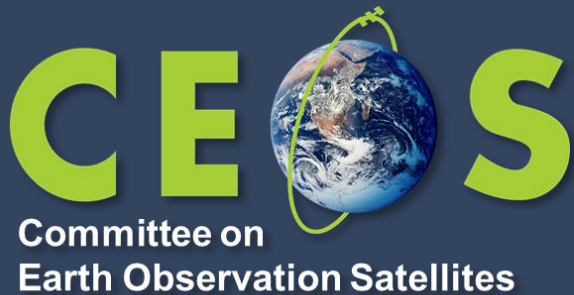


WGDisasters 23 From Building Damage Assessment to Post- Disaster Recovery Monitoring: An Integrated Very High- Resolution SAR and Geospatial Workflow for the 2023 Türkiye–Syria Earthquake



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Study Areas and EO / Ancillary Data



Study area: 2023 Türkiye-Syria earthquake case study — Cities: Islahiye, Kahramanmaraş, Nurdağı, Osmaniye, and Türkoğlu

Phase 1: rapid post-event damage assessment [1]



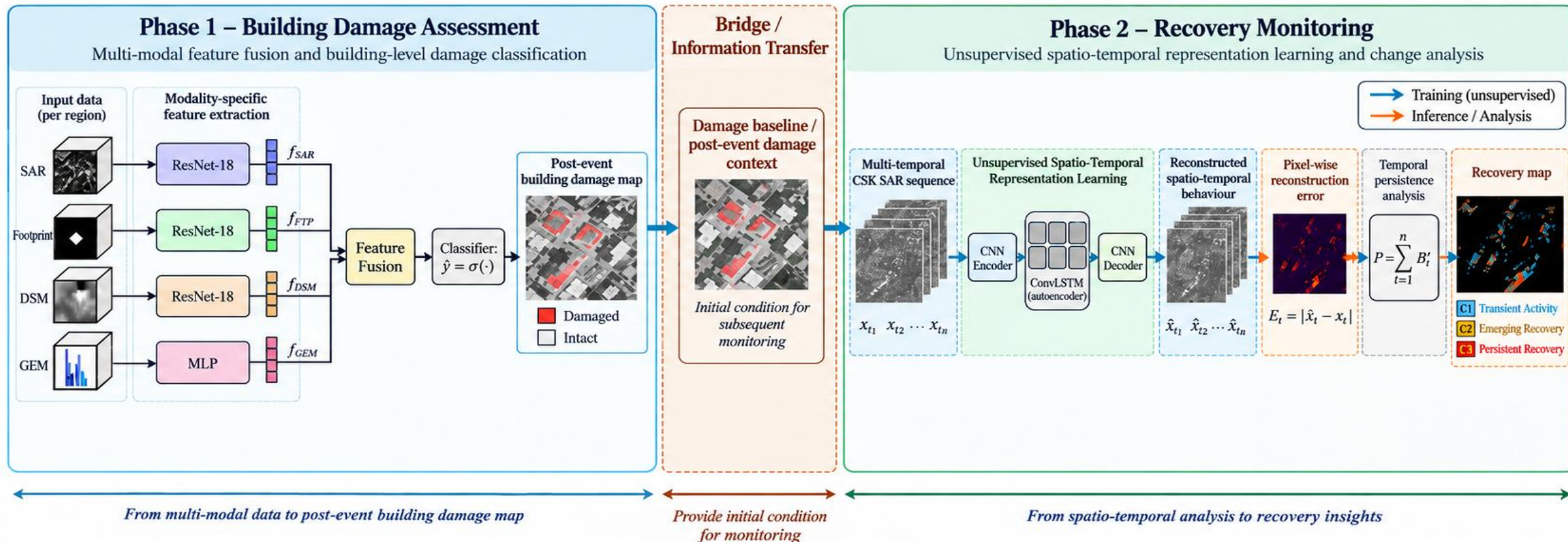
Phase 2: multi-temporal recovery monitoring and interpretation [2]

