

1. ABSTRACT

Landslide inventories are essential for disaster risk management, but their activity information may become outdated as slope conditions evolve. This study presents a reproducible workflow for assessing slow-moving landslides potentially affecting road corridors by integrating multi-mission Persistent Scatterer Interferometry (PSI), terrain information and existing landslide inventories.

Landslide polygons are screened according to Persistent Scatterer coverage and satellite-to-slope geometric compatibility. For each eligible polygon, mean and peak Line-of-Sight (LoS) velocities are estimated and related to the downslope direction. An R-index filter separates geometrically unobservable slopes from landslides showing no significant deformation, preventing misleading inactive classifications. Activity and intensity indicators are then derived using sensor-specific thresholds, while corroboration across independent products supports the prioritization of active/reactivated landslide candidates for further inspection.

The workflow was tested along the SS65 “della Futa” road corridor in Tuscany using eight ascending and descending PSI products from Sentinel-1, COSMO-SkyMed and SAOCOM, accessed through the IRIDE Lot 2 Living Lab. Results highlight the complementary contribution of C-, X- and L-band observations, the influence of acquisition geometry and the different roles of mean and peak velocity indicators.

2. BACKGROUND

OPERATIONAL NEED

Landslides can disrupt road-service continuity, increase maintenance costs and threaten road users.

Infrastructure managers therefore need updated evidence to identify road sections affected by active or potentially reactivating slope processes and to prioritize surveillance and mitigation measures.

However, the activity information contained in existing landslide inventories may not reflect recent changes in slope behavior.

SCIENTIFIC BASIS

PSI-based methods provide a consolidated framework for updating pre-mapped slow-moving landslides.

They use Persistent Scatterer velocities within landslide polygons to derive representative deformation indicators and support activity and intensity classification.

Previous studies have also demonstrated the importance of PS coverage, land cover and satellite acquisition geometry.

REMAINING CHALLENGE

Operational applications must distinguish between:

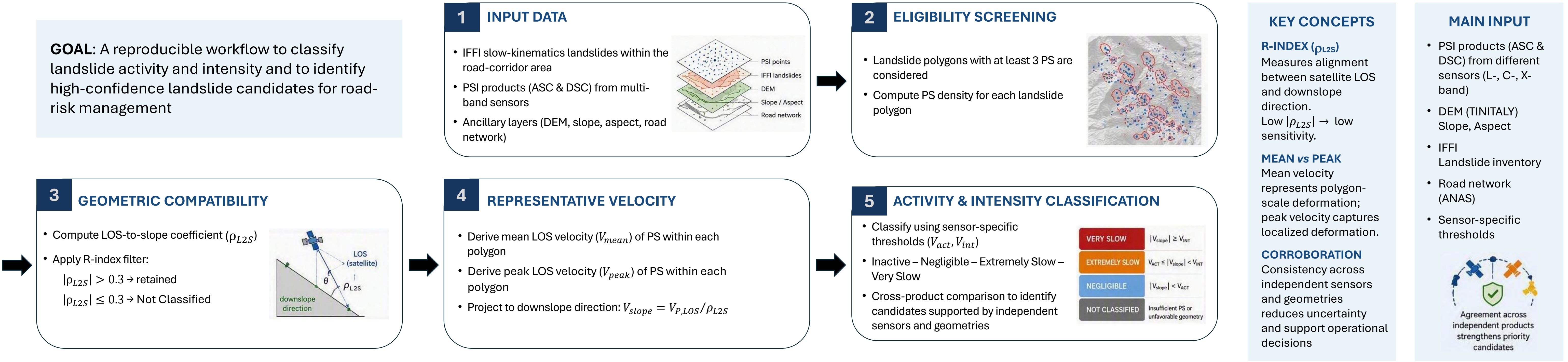
- absence of significant deformation and
- insufficient satellite sensitivity to the expected movement direction.

They must also account for complementary sensor capabilities and for localized deformation that may be masked by polygon-averaged velocities.

A geometry-aware, multi-mission approach is therefore needed for reliable road-corridor screening.

