AFRIROCK 2025

PIONEERING PROGRESS :
THE FUTURE OF ROCK ENGINEERING

Monitoring Mining-Induced Subsidence and Sinkholes Using Multi-Band InSAR: A Case Study from Lubambe Copper Mine

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Sun City South Africa, July 22nd, 2025

Background Information

Lubambe Copper Mine

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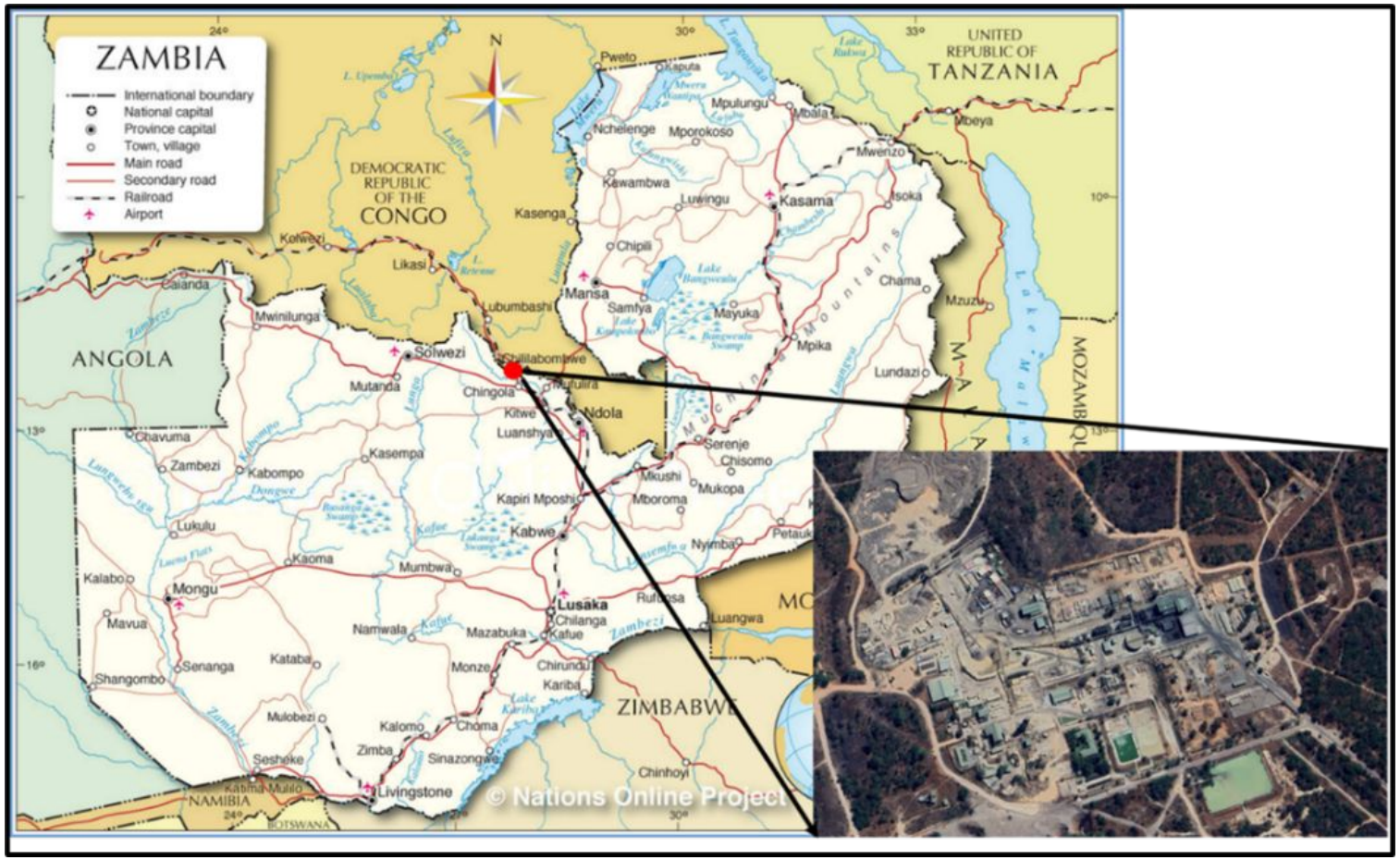
- **Underground Cave Mine** in the Zambian Copperbelt province
- Two main limbs (the south limb and the east limb)
- Mining method has open **unsupported voids** that can lead to rock collapse and surface caving



