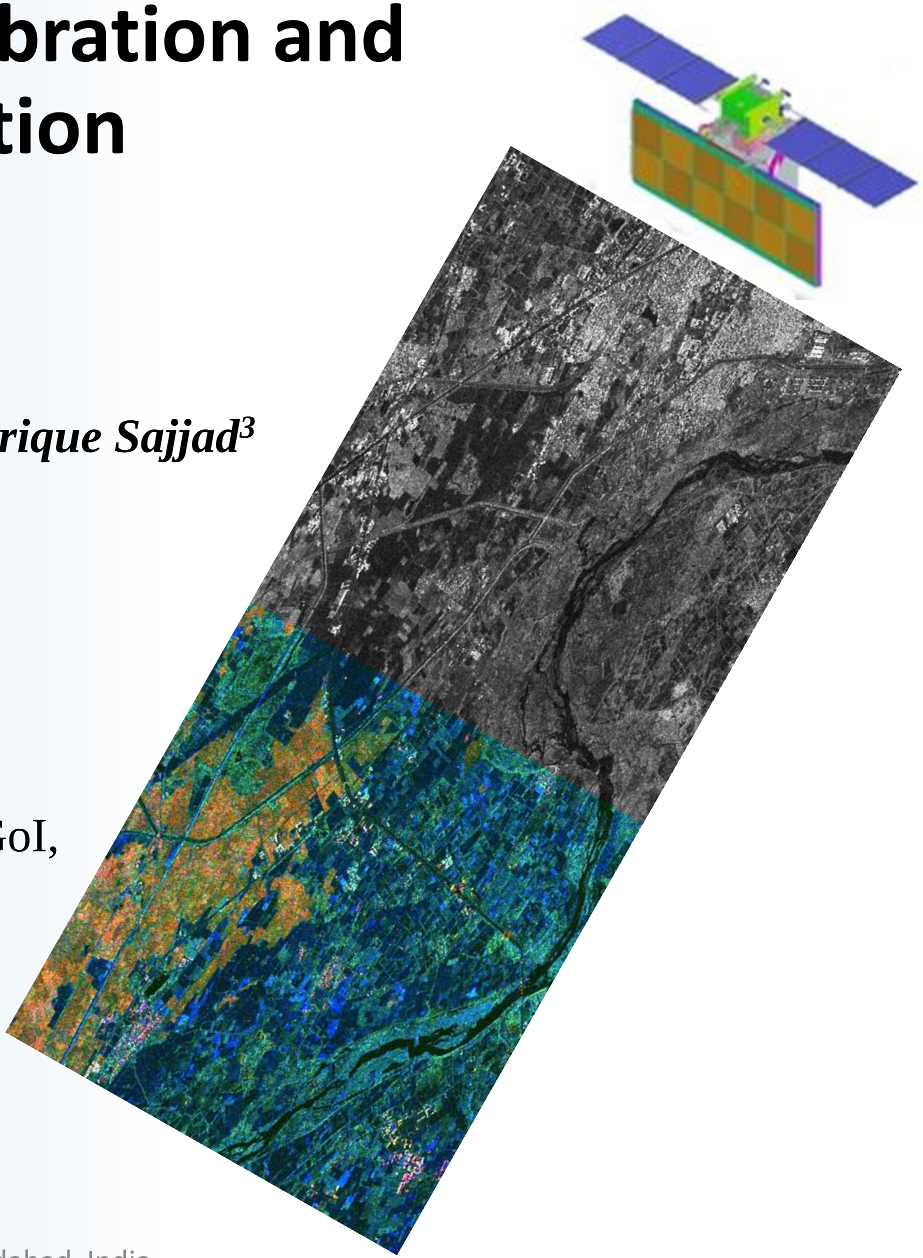
Ground-Based Synthetic Aperture Radar Calibration and Validation for Land Surface Deformation



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Introduction

- **Continuous slope monitoring is essential for the safety of mine workers and equipment**
- **Disadvantage with satellite SAR missions is longer time gap in repeat acquisition**
- **Ground-based SAR is an option for continuous monitoring of slopes**

