

Enhancing InSAR Reliability for Slope Hazard Management with Landslide Sensitivity Index

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Over the past decade, the proliferation of open-source data from the Sentinel-1 constellation has significantly broadened the global capacity for continuous terrain monitoring. Concurrently, the L-band SAR capabilities of Japan's ALOS-2 satellite have opened new possibilities for monitoring mountainous landslide hazards due to its superior vegetation penetration. Looking forward, the upcoming NISAR mission, featuring dual-frequency S-band and L-band sensors, holds immense potential for high-resolution geohazard observation. In alignment with these technological advancements, the Agency of Rural Development and Soil and Water Conservation (ARDSWC) in Taiwan has collaborated with various institutional partners to conduct extensive pilot projects, integrating Interferometric Synthetic Aperture Radar (InSAR) into slope stability management frameworks. Despite the power of InSAR in overcoming the spatial and safety limitations of traditional in-situ measurements, its efficacy remains highly dependent on the satellite's acquisition geometry relative to the actual downslope deformation. To address this, the InSAR Landslide Sensitivity Index (SIDX) is introduced as a critical metric for evaluating the viability of InSAR observations. Ranging from 0 to 1, SIDX is calculated by projecting the theoretical downslope displacement vector onto the satellite's line-of-sight (LOS), integrating Digital Elevation Model (DEM) derived topography with SAR geometric parameters. This presentation explores the dual application of SIDX as both an a priori assessment tool and a post-analysis validation instrument. In the planning phase, SIDX allows engineers to rapidly evaluate InSAR potential, preventing the misallocation of computational resources on slopes obscured by radar shadow, layover, or poor geometric alignment. In the post-analysis stage, SIDX serves as an essential reference; by comparing observed displacement with theoretical sensitivity, analysts can discern whether a lack

of detected movement signifies slope stability or "geometric blindness." Furthermore, we demonstrate that utilizing high-resolution DEMs (e.g., 1m resolution) yields a more precise SIDX evaluation, identifying viable scattering points on micro-topography that are often overlooked by 30m global DEMs. Ultimately, the integration of SIDX enhances the reliability and efficiency of InSAR-based landslide hazard management for both historical archives and future missions.



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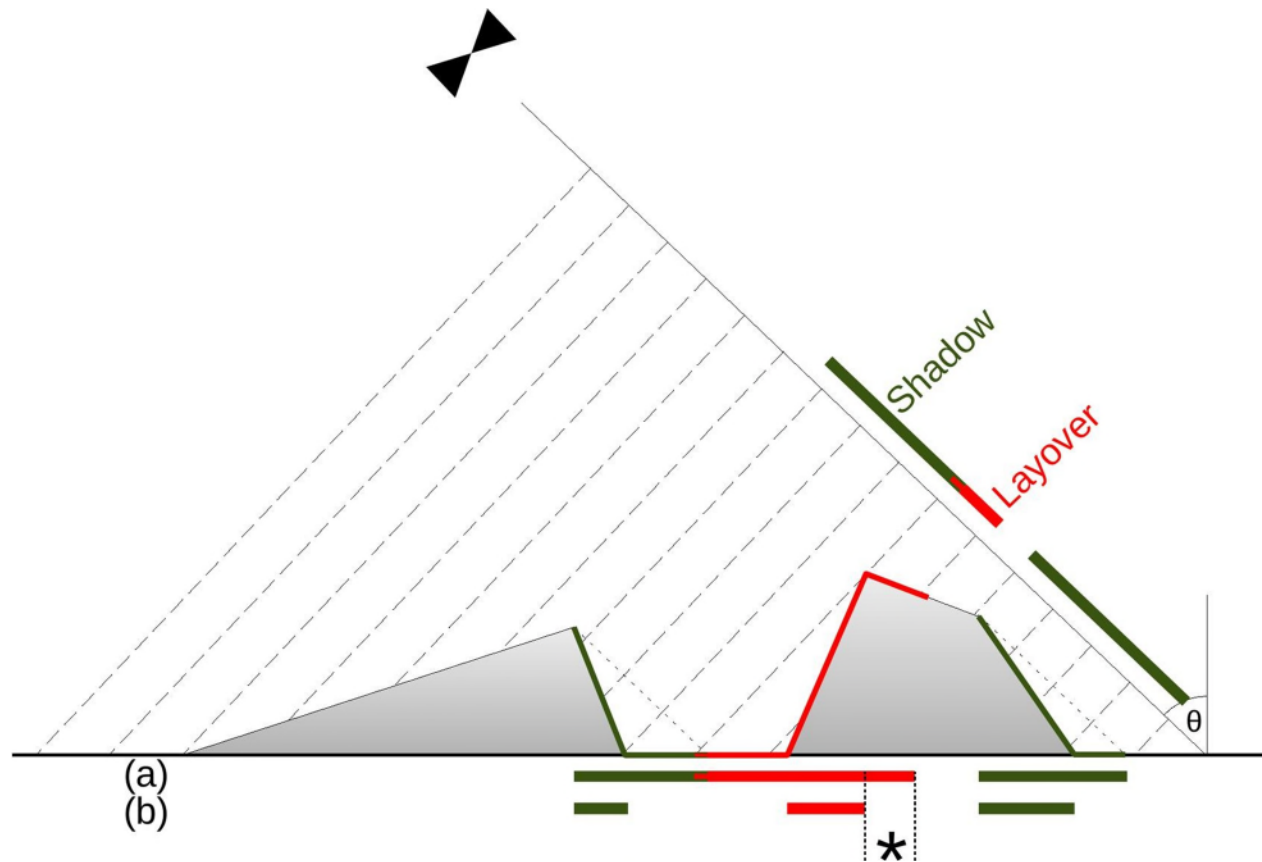
Agency of Rural Development and Soil and Water Conservation,
Ministry of Agriculture, Taiwan.