STATIC INVENTORIES + MULTI-MISSION PSI → UPDATED EVIDENCE FOR ROAD-NETWORK RISK SCREENING

3. METHODOLOGY



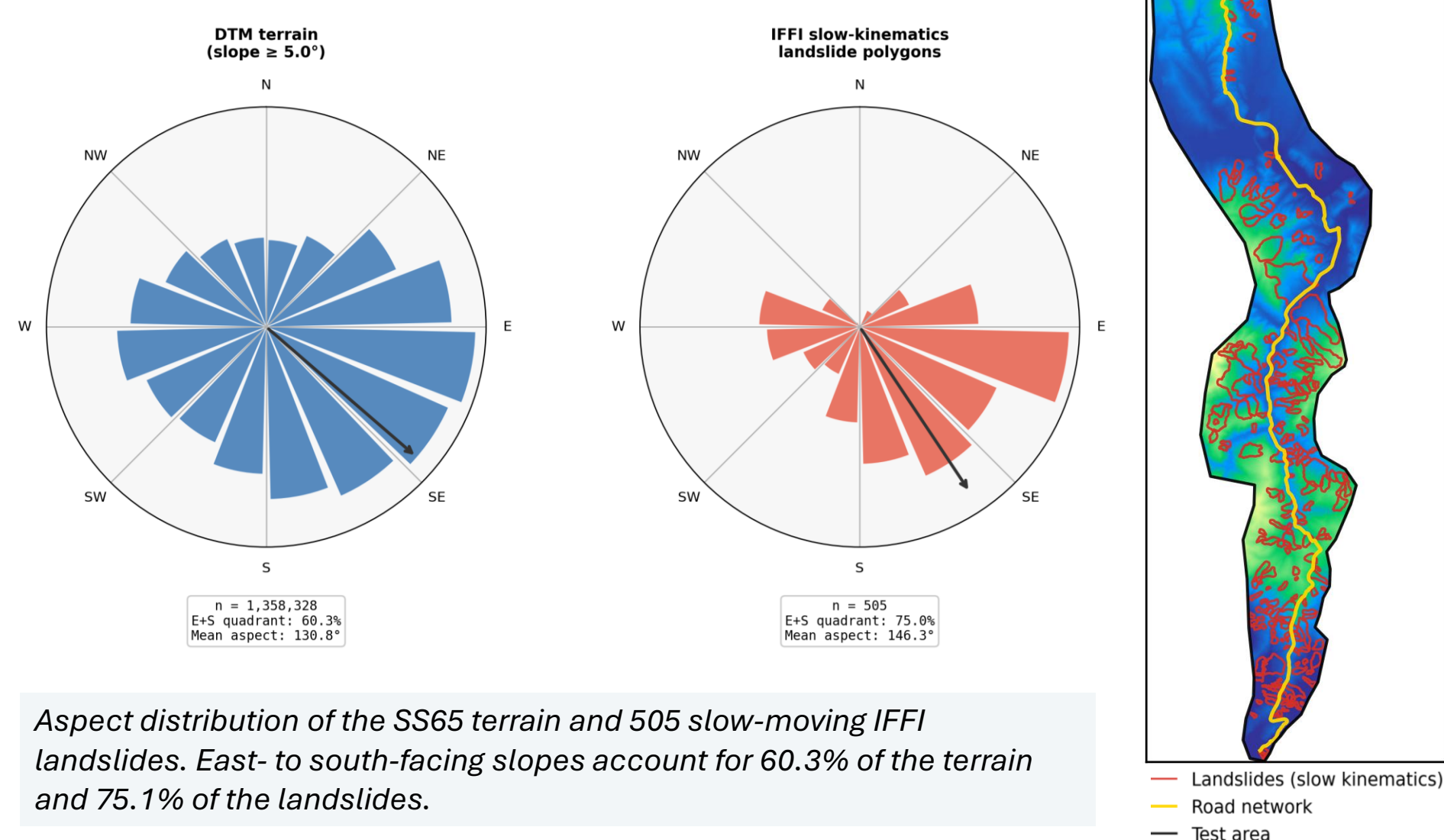
4. TEST APPLICATION: SS65 ROAD CORRIDOR

The test application covers an area along the SS65 “della Futa”, a state road managed by ANAS connecting Florence and Bologna across the Northern Apennines.

The corridor is characterized by complex geological conditions, widespread slope instability and a high density of slow-moving landslides.

Within the selected study area, 505 slow-kinematics landslide polygons were identified from the IFFI (*Inventario dei Fenomeni Franosi in Italia*) inventory.

The prevailing ESE-SSE orientation generally favors descending geometries along this corridor.