Analysis stage	Data	Coverage / source	Role in workflow
PHASE 1 — MULTIMODAL BUILDING DAMAGE ASSESSMENT (BDA)			
Phase 1	COSMO-SkyMed (CSK) post-event SAR data	Stripmap HIMAGE, HH polarization, ~2.5 m; one post-event acquisition per city	Main EO input for building-level damage detection
	Open Street Map (OSM) building footprints	OSM building footprints and damage annotations	Building footprints and damage labels for training and building damage detection (BDD)
	Digital Surface Model (DSM) layers	CartoSat-1 Euro-Maps DSM (~5 m)	Structural and topographic context
	Global Earthquake Model (GEM) layers	GED4GEM – Global Exposure Database for GEM [3]	Building-level exposure and vulnerability attributes
	Capella Space Spotlight SAR data	Capella Space Open Data, Spotlight (~0.4 m), Islahiye subset	Spatial-resolution benchmark and comparison with CSK Stripmap
PHASE 2 — RECOVERY AND RECONSTRUCTION MONITORING			
Phase 2	COSMO-SkyMed (CSK) post-event SAR time-series data	Stripmap HIMAGE, HH, ~2.5 m; 6 ascending orbit acquisitions per city, between Feb.-Mar. 2023 and Oct. 2024	Multi-temporal anomaly detection and persistence-based recovery mapping
	Optical imagery / time series	Google Earth + Sentinel-2	Interpretation and local validation of SAR-based anomalies
	Geological maps	General Directorate of Mineral Research and Exploration (MTA) geological maps, 1:100,000 scale	Geological context for interpreting the spatial distribution of recovery hotspots
	Nighttime Lights (NTL) comparison product	External comparison reference from Gong et al. [4] over the city of Nurdağı	Comparison with functional recovery signals

From Damage Assessment to Recovery Monitoring



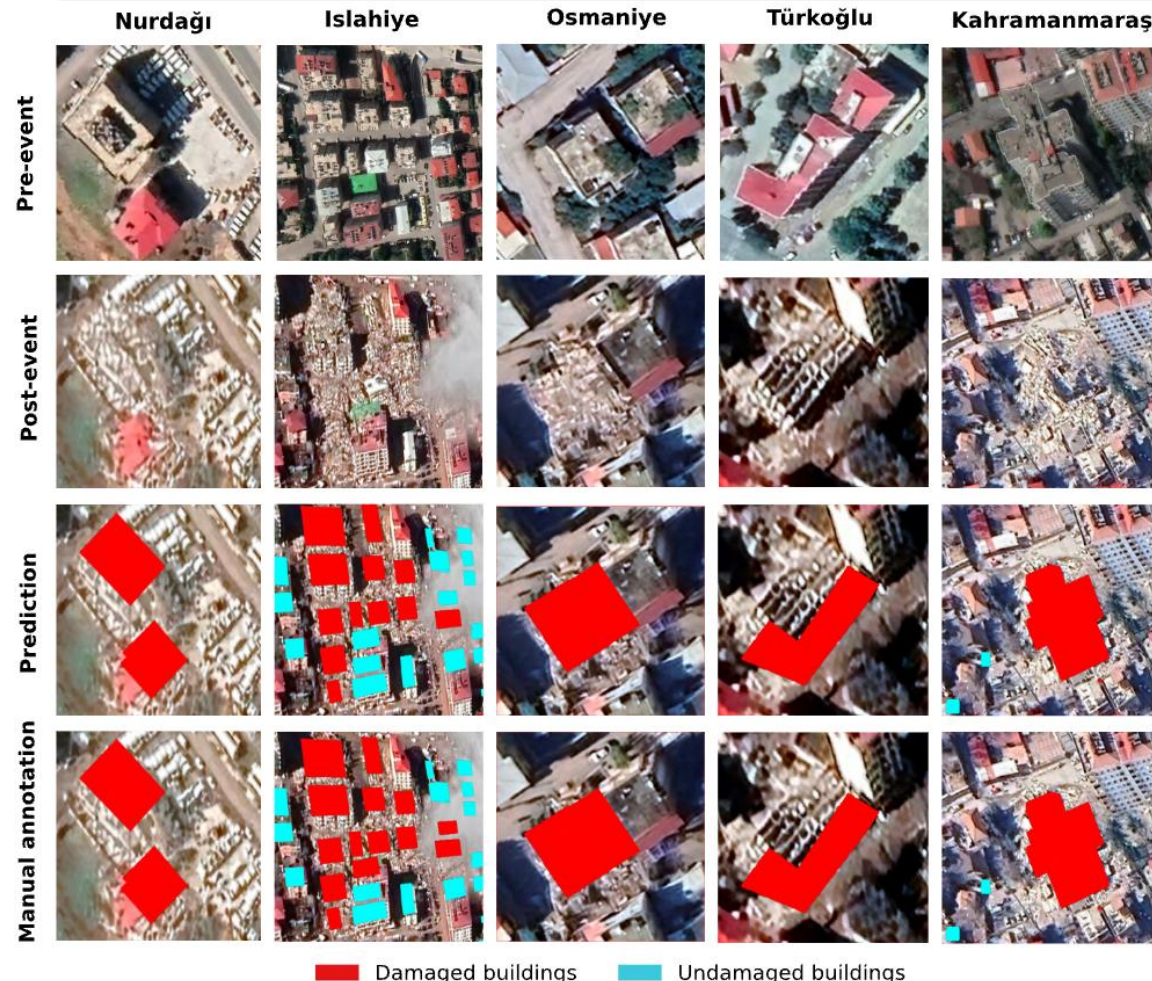
- ❖ Phase 1: multimodal building-level Building Damage Assessment (BDA).
- ❖ Bridge: the building damage map provides the post-event baseline for subsequent monitoring.
- ❖ Phase 2: unsupervised multi-temporal CSK SAR recovery monitoring tracks persistent post-event changes.
- ❖ Outcome / Action: extend EO support from rapid damage mapping to systematic recovery monitoring, maintaining high-resolution SAR acquisitions throughout the recovery phase.