Outlines

- Why InSAR Can Fail on Active Slopes
- The Interpretation Risk
- What is Landslide Sensitivity Index(SIDX)
- SIDX On BigGIS
- Examples with High Resolution SIDX

Why InSAR Can Fail on Active Slopes



(van Naticjine et al. 2022)

- InSAR measures displacement along the line of sight.
- True landslide movement is usually downslope, not LOS-aligned.
- Shadow and layover can block meaningful observation.
- A moving slope can therefore produce a weak or missing InSAR signal.
- Vegetation
- Unstable slope surface characteristic



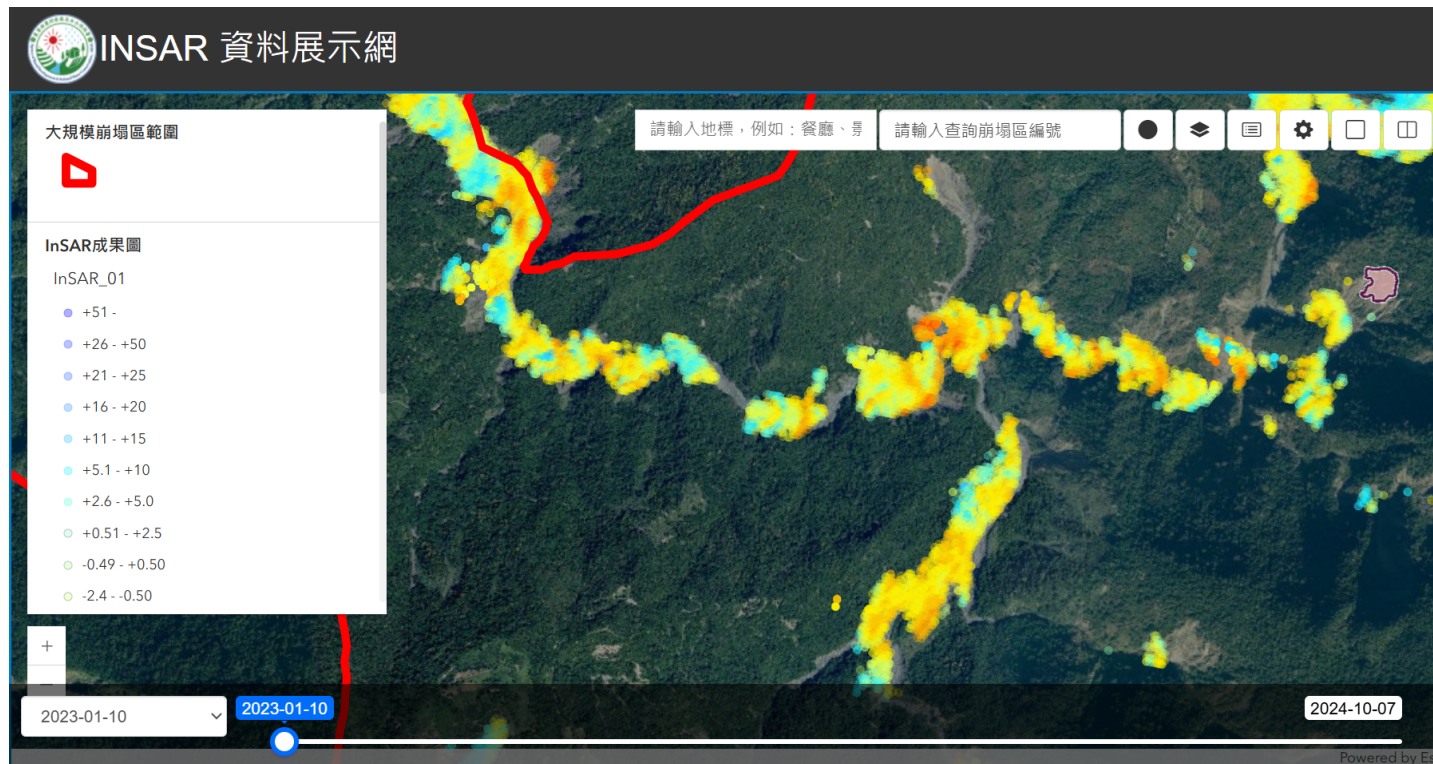
The Interpretation Risk

Weak or absent displacement can mean several different things.