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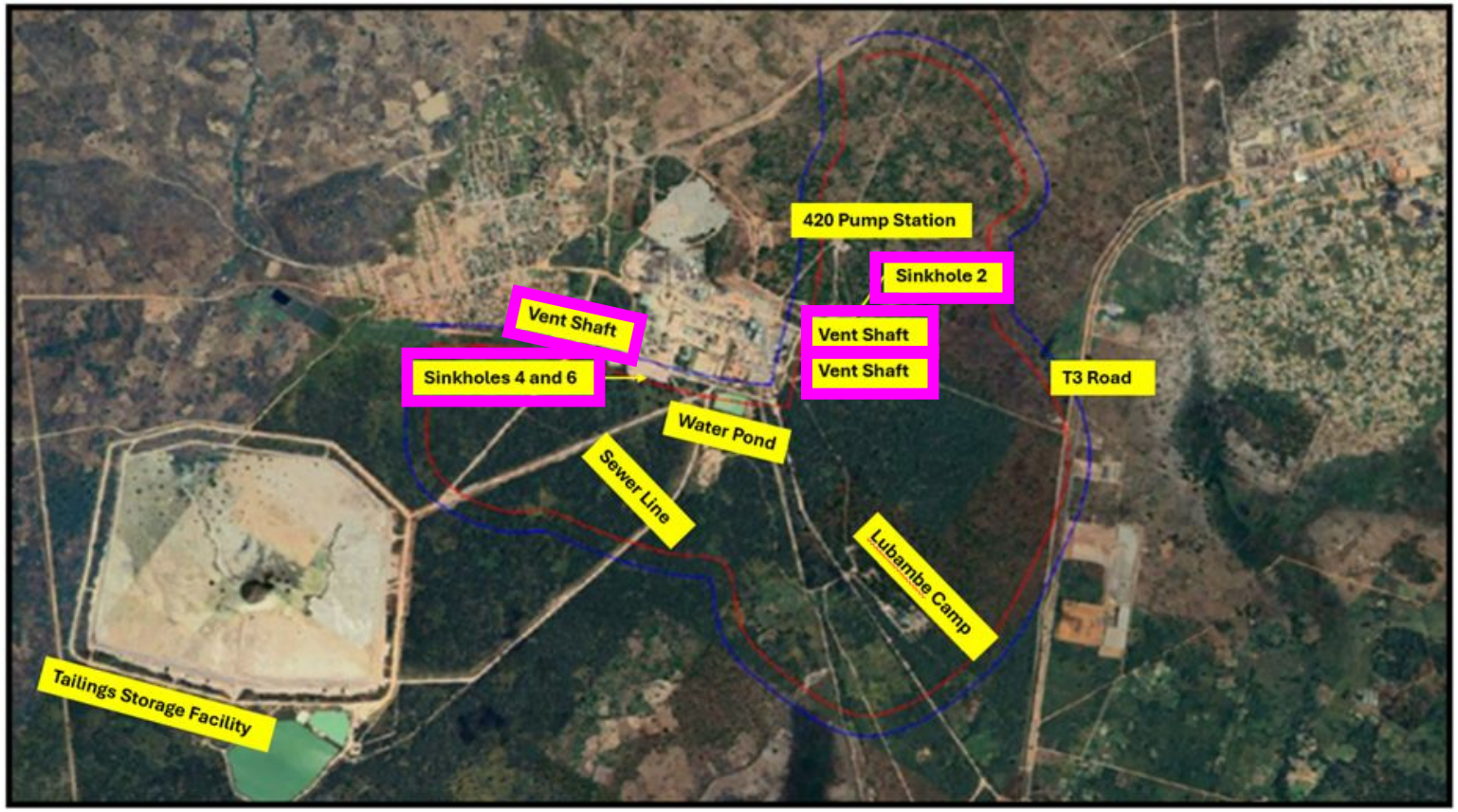
Background Information

- The cave extents lines are represented in red and blue, relevant infrastructure has been labelled in yellow
- **Highest risk areas** are the Vent Shaft and Sinkholes

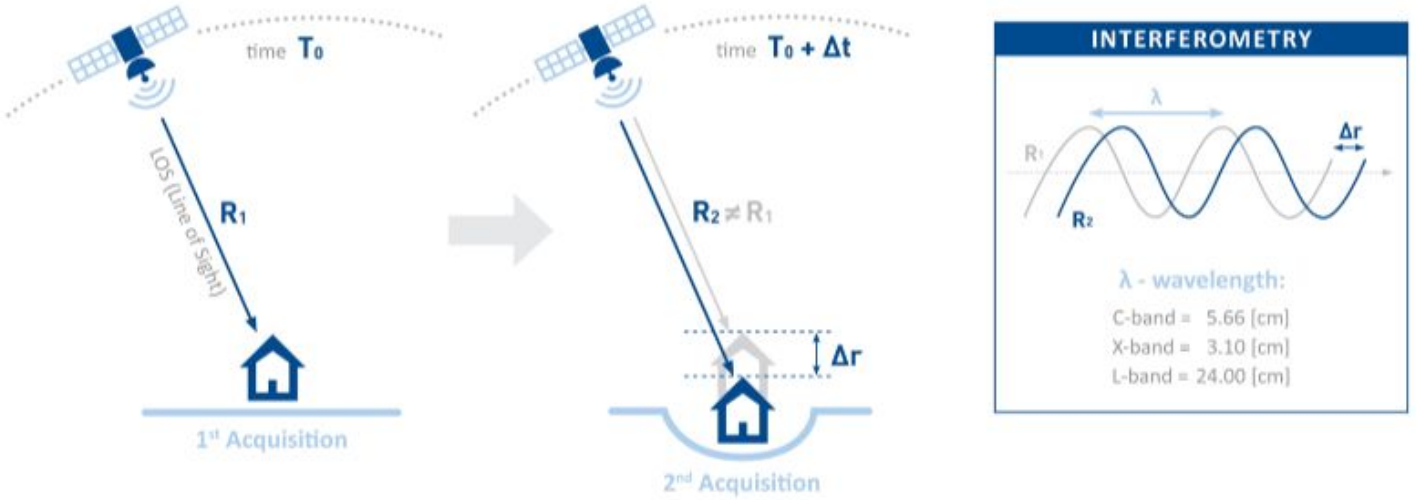


Background Information

- Over the past five years **sinkholes** have been developing near infrastructures
- These have caused **closure** of main access roads and been a **risk** to administrative offices and the mine camp
- **Ground-based monitoring systems** around high-risk areas
- **InSAR monitoring** over the entire site