Phase 1 – BDA: Main Results



Qualitative examples across five affected cities



Leave-One-City-Out (LOCO) performance on unseen cities

City	Input Configuration	Precision	Recall	F1 score	AUROC	Kappa
Islahiye	<i>CSK + FTP</i>	0.127	0.396	0.192	0.683	0.129
	<i>CSK + FTP + DSM</i>	0.312	0.260	0.284	0.750	0.252
	<i>CSK + FTP + DSM + GEM</i>	0.242	0.307	0.271	0.720	0.229
Kahramanmaraş	<i>CSK + FTP</i>	0.201	0.476	0.282	0.809	0.231
	<i>CSK + FTP + DSM</i>	0.361	0.339	0.350	0.824	0.318
	<i>CSK + FTP + DSM + GEM</i>	0.358	0.408	0.382	0.853	0.348
Nurdagi	<i>CSK + FTP</i>	0.240	0.240	0.318	0.661	0.174
	<i>CSK + FTP + DSM</i>	0.255	0.470	0.331	0.669	0.194
	<i>CSK + FTP + DSM + GEM</i>	0.276	0.416	0.332	0.668	0.207
Osmaniye	<i>CSK + FTP</i>	0.063	0.812	0.118	0.552	0.031
	<i>CSK + FTP + DSM</i>	0.106	0.106	0.143	0.606	0.106
	<i>CSK + FTP + DSM + GEM</i>	0.150	0.188	0.167	0.625	0.120
Türkoğlu	<i>CSK + FTP</i>	0.217	0.217	0.217	0.648	0.178
	<i>CSK + FTP + DSM</i>	0.226	0.304	0.259	0.631	0.216
	<i>CSK + FTP + DSM + GEM</i>	0.333	0.348	0.340	0.653	0.306

Main findings

- Predictions closely match reference / OSM damage annotations across five cities.
- DSM and GEM features generally improve F1 & Kappa over the CSK and footprint (*CSK + FTP*) baseline under LOCO.
- The results indicate that integrating structural, exposure and vulnerability context can strengthen building-level damage assessment and cross-city generalization, particularly when transferring the model to unseen cities.
- Remaining performance differences mainly reflect cross-city domain shift and class imbalance.