PSI DATASET OVERVIEW

8 PSI PRODUCTS ASC + DSC GEOMETRIES 2018-2024 OBSERVATION PERIOD

SENTINEL-1

C-BAND

SAOCOM

L-BAND

COSMO-SKYMED

X-BAND

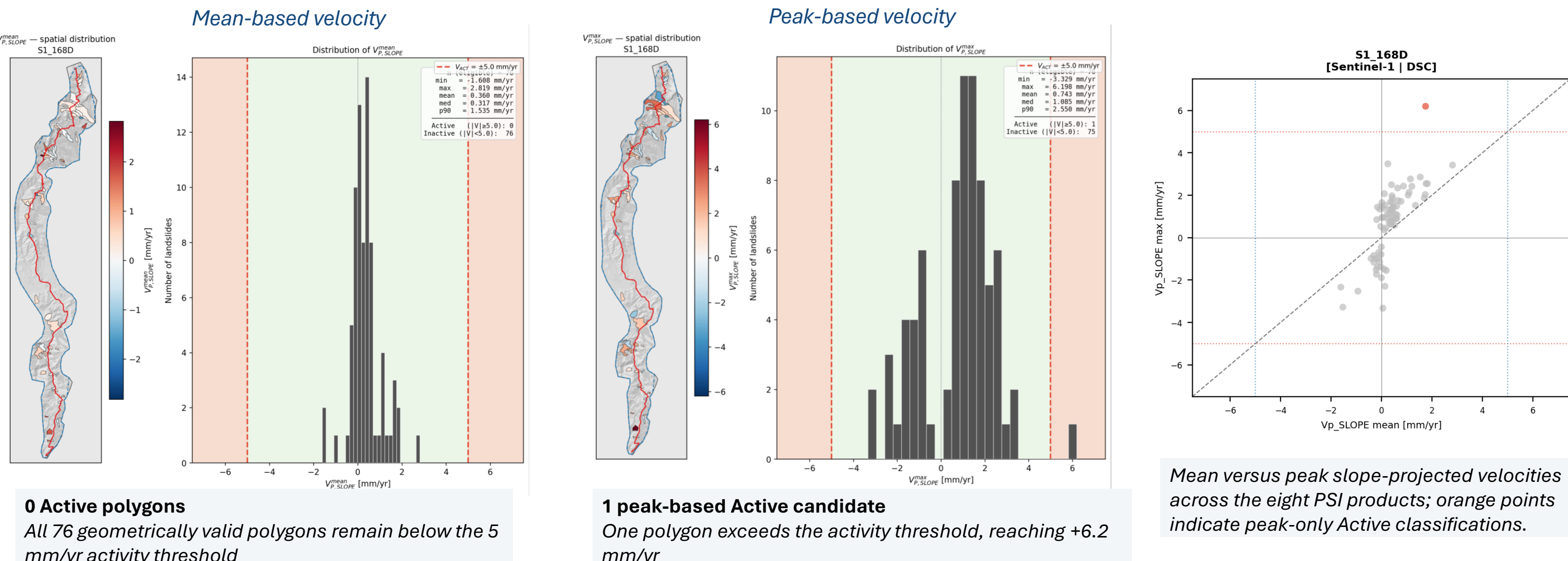
Eight single-geometry LOS products processed independently

OBJECTIVE OF THE TEST APPLICATION: Validate the workflow on a real road corridor, compare sensor and acquisition geometries, and **DERIVE TRANSFERABLE GUIDELINES FOR THE ANAS ROAD NETWORK.**

5. RESULTS

REPRESENTATIVE APPLICATION: Sentinel-1 track 168 Descending

S1_168D was selected to illustrate the complete workflow on a representative product covering nearly the entire SS65 test area. Of the 92 landslides meeting the minimum PS coverage requirement, 76 remained classifiable after geometric screening. Mean-based velocities remained below the activity threshold, whereas the peak-based indicator identified one localized Active candidate.



CROSS-PRODUCT SYNTHESIS

The cross-product comparison reveals marked differences in landslide coverage, eligibility and geometric suitability. Within their effective coverage, SAOCOM products achieve the highest eligibility rates, qualifying 66.7-80.5% of mapped landslides. This result highlights the value of L-band observations for sampling the vegetated slopes of the SS65 corridor.

Descending geometries generally retain a larger proportion of geometrically compatible polygons, reflecting their better alignment with the prevailing ESE-SSE slope orientation.

Mean-based classification identifies no Active polygons, providing a conservative measure of spatially distributed deformation. Peak-based classification produces 24 detections corresponding to 20 unique polygons.

SAO_11132D is the most informative individual product for the pilot area, combining broad coverage, 358 eligible landslides, the largest geometrically valid sample (258 polygons) and the highest number of peak-based detections (13).