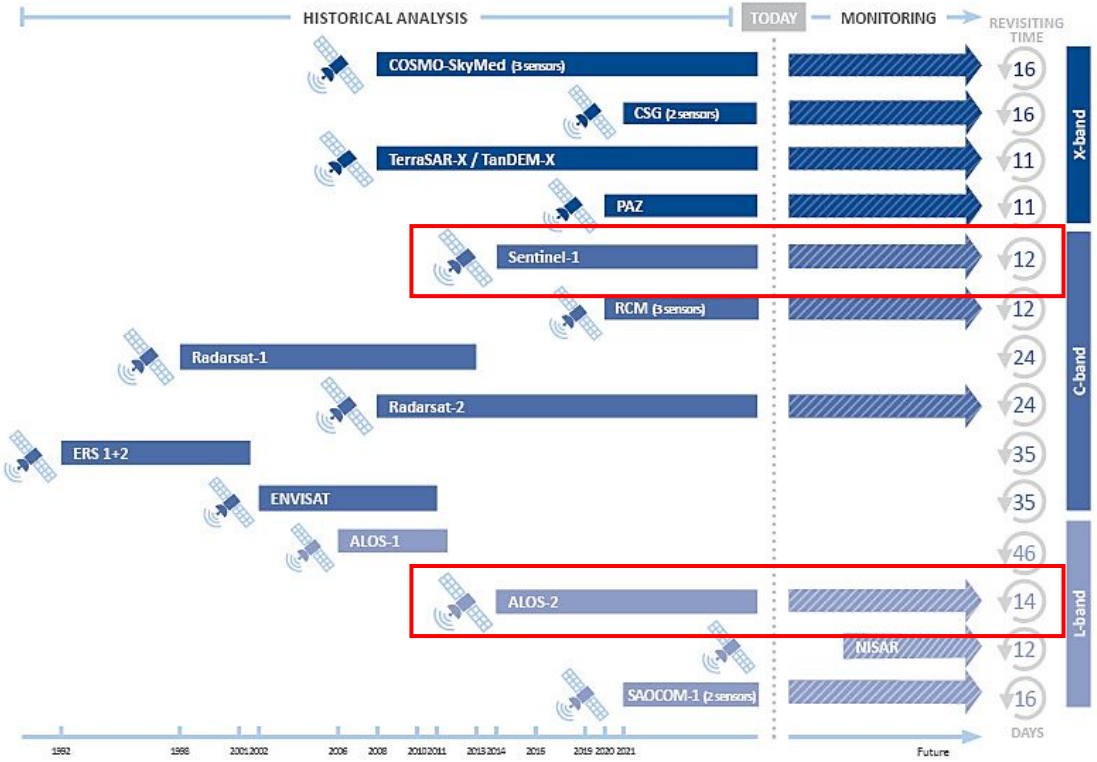
SqueeSAR Technique

- **InSAR** is a remote sensing technique that provides high precision measurements of ground displacement in the form of a point cloud
- By analyzing a stack of SAR images acquired over a site, it identifies and measures the movement of **radar reflectors on the ground surface**



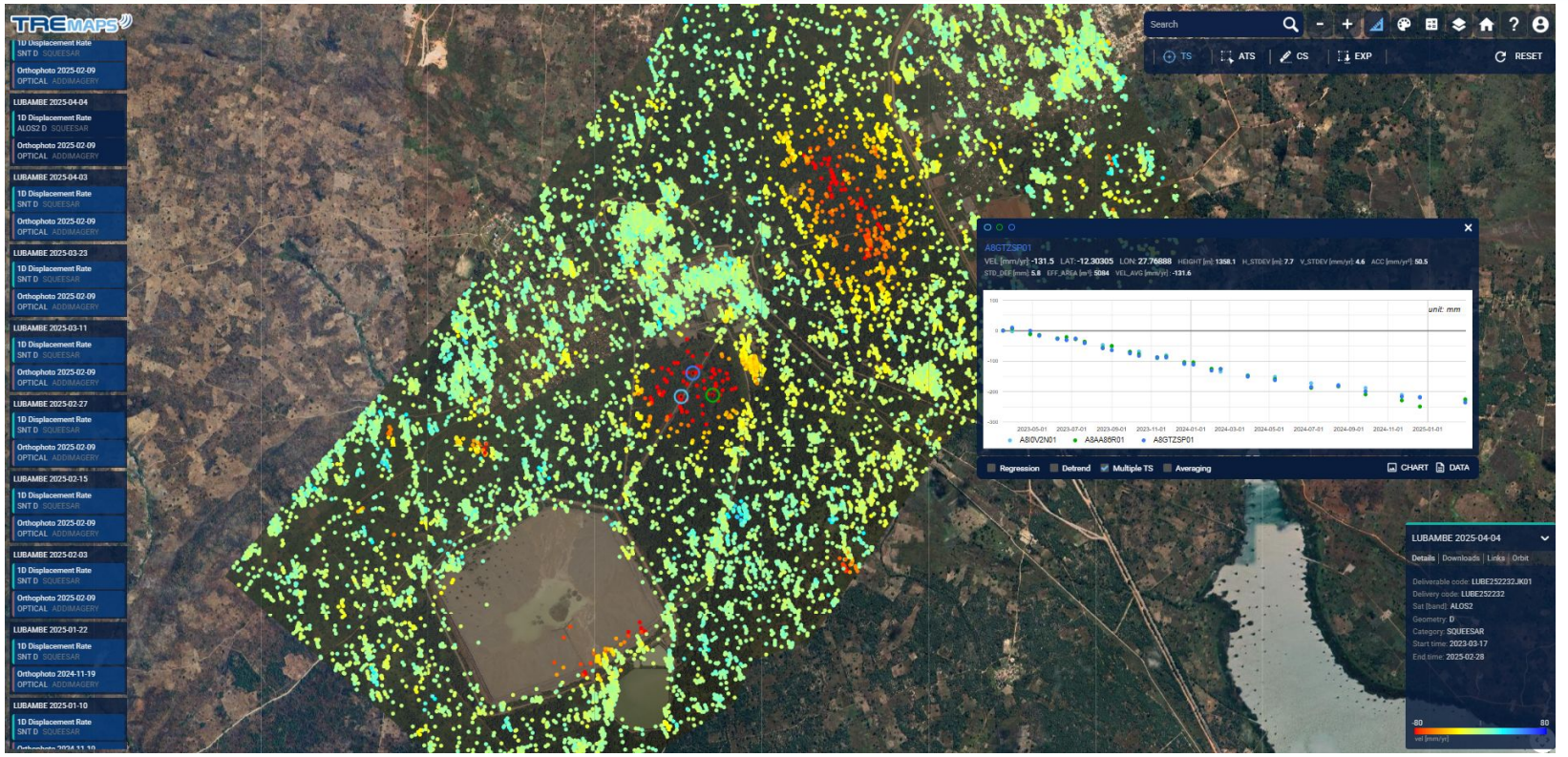
Different satellites for different needs