- **Post-event-only VHR SAR** supports rapid building-scale BDA when pre-event or cloud-free optical imagery is unavailable.
- **Structural, exposure and vulnerability layers ($DSM + GEM$)** improve **F1 score** and **Kappa** and support **cross-city generalization**, especially when transferring the model to unseen cities.
- **SAR spatial resolution** defines the **operational scale**: **Capella Spotlight** (~0.4 m) achieves the strongest AUROC, Precision and Recall, while **CSK Stripmap** (~2.5 m) offers a **practical compromise** between **spatial detail** and **operational availability**.
- **Sentinel-1 (S1, ~10 m)** is useful for broad-area screening, but less effective for fine building-level assessment.

Benchmark / spatial-resolution effect

Metric	<i>Sun et al. [5]*</i>	<i>This paper (SAR + FTP + DSM + GEM)**</i>	<i>This paper (SAR + FTP + DSM + GEM)***</i>
AUROC	0.769 ± 0.032	0.763 ± 0.037	0.780 ± 0.043
F1 score	0.282 ± 0.077	0.295 ± 0.038	0.289 ± 0.024
Precision	0.237 ± 0.116	0.255 ± 0.070	0.297 ± 0.139
Recall	0.427 ± 0.104	0.395 ± 0.099	0.436 ± 0.191
Kappa	–	0.251 ± 0.044	0.243 ± 0.031

* Capella Spotlight + FTP only; ** CSK Stripmap; *** Capella Spotlight.