It may indicate:

- real stability
- motion below the detection limit
- poor observation geometry

Without a detectability indicator, null results are easy to over-interpret.



<https://ls.ardswc.gov.tw/static/insar.html>

InSAR data:

Contracted Projects with Dr. Chen, R.-F. (National Taipei University of Technology)



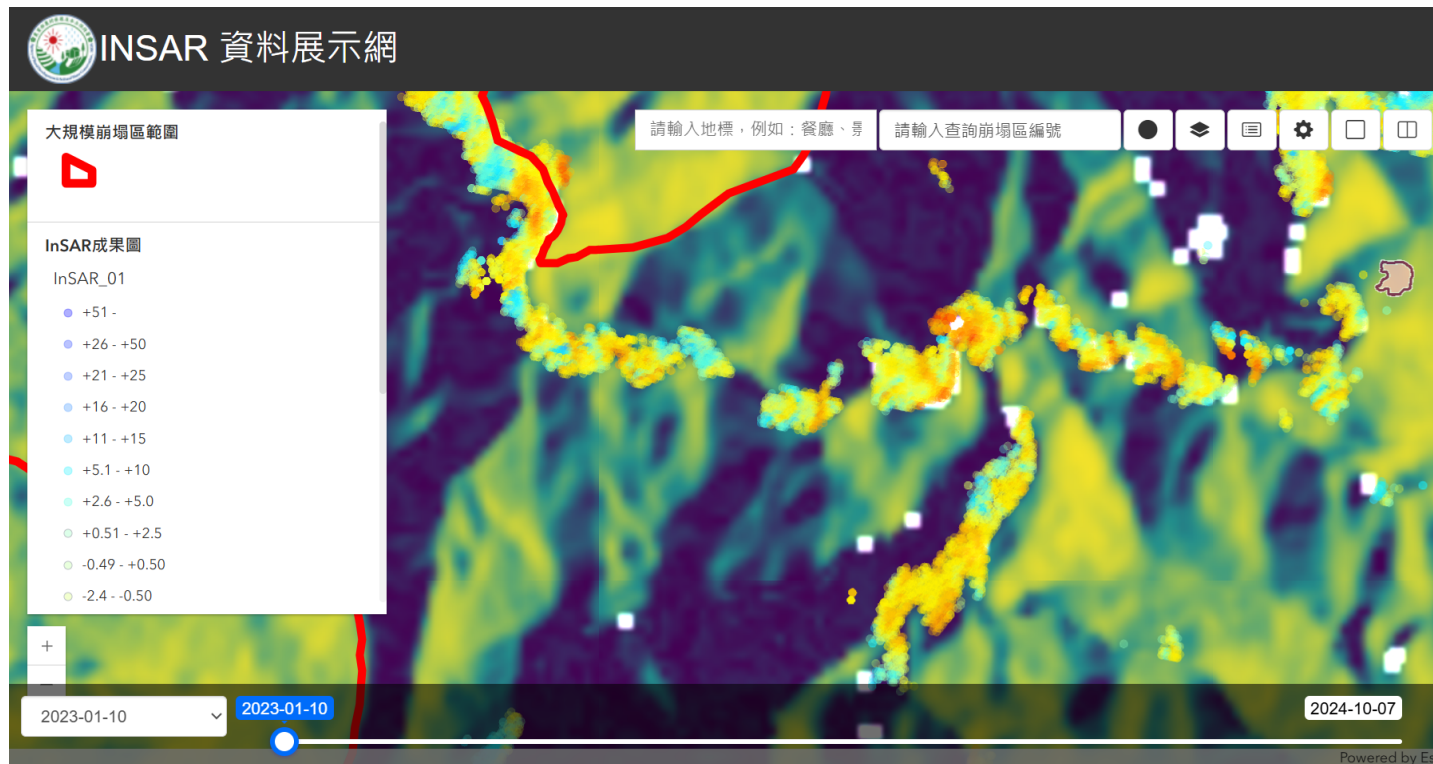
The Interpretation Risk

Weak or absent displacement can mean several different things.

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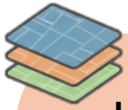
- real stability
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<https://ls.ardswc.gov.tw/static/insar.html>

What is Landslide Sensitivity Index(SIDX)



Layer Description:

Slope Deformation InSAR Sensitivity Index(InSAR Landslide Sensitivity Index, SIDX) is a function derived from the Digital Elevation Model (DEM)'s aspect (α) and slope (β), and SAR satellite measurement geometry's Line-Of-Sight(LOS)'s incidence angle (θ) and effective azimuth ($\gamma'(\phi)$) combined function:

$$s(\alpha, \beta, \theta, \phi) = |\sin(\beta) \cos(\theta) + \sin(\theta) \sin(\alpha - \gamma'(\phi)) \cos(\beta)|$$