PSI Product	Orbit	Covered Landslides (n)	Eligible PS ≥ 3 (n)	R-index Excluded (% eligible)	Geometrically Valid (n)	Active mean (n)	Active peak (n)
S1_168D	DSC	503	92	17%	76	0	1
S1_015A	ASC	504	116	28%	84	0	3
SAO_11131D	DSC	12	8	13%	7	0	0
SAO_21333A	ASC	174	140	41%	82	0	2
SAO_11132D	DSC	499	358	28%	258	0	13
CSM_150A_FIR	ASC	85	26	58%	11	0	1
CSM_197D_FIR	DSC	268	72	29%	51	0	2
CSM_150A_PST	ASC	266	60	53%	28	0	2

Cross-product comparison of landslide eligibility, geometric compatibility and peak-based activity detections

6. DISCUSSION & CONCLUSIONS

1. SENSOR AND GEOMETRY SELECTION

Sensor suitability is context-dependent. L-band observations provide broader sampling of vegetated landslide surfaces, whereas X-band products offer denser measurements over artificial structures and exposed surfaces. Acquisition geometry must be selected according to local slope orientation, since geometrically unfavorable observations cannot support a reliable activity classification.

2. MEAN AND PEAK INTERPRETATION

Mean- and peak-based indicators provide complementary, not interchangeable, information. Polygon means represent spatially distributed deformation and provide a conservative baseline. Peak values reveal localized activity that may be attenuated by averaging, but are more sensitive to isolated scatterers, internal heterogeneity and potential outliers.

3. FROM DETECTION TO OPERATIONAL PRIORITY

A peak-based Active classification should be treated as a candidate, not as definitive evidence of landslide reactivation. Confidence increases when deformation is supported by independent products with compatible viewing geometries. Priority candidates should then be assessed through PS time-series inspection, ancillary information and targeted field verification.

KEY TAKE-HOME MESSAGES

L-BAND FOR VEGETATED SLOPES SAOCOM maximizes eligibility on vegetated slopes	GEOMETRY IS CRUCIAL DSC geometries are generally more compatible with the ESE-SSE slope orientation of this corridor	R-INDEX FILTER IS ESSENTIAL Distinguishes <i>Not Classified</i> (geometric) from <i>Inactive</i> (no deformation)	MEAN AND PEAK VELOCITY ARE COMPLEMENTARY Distributed vs Localized signal	CORROBORATION BUILDS CONFIDENCE Independent multi-sensor evidence is a key for prioritizing landslide to be verified
--	--	---	--	--

FUTURE WORK

- VALIDATE PRIORITY CANDIDATES**
Inspect PS time-series and spatial distributions, starting from independently corroborated candidates, and compare with field evidence and ANAS event records.
- SCALE UP THE WORKFLOW**
Extend the methodology to the entire ANAS road network in Tuscany, using slope-aspect screening to select the most suitable sensors and acquisition geometries.
- INTEGRATE FOR ROAD-RISK PRIORITIZATION**
Combine landslide activity and intensity with road exposure, infrastructure criticality and traffic importance to support mitigation planning.

REFERENCES

- Cigna, F., Bianchini, S., & Casagli, N. (2013). How to assess landslide activity and intensity with Persistent Scatterer Interferometry: the PSI-based matrix approach. *Landslides*, 10, 267-283.
- Confuorto, P., et al. (2023). Sentinel-1 P-SBAS data for the update of the state of activity of national landslide inventory maps. *Landslides*, 20, 1083-1097.
- Notti, D., et al. (2014). A methodology for improving landslide PSI data analysis. *International Journal of Remote Sensing*, 35(6), 2186-2214.
- Rosi, A., et al. (2018). The new landslide inventory of Tuscany updated with PS-InSAR. *Landslides*, 15(1), 5-19.
- Solari, L., et al. (2020). Satellite interferometric data for landslide intensity evaluation in mountainous regions. *International Journal of Applied Earth Observation and Geoinformation*, 87, 102028.
- Data: ISPR-PAFFI; TINITALY/01; IRIDE Lot 2 Living Lab PSI products.

ACKNOWLEDGEMENT

This research was carried out during C. Lanni's internship at the Italian Space Agency (ASI), under the supervision of D. Tapete, within the Second-Level Master's Programme in Space Science and Technology at the University of Rome Tor Vergata, Italy. ANAS S.p.A. is acknowledged for providing the operational context for applying the methodology to road-corridor landslide monitoring.

The PSI data were accessed through the IRIDE Lot 2 Living Lab, developed by e-GEOS S.p.A. under the IRIDE Precursor Service Segment implementation. The IRIDE Programme is managed by the European Space Agency (ESA), with the support of ASI, and funded through the National Recovery and Resilience Plan (PNRR) and the National Complementary Plan (PNC).