- **C-Band satellite Sentinel** → higher spatial resolution and sensitivity to small displacements → **focus on the infrastructure**
- **L-Band satellite ALOS-2** → longer wavelength → **greater penetration capacity through vegetation**, but lower sensitivity to small displacements
- Using these two wavelengths together provided **complementary coverage** over the site



Lubambe InSAR Monitoring

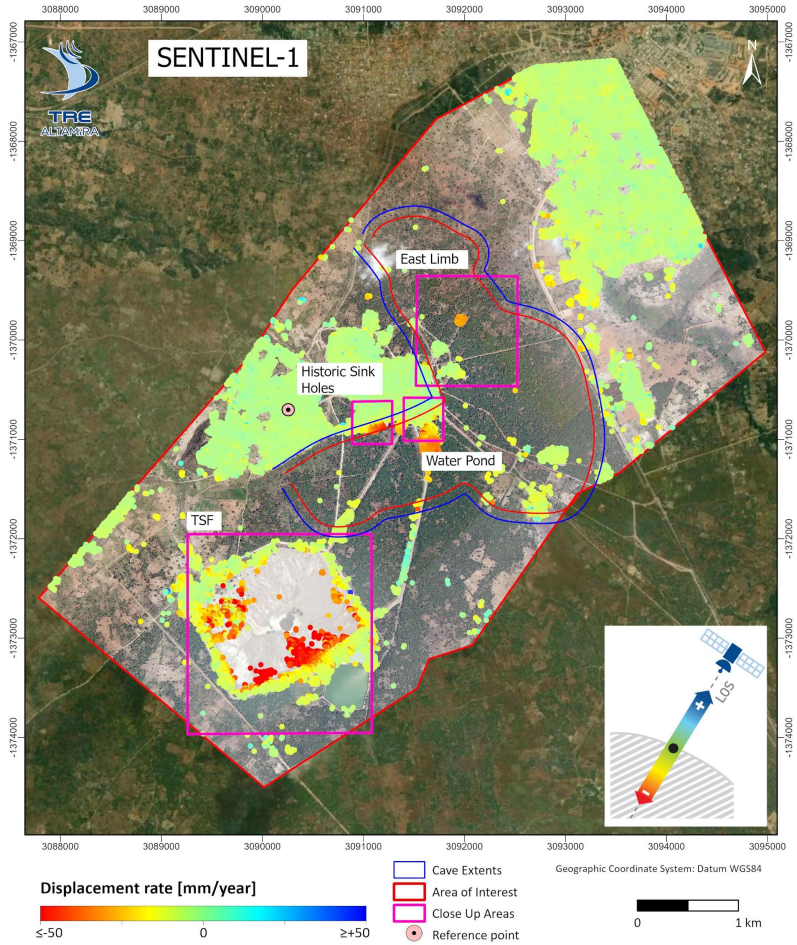
- Monitoring period: Mar 2023 – Feb 2025
- SqueeSAR® analyses of the single geometry datasets (1D measurements)
- **Monitoring Frequency**: SNT (12 days), ALOS (quarterly)
- Monthly data delivery on TREmaps **web-platform**

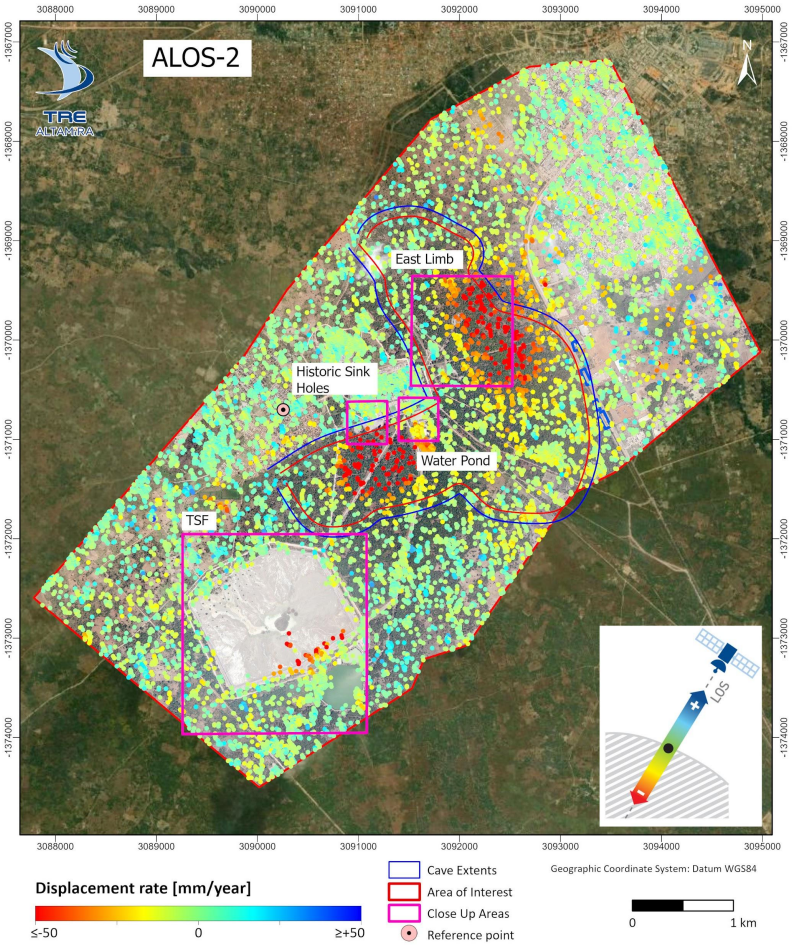


Satellite	Orbit	LOS Angle (°)	Wavelength	Cell Resolution
SNT	Descending	32.4	~5.6 cm	5 x 20 m
ALOS-2	Descending	35.8	~23.6 cm	50 x 15 m