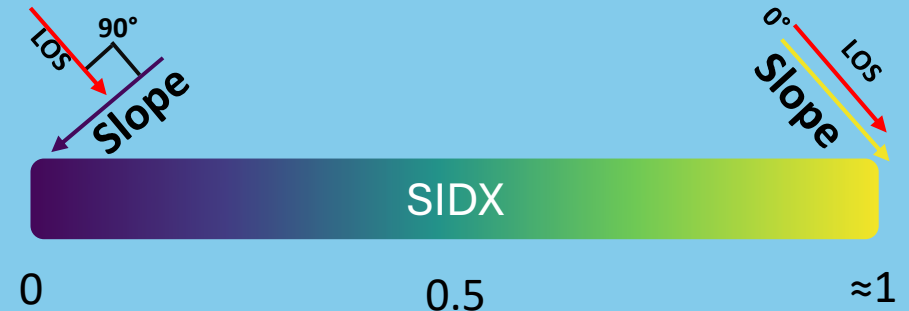
Its physical meaning is the projection of the downslope unit vector onto the LOS unit vector, which can be used to predict whether InSAR measurement geometry is sensitive to a specific slope surface unit.



This layer is from van Natijne et al. (2022), computed using the European Space Agency (ESA)'s Copernicus mission data.

Satellite Parameters	ESA Copernicus Sentinel-1
Digital Elevation Model	ESA Copernicus DEM GLO-30 (30m)

	BigGIS Corresponding Layers for Taiwan in
1	Sentinel-1 Ascending Track 69 (30m resolution)
2	Sentinel-1 Descending Track 105 (30m resolution)
3	Sentinel-1 Ascending/Descending Max (30m resolution)



Usage Notes:

SIDX ranges from 0 to 1. The smaller the value, the less sensitive the satellite LOS measurement is to downslope motion, meaning InSAR cannot achieve good results on this slope because the downslope displacement projected onto LOS is very small. The closer the value is to 1, the opposite holds, meaning the LOS direction measurement captures a greater portion of downslope displacement.

Notes:

SIDX only uses the measurement geometry relationship between the satellite and terrain morphology. It does not account for surface vegetation, bare ground, or man-made structures.

Original Data:

https://data.4tu.nl/articles/_/14095777

References:

van Natijne AL, Bogaard TA, van Leijen FJ, et al (2022) World-wide InSAR sensitivity index for landslide deformation tracking. International Journal of Applied Earth Observation and Geoinformation 111:102829.
<https://doi.org/10.1016/j.jag.2022.102829>



Global Slope InSAR Monitoring Rapid Assessment Index: SIDX



Traditional Survey Limits
Costly and hazardous; limited to known sites. InSAR enables safe, wide-area monitoring.

WHY Why Is SIDX Needed?



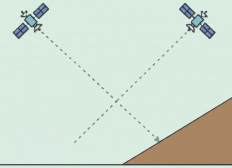
InSAR Pre-Assessment
Evaluate monitoring viability before investing time and resources; also for post-analysis verification.



WHAT What Is SIDX (InSAR Sensitivity Index)?

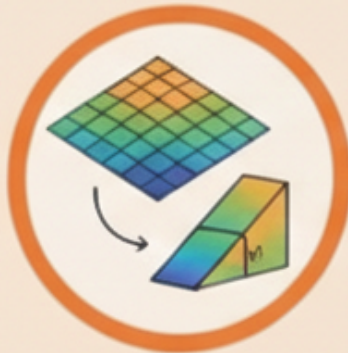


InSAR Landslide Sensitivity Index
A 0-to-1 index assessing InSAR sensitivity to downslope displacement.



Radar + Terrain Geometry
Combines satellite azimuth, incidence angle, terrain orientation, and neighbor effects.

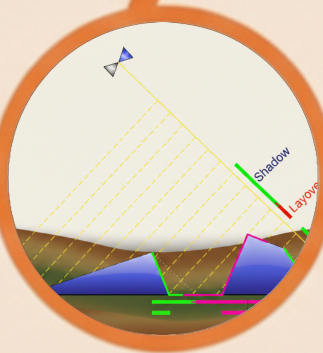
HOW How Is It Calculated?



1. Slope Geometry
Use DEM to calculate slope and aspect per grid cell.



2. Radar Geometry
Incorporate Sentinel-1 orbital parameters and incidence angle.



3. Terrain Effects
Exclude shadow and layover from surrounding terrain.

WHERE

Where Is It Applicable?



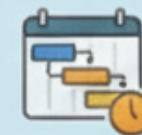
91% of global landslide-prone slopes are monitorable
Combining satellite and terrain geometry data.



WHO & WHEN Who Needs It? When?



