers

Yifan Zhang

Persistent Scatters Selection based on Temporal-Spatial Vision Transformers.

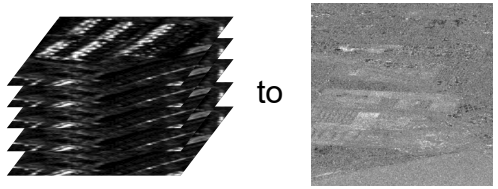
Research background

Persistent scatterers (PS) selection



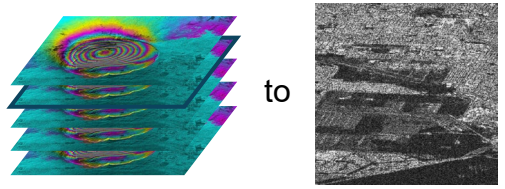
PS selection is the cornerstone of PS-InSAR processing

Amplitude-based



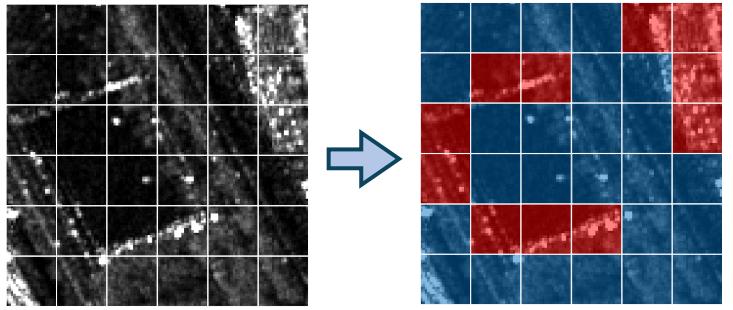
Amplitude images DA map

Phase-based



Phase stacks TPC map

Deep Learning-based PS selection



Binary semantic segmentation

Steps:

① SAR amplitude or Interferometric phase input

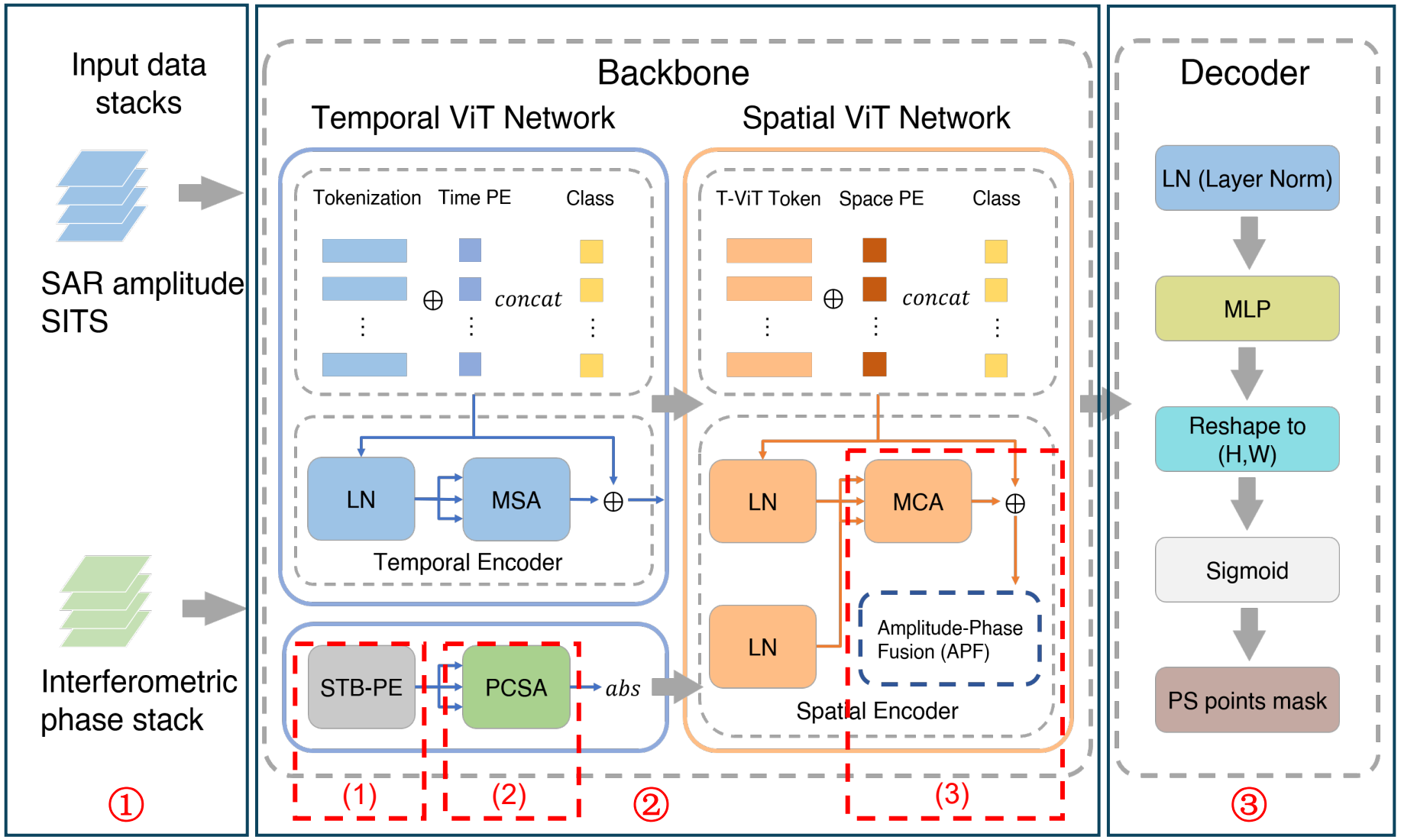
② Feature extraction and classifying each pixel