InSAR Overview (C-Band and L-Band)

- Displacement Areas were observed in both datasets (Historic Sink Holes, East Limb, Water Pond)
- Extents of the displacement areas were better observed with the L-Band Dataset
- Largest displacement areas corresponded with observed sinkholes in both datasets





Sinkhole 2

- **Historic open stope located** 35 m below the surface and overlain by weak overburden material with high kaolinite concentrations
- These conditions were further exacerbated by collection of **stormwater and overflows**
- Cause the eventual **collapse** in this area as seen in the photo

Sinkhole 2 – C Band Results

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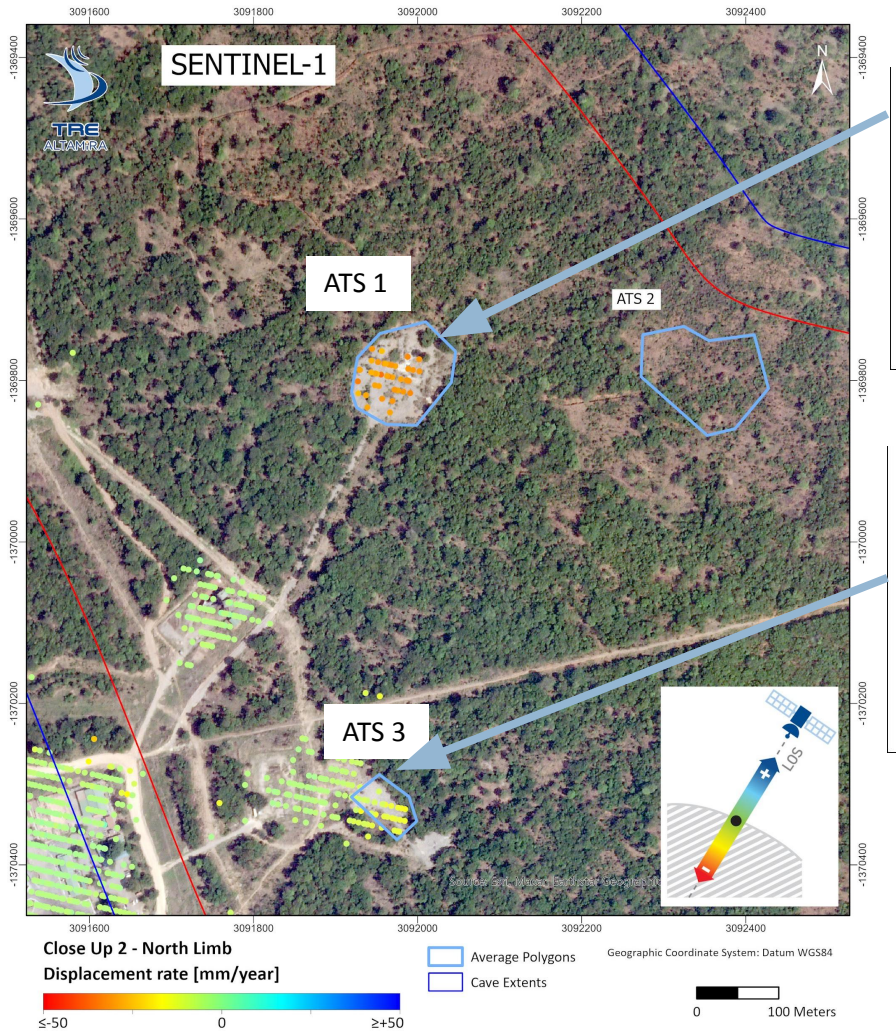
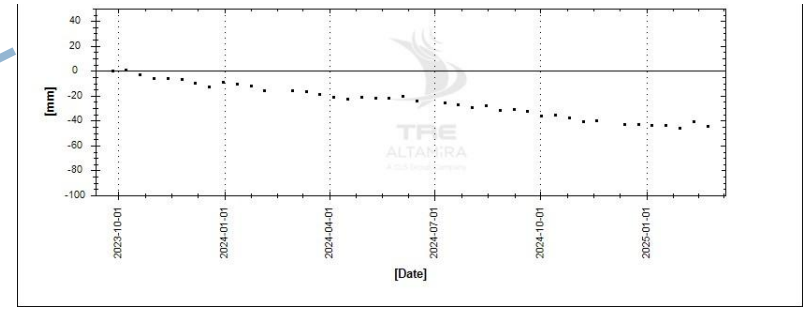
C- Band

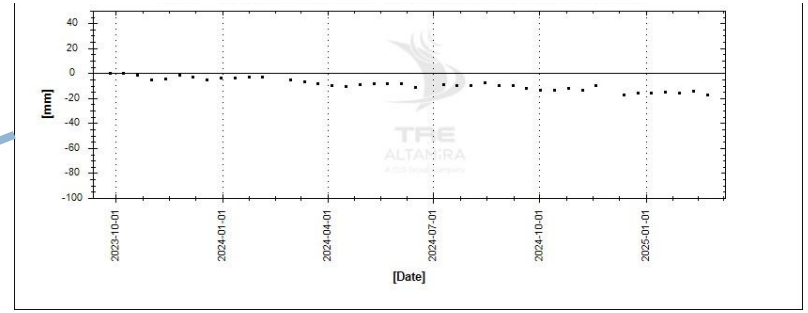
- Time series (ATS 3) over the sinkhole area shows **continuous movement** of approximately - 11 mm/yr
- ATS 1 shows an additional area to the north that has experienced displacement over the monitoring period (-31 mm/year), no visible surface deformation has been reported on site