Cross-city operational comparison

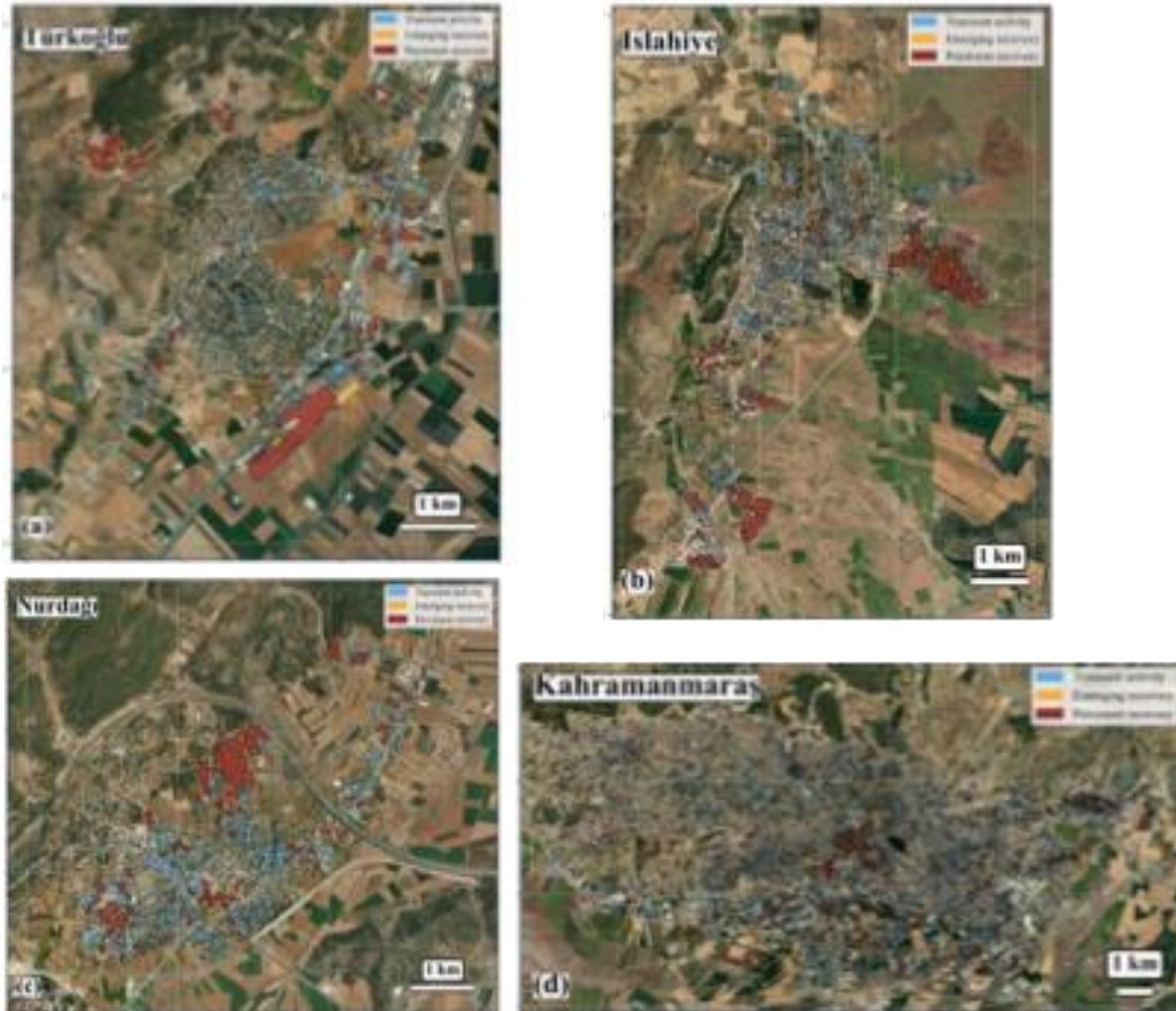
City	Input Configuration	Precision	Recall	F1	AUROC	Kappa
Islahiye	<i>S1 + FTP + DSM + GEM</i>	0.127	0.285	0.176	0.661	0.117
	<i>CSK + FTP + DSM + GEM</i>	0.242	0.307	0.271	0.720	0.229
Kahramanmaraş	<i>S1 + FTP + DSM + GEM</i>	0.201	0.401	0.270	0.767	0.220
	<i>CSK + FTP + DSM + GEM</i>	0.358	0.408	0.382	0.853	0.348
Nurdağı	<i>S1 + FTP + DSM + GEM</i>	0.231	0.414	0.297	0.630	0.154
	<i>CSK + FTP + DSM + GEM</i>	0.276	0.416	0.332	0.668	0.207
Osmaniye	<i>S1 + FTP + DSM + GEM</i>	0.075	0.500	0.131	0.593	0.052
	<i>CSK + FTP + DSM + GEM</i>	0.150	0.188	0.167	0.625	0.120
Türkoğlu	<i>S1 + FTP + DSM + GEM</i>	0.214	0.261	0.235	0.643	0.192
	<i>CSK + FTP + DSM + GEM</i>	0.333	0.348	0.340	0.653	0.306

Operational takeaway: combining VHR SAR with structural, exposure and vulnerability information improves robust post-event BDA across unseen urban areas.

Phase 2 – Recovery Monitoring: Main Results



City-scale recovery maps from CSK SAR anomaly persistence



Main findings and interpretation

	Class	Persistence rule	Meaning
	C1 – Transient activity	$P = 1$	Short-lived anomaly
	C2 – Emerging recovery	$2 \leq P < \tau$	Ongoing transformation
	C3 – Persistent recovery	$P \geq \tau$	Sustained structural change

Note: $\tau = 3$ in this implementation (C1: $P = 1$; C2: $P = 2$; C3: $P \geq 3$).

Key Takeaways:

- ◆ Recovery-related SAR patterns are **strongly heterogeneous across cities**.
- ◆ Smaller towns show **localized coherent hotspots**; Kahramanmaraş is more **fragmented and distributed**.
- ◆ **Recovery classes** describe the **recurrence and persistence** of SAR anomalies, rather than the exact timing of reconstruction.
- ◆ Over the **20-month observation period**, the **cumulative footprint of detected changes progressively expands**, with **different patterns across cities**.