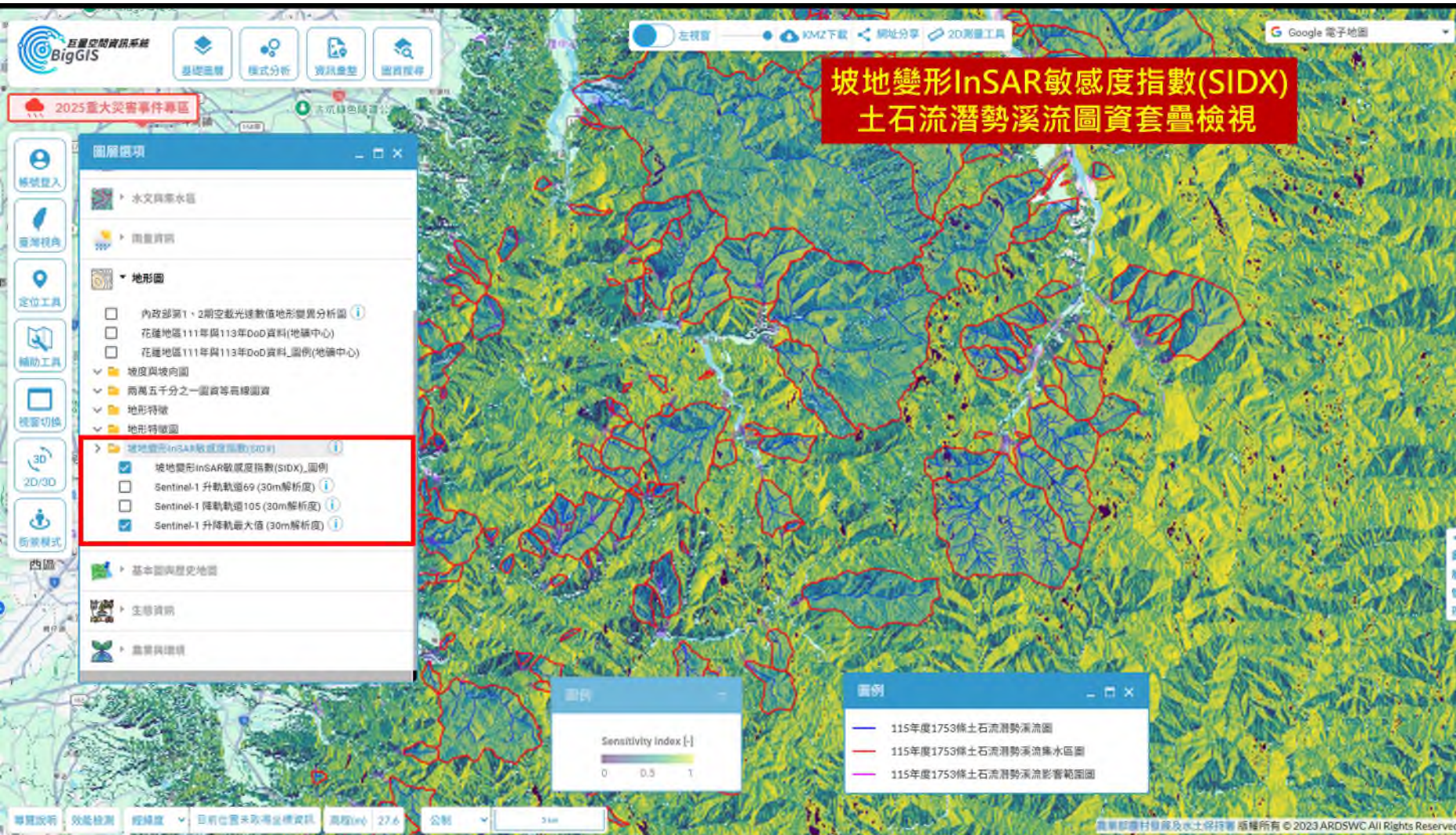
Target Users
Landslide Experts & Slope Engineers
For monitoring planning and satellite data analysis.



When to Use
During InSAR project planning and post-analysis verification.