Monitoring Requirements

Maximum Unambiguous Change of Distance

$$\Delta r_{max} = \pm\frac{\lambda}{4} = 4.3\ mm \text{ Ku−band}$$

$$|V_{max}| = \frac{\lambda}{4\Delta t}$$

At 10 minutes sampling interval, the maximum unambiguous velocity is 0.6 m/day for Ku-band and 10 m/day for L-band

Velocity per day mm/d	Class	Ku-band λ=17 mm	C-band λ= 56 mm	L-band λ= 235 mm
2000	4	3 min	2 min	8 min
80	3	1.2 h	4 h	18 h
0.6	2	7 d	23 d	98 d

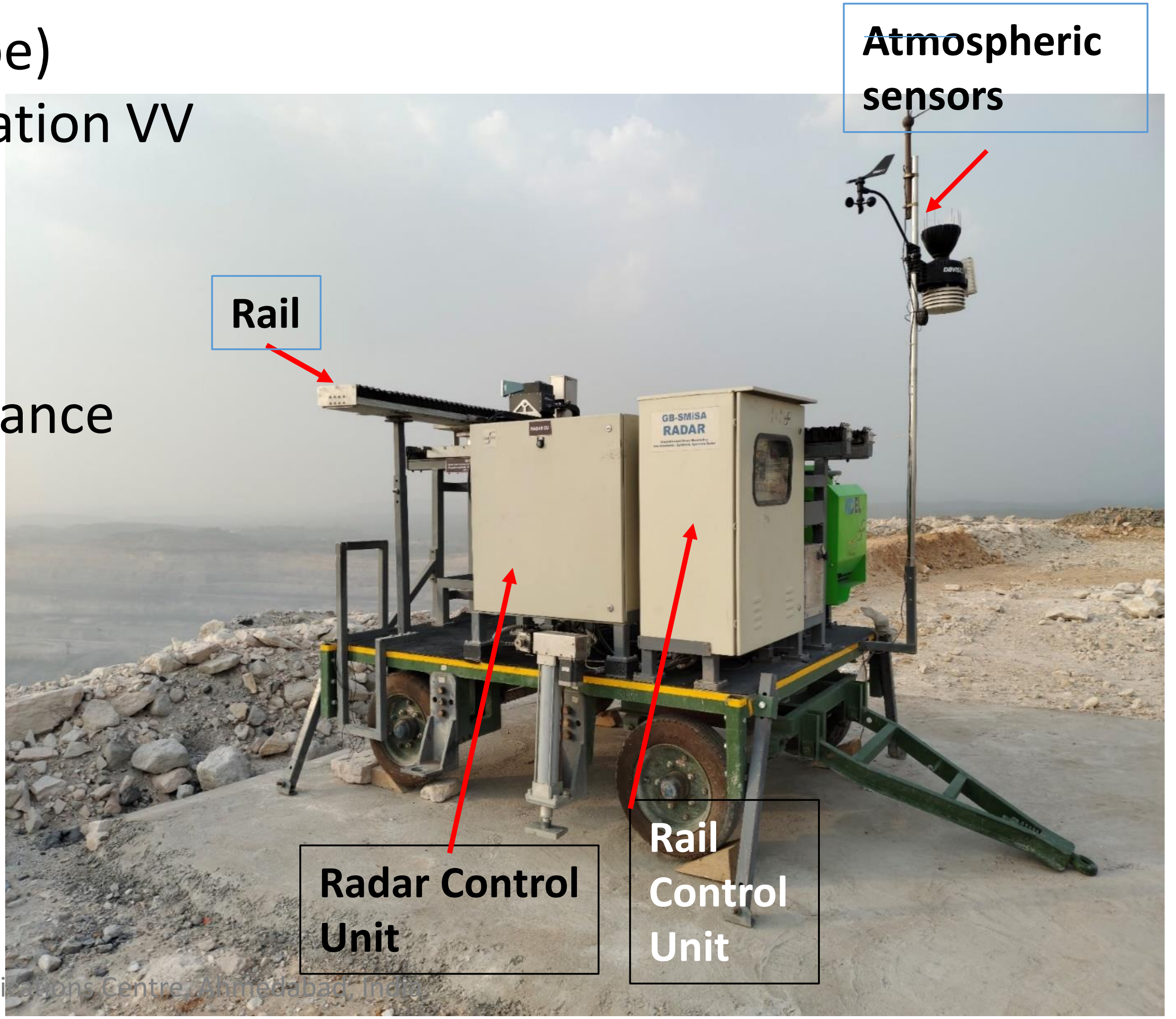
S Rödelsperger, Real-time Processing of Ground Based Synthetic Aperture Radar (GB-SAR) Measurements, Ph.D. thesis, Tech. Uni. Darmstadt, 2011.