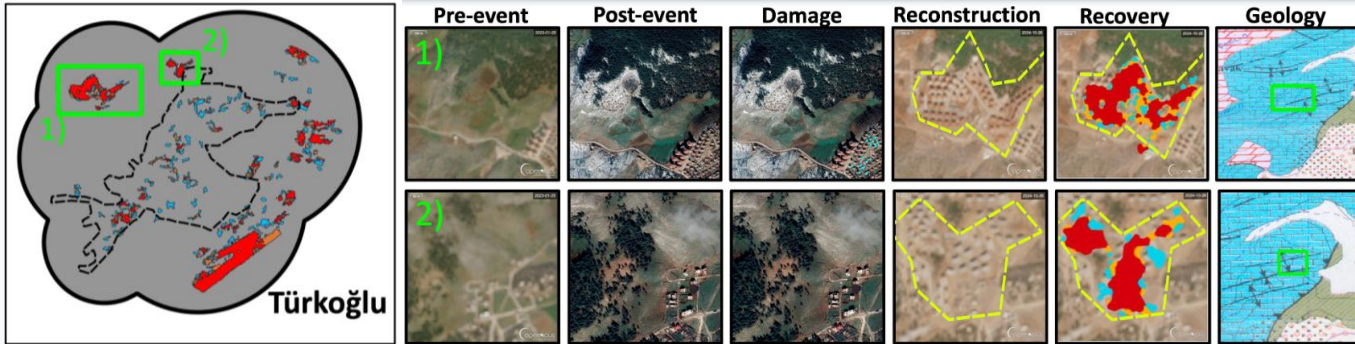
Recovery-related changes are spatially heterogeneous, with distinct patterns emerging across different urban contexts.

Phase 2 – Recovery Monitoring: Interpretation & Validation (1/2)



Selected local examples linking SAR recovery patterns, optical evidence and geology

Türkoğlu – localized persistent recovery hotspot



Legend

Damage legend

- Damaged buildings
- Undamaged buildings

Recovery legend

- Persistent recovery
- Emerging recovery
- Transient activity

Geology legend

- Alluvial pebble
- Dolomitic limestone
- Alluvium
- Hatay ophiolites

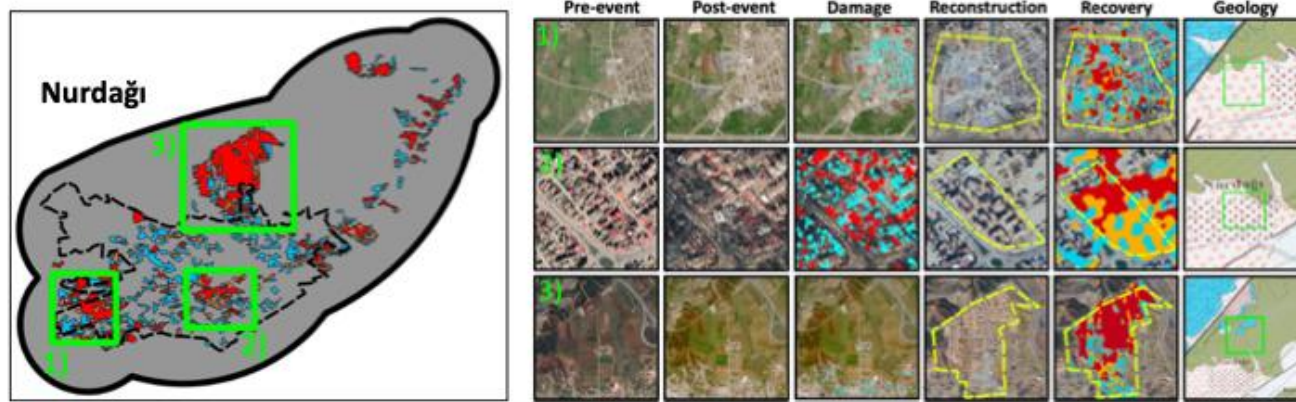
Optical reference

- Manually delineated optically visible reconstruction area

Interpretation and role of geology

- VHR optical evidence helps assign physical meaning to persistent SAR anomalies.
- MTA geological maps are used as contextual layers, not as direct inputs to the SAR anomaly model.
- Representative cases show a recurring contrast: rebuilding/temporary settlements often remain on alluvial areas, while some new developments occur on more consolidated units.
- Interpretation remains exploratory; future work should quantify recovery density across lithological units.