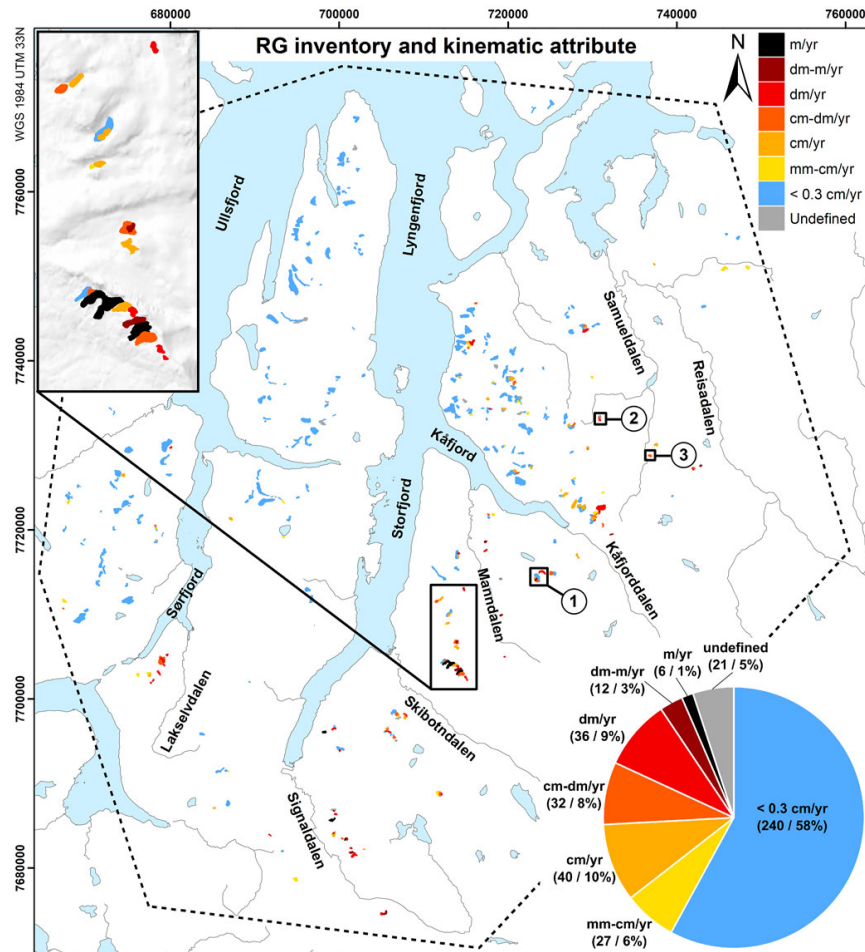
• SIDX on BigGIS



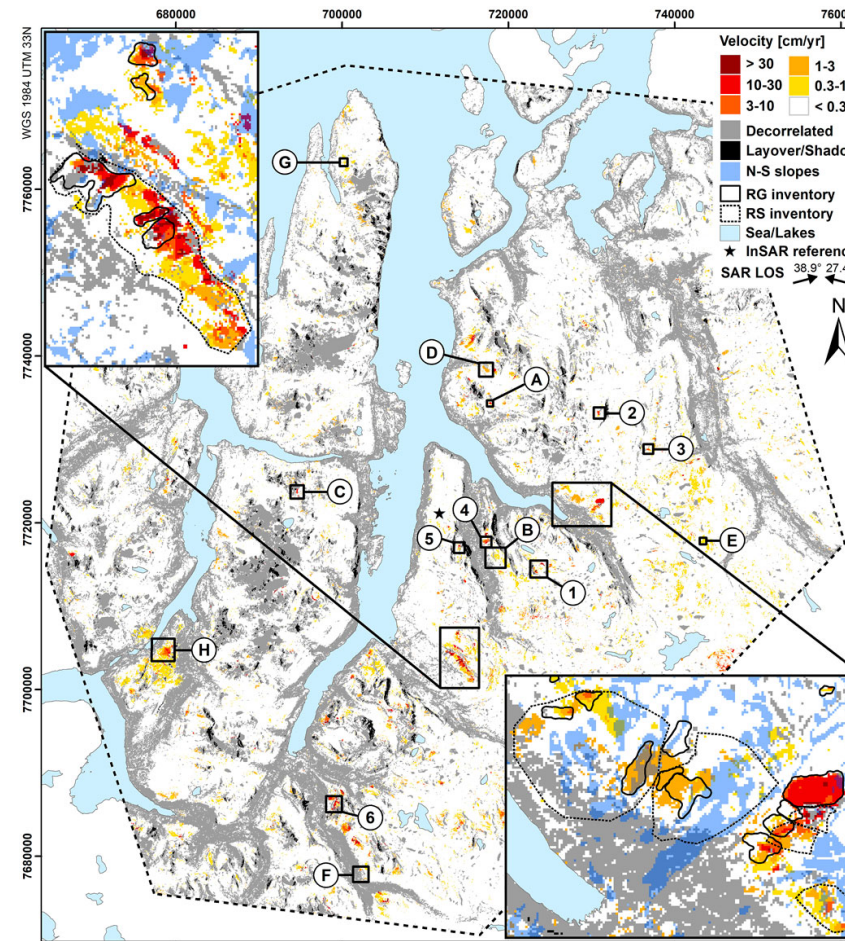
- Users can quickly verify InSAR reliability!