Design and Development

Radar System — Control Panel — Work Station

Technique : FMCW (Continuous, not Stepped type)
Frequency : 17.3 GHz (1.73 cm, Ku-band), Polarization VV
Bandwidth : 250 MHz, Resolution = 0.60 m
Rail length: 2 m
Synthetic Aperture Length : 1.45 m
Azimuth Resolution : 5.98 mrad (6 m at 1 km distance
Radiated Power : 0.50 W (27dBm)
Antenna : Horn type
Antenna Beamwidth (E x H) : 10^0 x 30^0)
Scan Time : 7 sec with velocity 0.2 m/s

Maximum Distance : 1.5 km



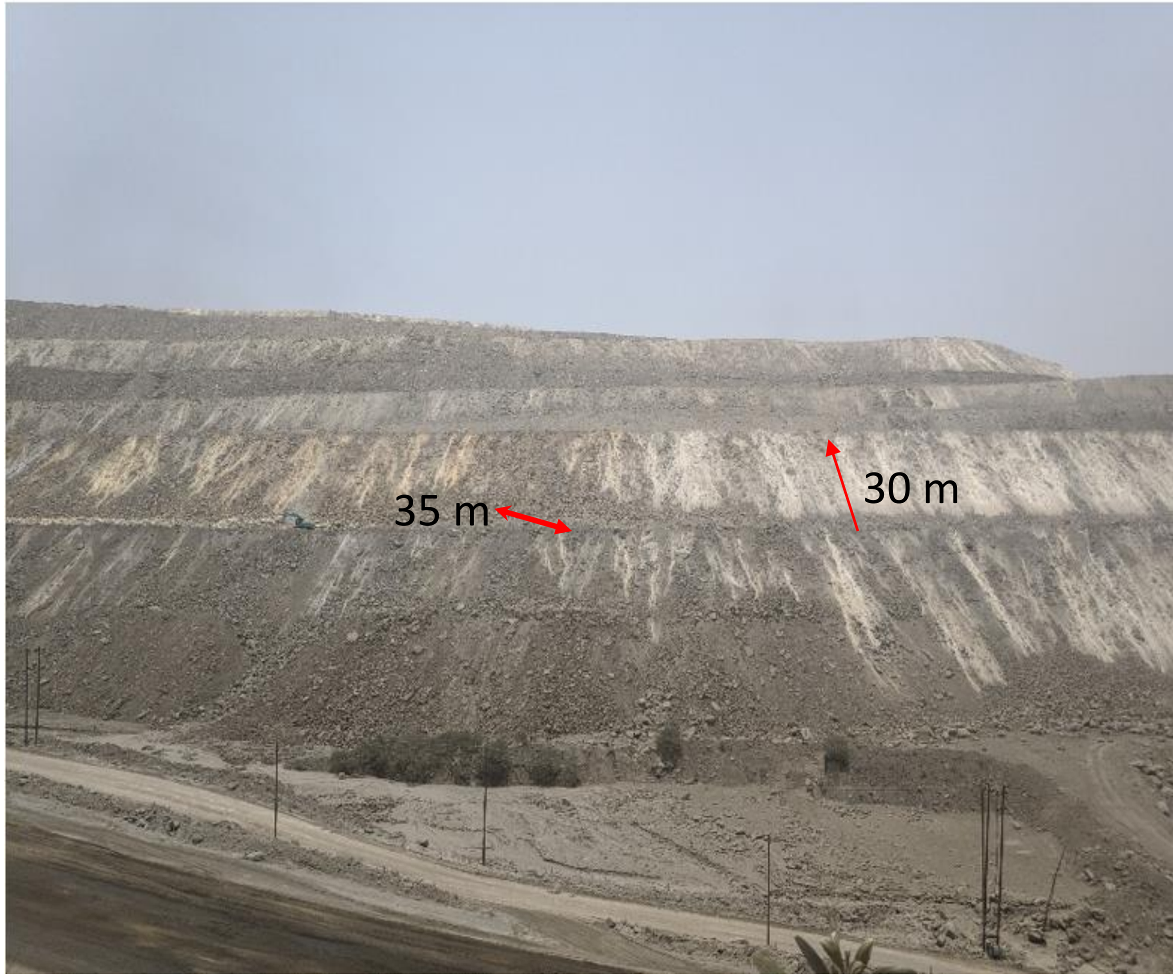
Installation of GB-SAR with different Units