ATS 1 – deformation rate: - 31.95, standard deviation 1.26



ATS 3 – deformation rate: - 10.66, standard deviation 0.9



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Sinkhole 2 – L Band Results

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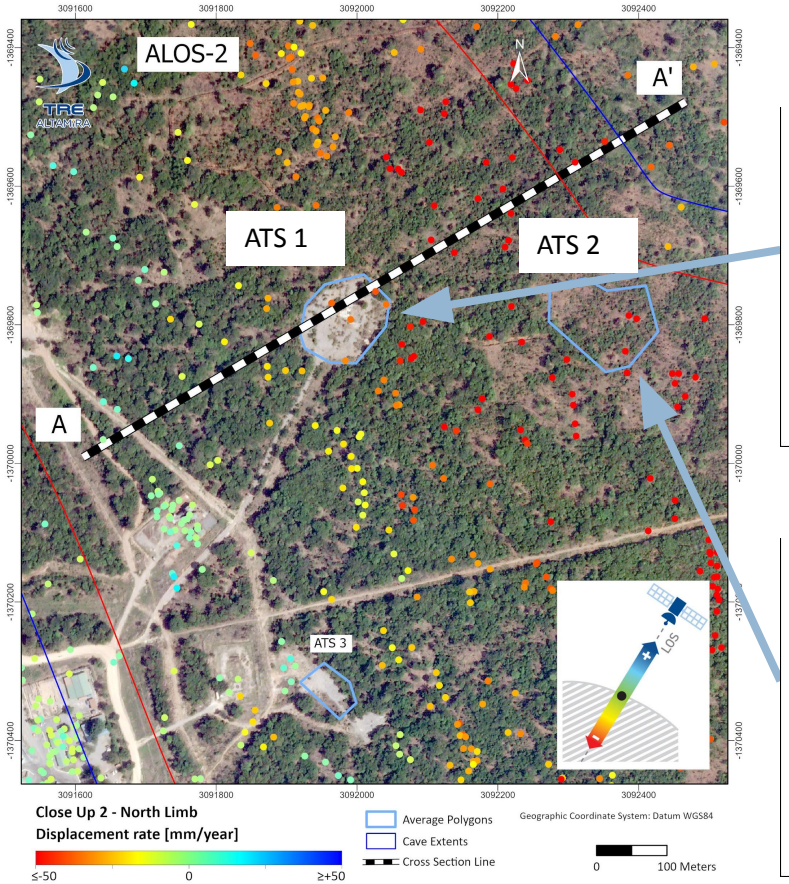
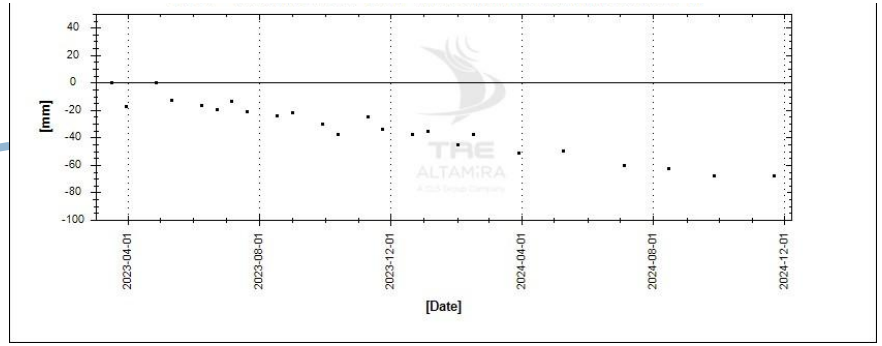
L- Band

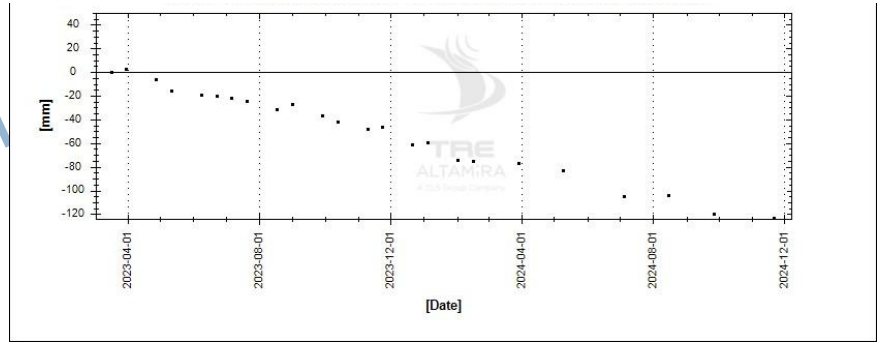
- The L-Band data has **wider coverage** and shows a **larger displacement area**
- ATS 1 shows approximately -40 mm/yr and ATS 2 showed a larger displacement of about -77 mm/yr.