Using InSAR to update landslide category: Norway



Norway Rockslide Category

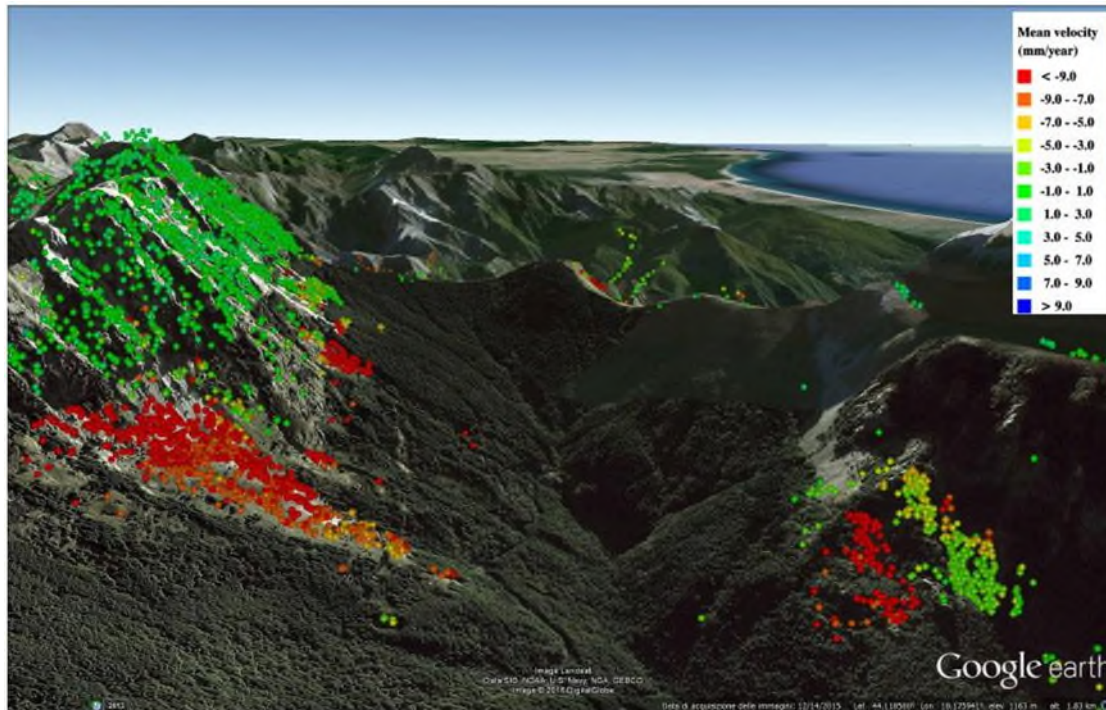


Classified InSAR results

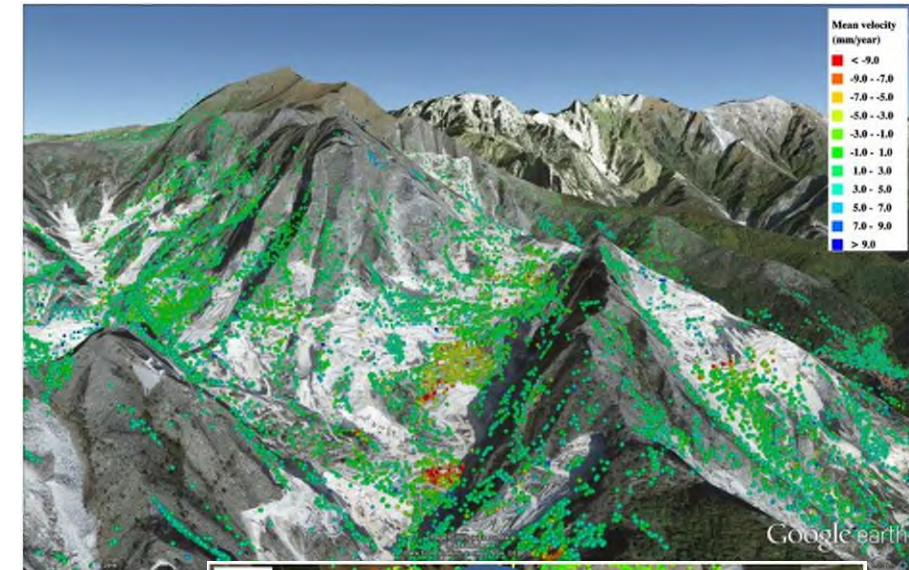
Through InSAR analysis, researchers successfully updated the existing inventories of rock glaciers (RG) and rockslides (RS). Within the study area, 54 newly identified rock glaciers and 20 rockslides were discovered and subsequently integrated into the database.

(Rouyet et al. 2021)

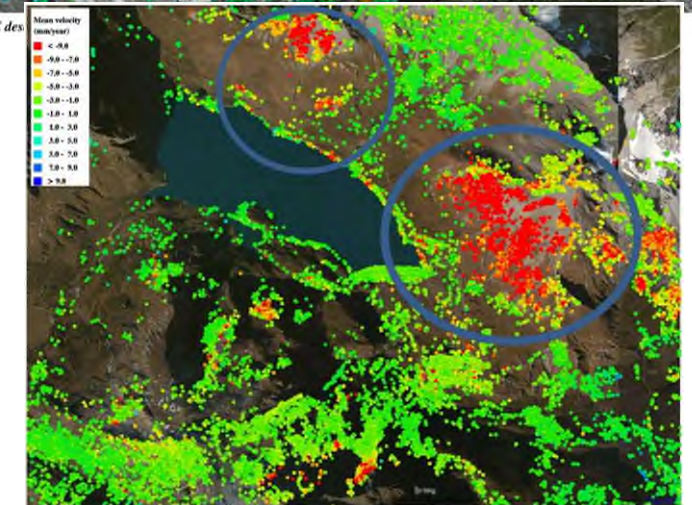
Using InSAR to update landslide category: Italy



COSMO-SkyMed HIMAGE descending (2011-2014)