Experiments for Calibration and Validation

Test Site: Dudhichua Coal Mines, Singrauli District of Madhya Pradesh (M.P), India

90% medium and coarse-grained sand stone

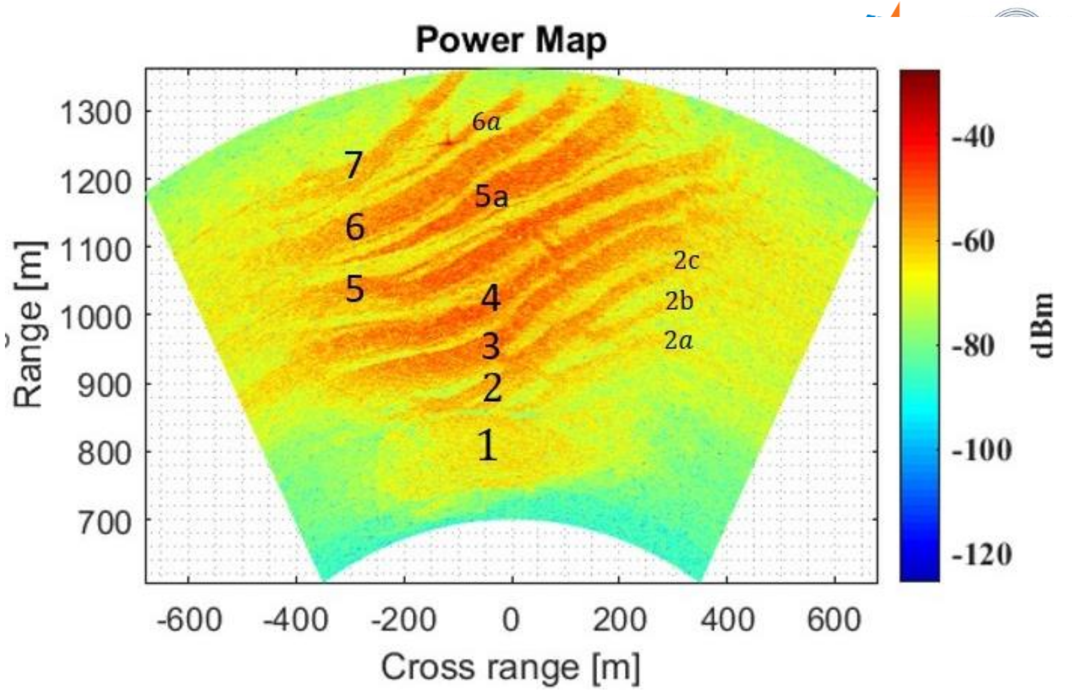
Big stones of varying sizes also present