ATS 1 – deformation rate: - 39.55, standard deviation 4.1



ATS 2 – deformation rate: - 76.93, standard deviation 3.15



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Sinkhole 2 – L Band Results

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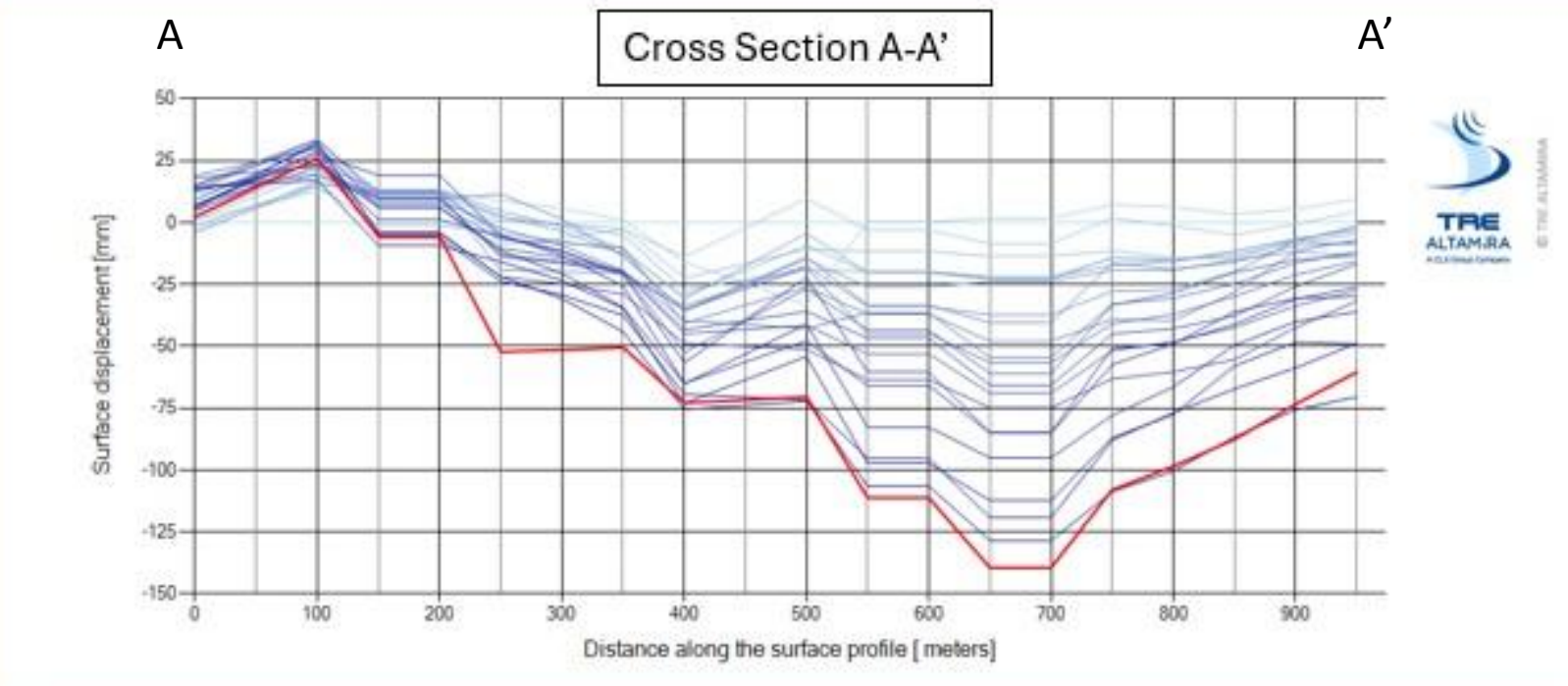
L- Band

- **Settlement profile** shows increased settlement within the cave extents up to a maximum of 140 mm over the entire monitoring period (> 1 year)



New Cracks – C Band Results

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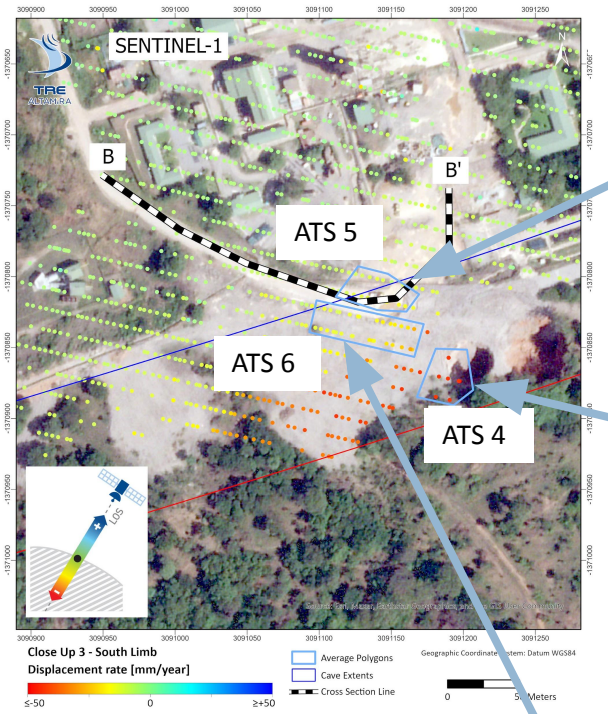
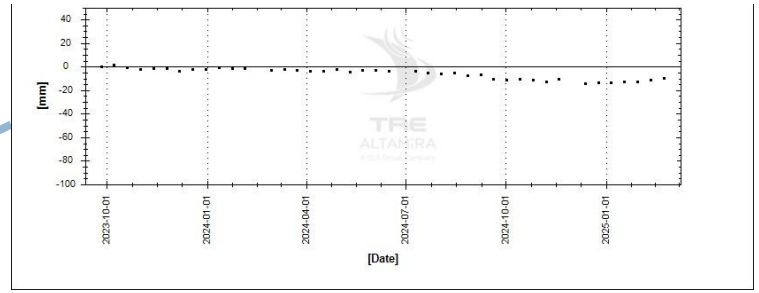
C- Band

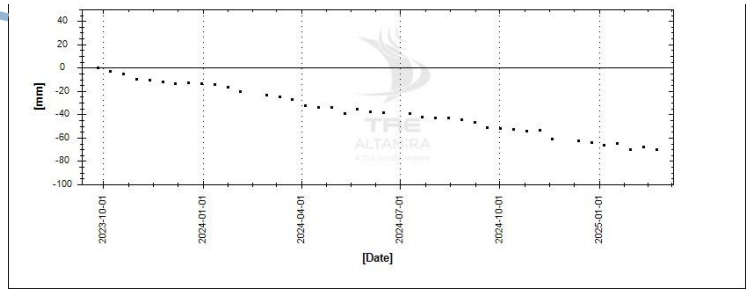
- **Historic Sinkholes** in proximity to high traffic road (profile B-B’)
- **Largest deformation rates** seen close to the sinkholes (approximately -50 mm/year) and then decreasing towards the road
- ATS 6 showing approximately – 16 mm/year of settlement
- **New cracks observed** in the area of ATS 5 and ATS 6