COSMO-SkyMed HIMAGE descending

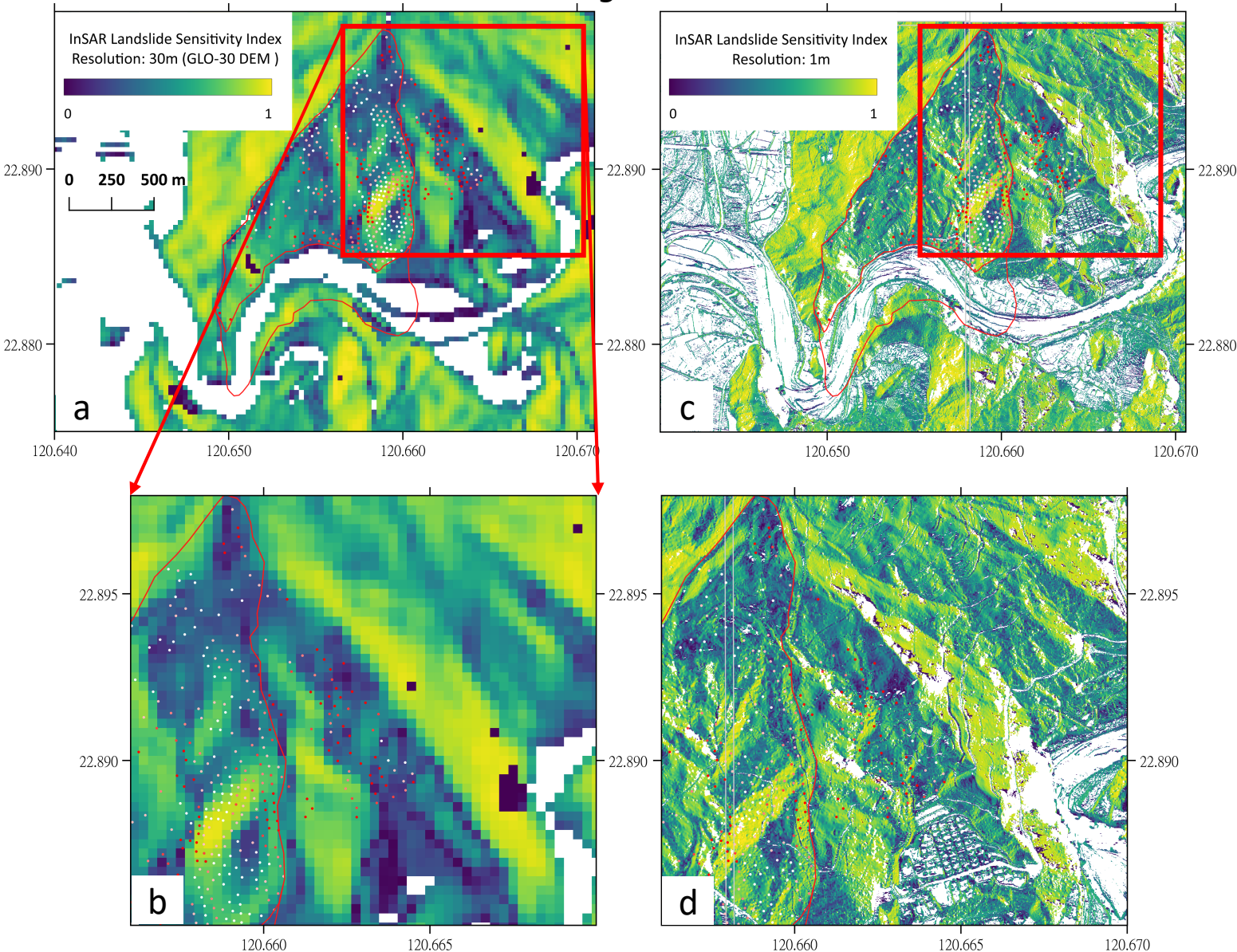


COSMO-SkyMed HIMAGE descending (2011-2014)

Costantini M, Ferretti A, Minati F, et al (2017) Analysis of surface deformations over the whole Italian territory by interferometric processing of ERS, Envisat and COSMO-SkyMed radar data. Remote Sensing of Environment 202:250–275. <https://doi.org/10.1016/j.rse.2017.07.017>

High-Resolution DEM Produces More Realistic SIDX Results

Case: Kaohsiung LL009 (Maolin)



Why Use High-Resolution DEM for SIDX?

While 30m global DEMs produce usable SIDX values, they underestimate terrain variations within each grid cell when finer-scale slope deformations are of interest. The coarser resolution misses small-scale topographic undulations that could provide stable SAR backscatter at meter-level pixel resolution.

Example: Kaohsiung LL009 (Maolin) — Under 30m DEM (Figs. a, b), areas classified as low sensitivity (dark blue) reveal finer terrain variations under 1m DEM (Figs. c, d), showing parts with high InSAR sensitivity for slope displacement detection. This location can indeed produce suitable InSAR reflection points.

Colored points: MT-InSAR products from Agency-commissioned projects.

InSAR data:
Contracted Projects with Dr. Chen, R.-F.
(National Taipei University of Technology)



Conclusions

- **SIDX improves reliability of InSAR-based slope monitoring by making detectability explicit.**
- **It helps distinguish geometric blindness from true stability.**
- **High-resolution DEMs improve slope-scale detectability assessment.**