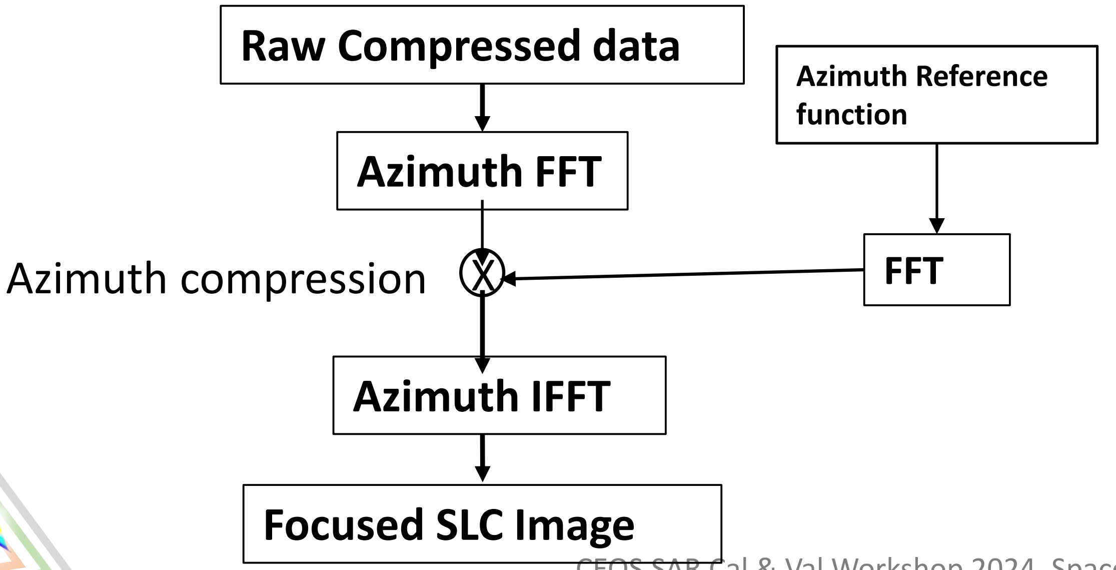
Benches are typically 30 m in height and 35 m in width. Total height 200 m with a slope of 30^0.