Nurdağı – reconstruction area interpreted with geological context

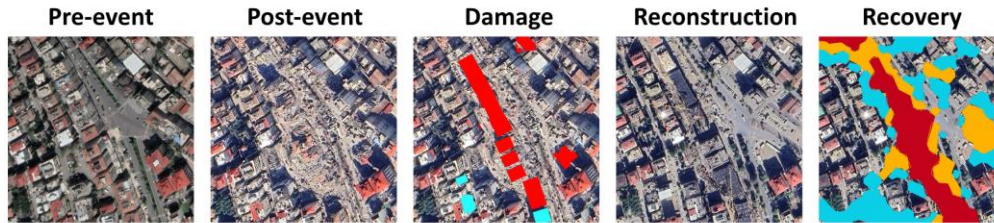


Geology does not drive the recovery map directly; it supports interpretation of where persistent reconstruction-related patterns emerge.

Phase 2 – Recovery Monitoring: Interpretation & Validation (2/2)



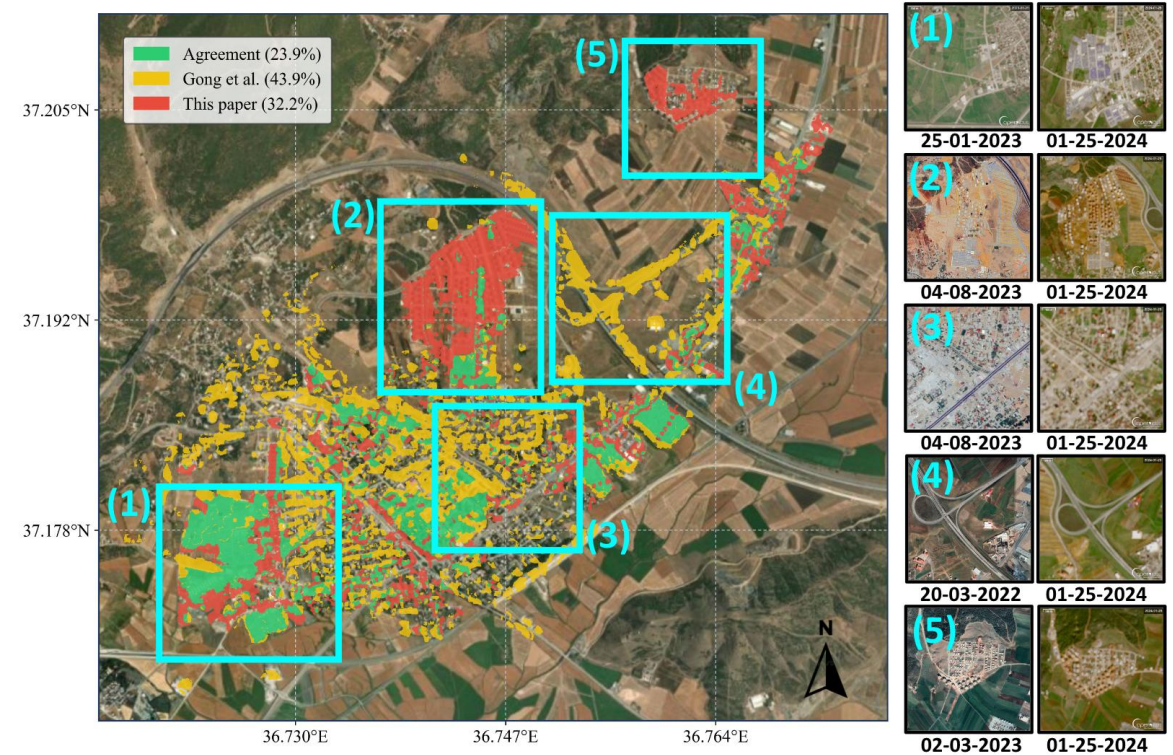
Independent visual evidence through drone imagery



Independent post-event evidence



Complementarity with NTL-based products from [4]



Local overlap assessment — LOCO outputs

87.2%
SAR agreement

65.7%
Optical coverage

59.9%
IoU

Operational interpretation

- ◆ SAR → physical/structural transformations
- ◆ NTL → nighttime activity / electricity restoration

High-resolution SAR highlights persistent change patterns, while optical and NTL observations provide complementary evidence for their physical and functional interpretation.