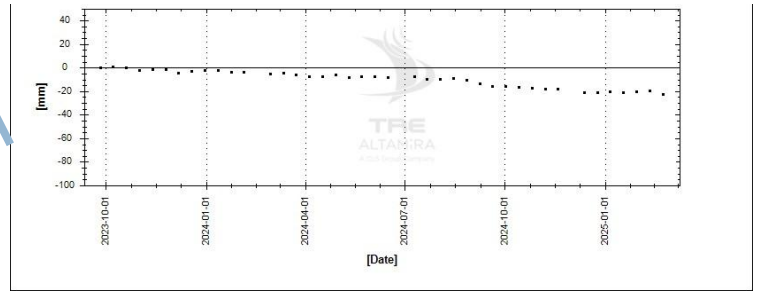
ATS 5 – deformation rate: - 9.87, standard deviation 0.96



ATS 4 – deformation rate: - 48.09, standard deviation 1.24



ATS 6 – deformation rate: - 16.34, standard deviation 1.04



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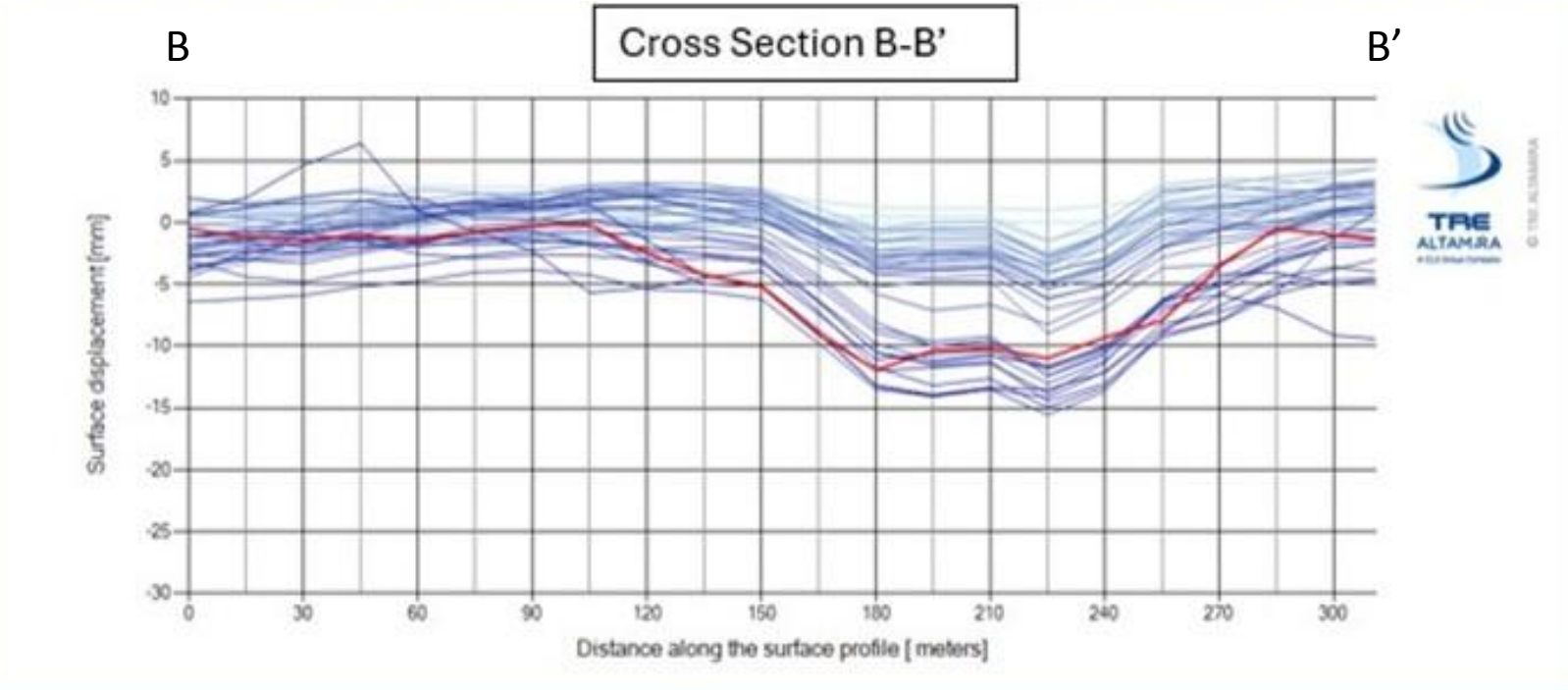
New Cracks – C Band Results

C- Band

- Settlement profile shows increased **settlement as it approaches the sinkhole area** up to a maximum of 15 mm over the entire monitoring period (> 1 year)



Conclusions

- **Multi-Band InSAR Benefits**: C-Band provides medium-resolution data for geotechnical assets and infrastructure, while L-Band highlighted subsidence in vegetated regions.
- **Integrated Monitoring Approach**: Combining InSAR and regular inspections improves risk mitigation.
- **Proactive Risk Management**: Detection of subsidence and sinkhole precursor movements enables timely interventions, preventing damage to infrastructure.
- **Case Study Insights**: Monitoring has helped assess and respond to sinkhole reactivations, road damage, and structural risks.

Future Works

- Implement alert thresholds for different areas based on the different assets, rock properties and expected displacements.
- Compare ground based and InSAR displacements over the past events to gain more insights into the failure events and better calibrate the monitoring system.

THANK YOU

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