③ Feature projection and output PS mask

Issue: The temporal and spatial characteristics of amplitude and phase are still not fully utilized.

Persistent Scatters Selection based on Temporal-Spatial Vision Transformers.

Methodology



Steps:

① Dual-Branch input

② Contextual feature extraction

③ Feature projection and output

Innovations :

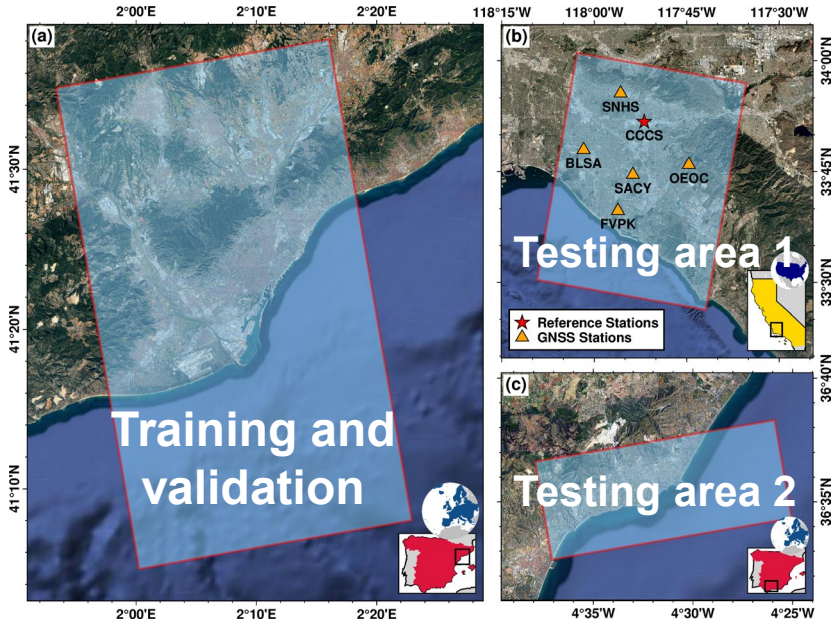
(1) spatial-temporal baseline encoding

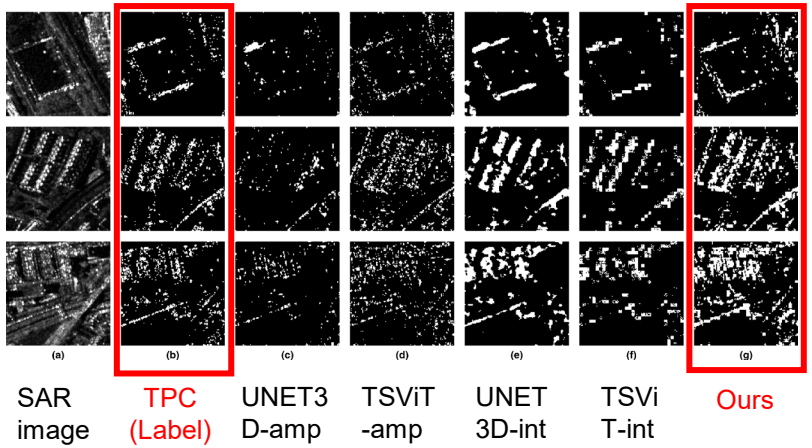
(2) Phase consistent self-attention

(3) Two-stage feature fusion

Persistent Scatters Selection based on Temporal-Spatial Vision Transformers.