Phase 2 – Recovery Monitoring: Operational Lessons



- **Systematic, temporally consistent high-resolution SAR acquisitions** are a key enabler for monitoring recovery beyond emergency response.
- **Unsupervised SAR time-series analysis is operationally relevant** when recovery labels are unavailable, enabling monitoring of candidate physical transformations without labelled recovery data.

EO acquisition requirements

EO requirement	Operational implication
High spatial resolution	Resolve construction-scale physical changes
Consistent SAR geometry and acquisition mode	Preserve comparability across the time series
Regular post-event acquisitions	Improve temporal attribution of recovery-related changes
Long-term coverage	Extend monitoring from response into recovery

From research prototype to operational uptake

Status: research prototype – further validation is required

Needed for operational uptake:

- **standardized recovery reference datasets** and uncertainty assessment
- **denser and more regular SAR time series** for temporal attribution
- **multi-event and cross-region validation**
- **institutional end-user engagement** to define validation and service requirements

Sensor	Role in this study
SAR	Physical surface / structural change signals
Optical	Semantic interpretation / local validation
NTL	External functional recovery indicator

CEOS opportunity: extend coordinated EO acquisition strategies beyond rapid response to support systematic recovery monitoring.

- [1] L. Russo, D. Tapete, S. L. Ullo and P. Gamba, "A Deep Learning Framework for Building Damage Assessment Using VHR SAR and Geospatial Data: Demonstration on the 2023 Türkiye Earthquake," in *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 19, pp. 1054-1070, 2026, doi: 10.1109/JSTARS.2025.3637588.
- [2] Russo, L., Tapete, D., Ullo, S. L., & Gamba, P. (2026). Monitoring Post-Disaster Urban Recovery Using High-Resolution SAR Time Series and Unsupervised Learning: Evidence from the 2023 Türkiye - Syria Earthquake. *arXiv preprint arXiv:2607.24180*.
- [3] Yepes-Estrada, C., Calderon, A., Costa, C., Crowley, H., Dabbeek, J., Hoyos, M. C., Martins, L., Paul, N., Rao, A., & Silva, V. (2023). Global building exposure model for earthquake risk assessment. *Earthquake Spectra*, 39(4), 2212–2235. <https://doi.org/10.1177/87552930231194048>
- [4] Gong, Y., Li, X., Li, D., & Zhang, X. (2025). Urban recovery patterns after the 2023 Turkey-Syria earthquake revealed by SDGSAT-1 nighttime light data. *Remote Sensing of Environment*, 328, 114888. <https://doi.org/10.1016/j.rse.2025.114888>
- [5] Sun, Y., Wang, Y., & Eineder, M. (2024). QuickQuakeBuildings: Post-Earthquake SAR-Optical Dataset for Quick Damaged-Building Detection. *IEEE Geoscience and Remote Sensing Letters*, 21, 1–5. <https://doi.org/10.1109/LGRS.2024.3406966>

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THANK YOU FOR THE ATTENTION

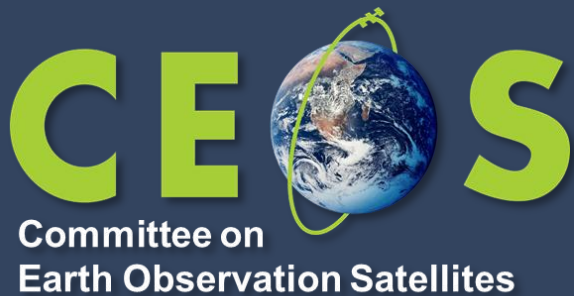
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