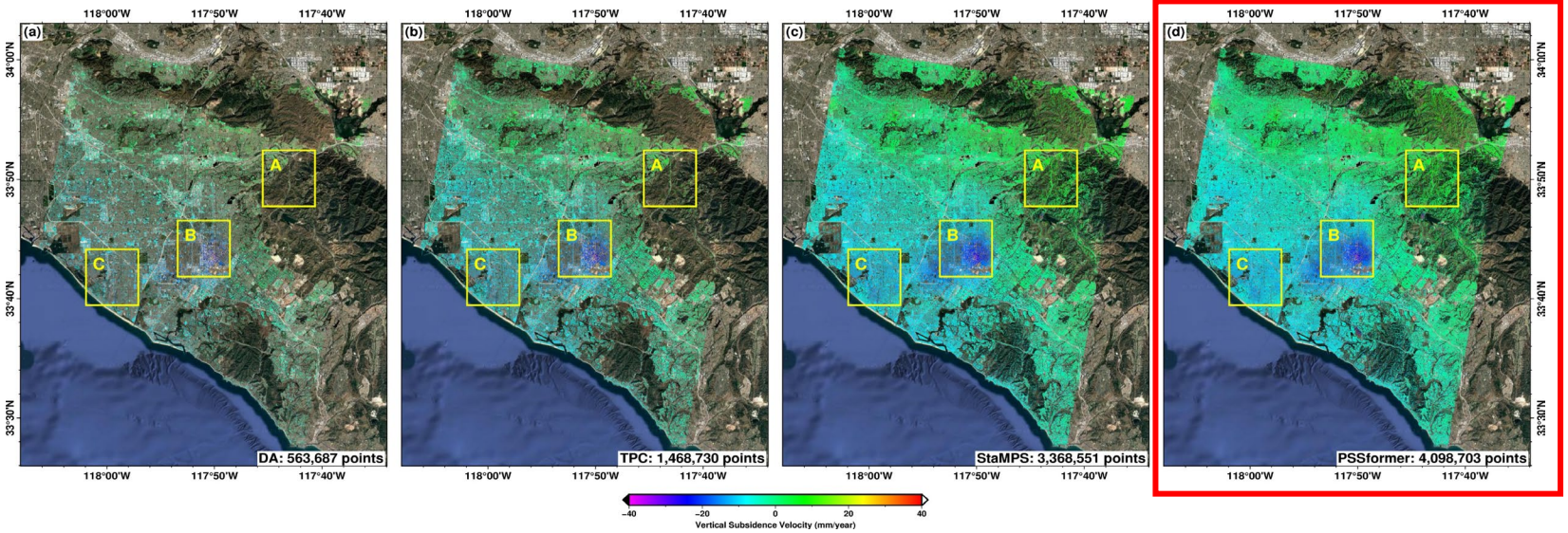
Experiments results

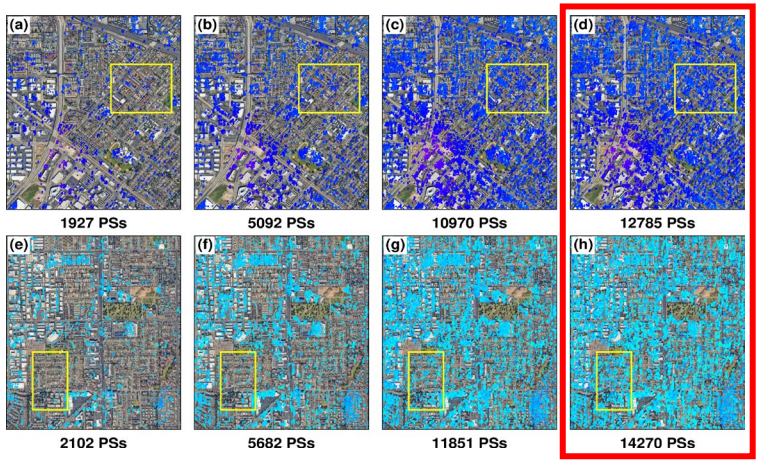


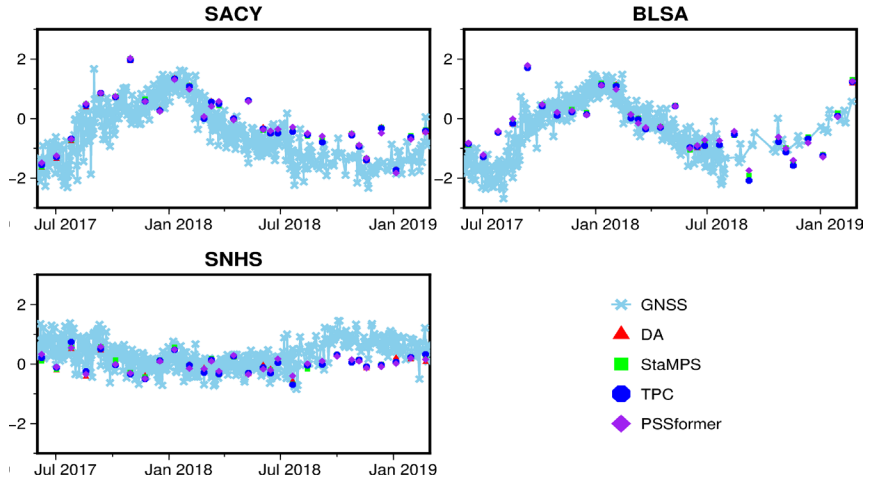


- Recall increased by **5.1%**

California dataset







- PSSformer achieved **the most PSs (67.78%)** and **the lowest RMSE**.

CONCLUSIONS



- **The first year** of the DRAGON 6 project has **started to produce results**.
- **9 Young Scientists** from different universities have **presented results in the Symposium**.
- **Their work** and collaboration with senior researchers have made it possible to **start achieving the project's objectives**.
- **Access to the data from third-party missions**, necessary for the project, **has been secured**.
  - **New acquisitions** over relevant test-sites have been agreed with Hisdesat (PAZ) and are on their way with DLR (TSX).
  - Access to **archived data** for PAZ, TSX, and RCM granted.
- **The participation of project members** in the DRAGON 6 2025 Symposium **has strengthened ties among all of them**.