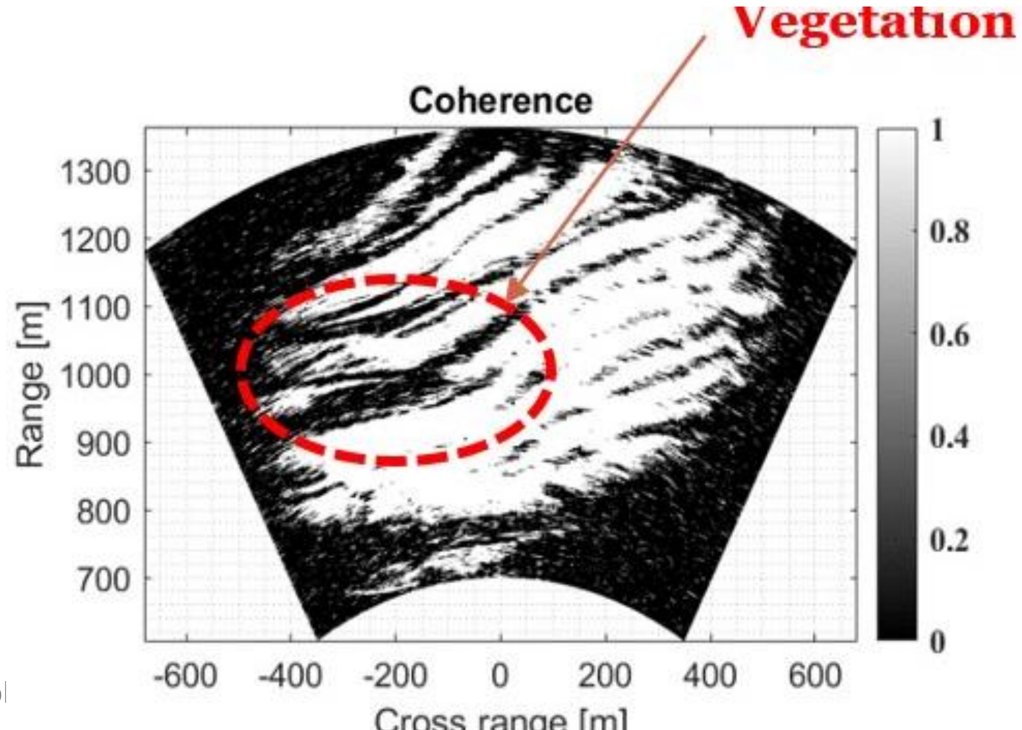
GB-SAR Power Image

Photograph overburden dump



Range-Doppler algorithm

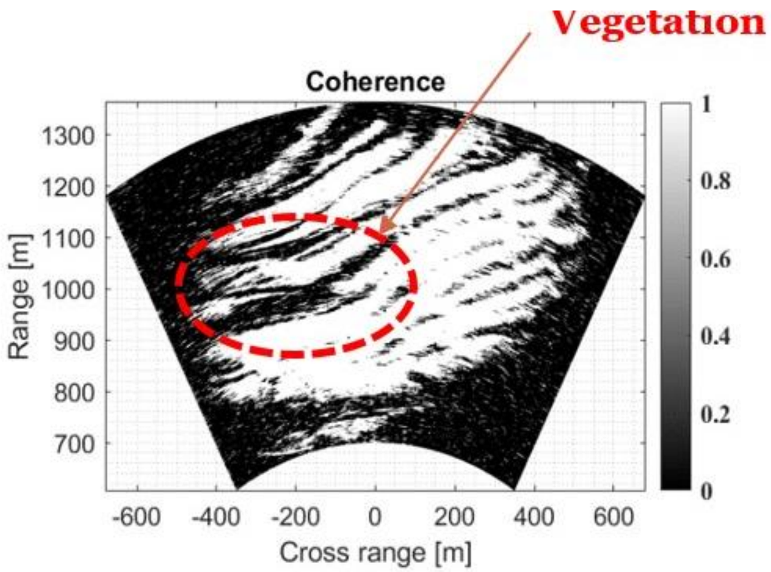




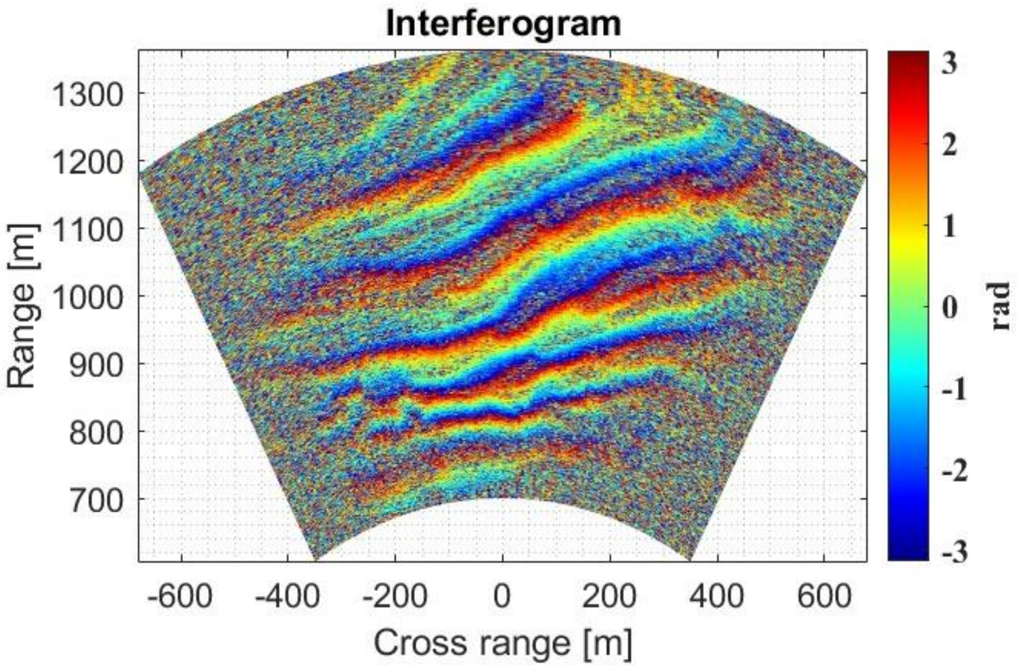
InSAR Mode for DEM Generation

Radar is moved by 15 cm vertically

Baseline experiment (15 cm wooden block)



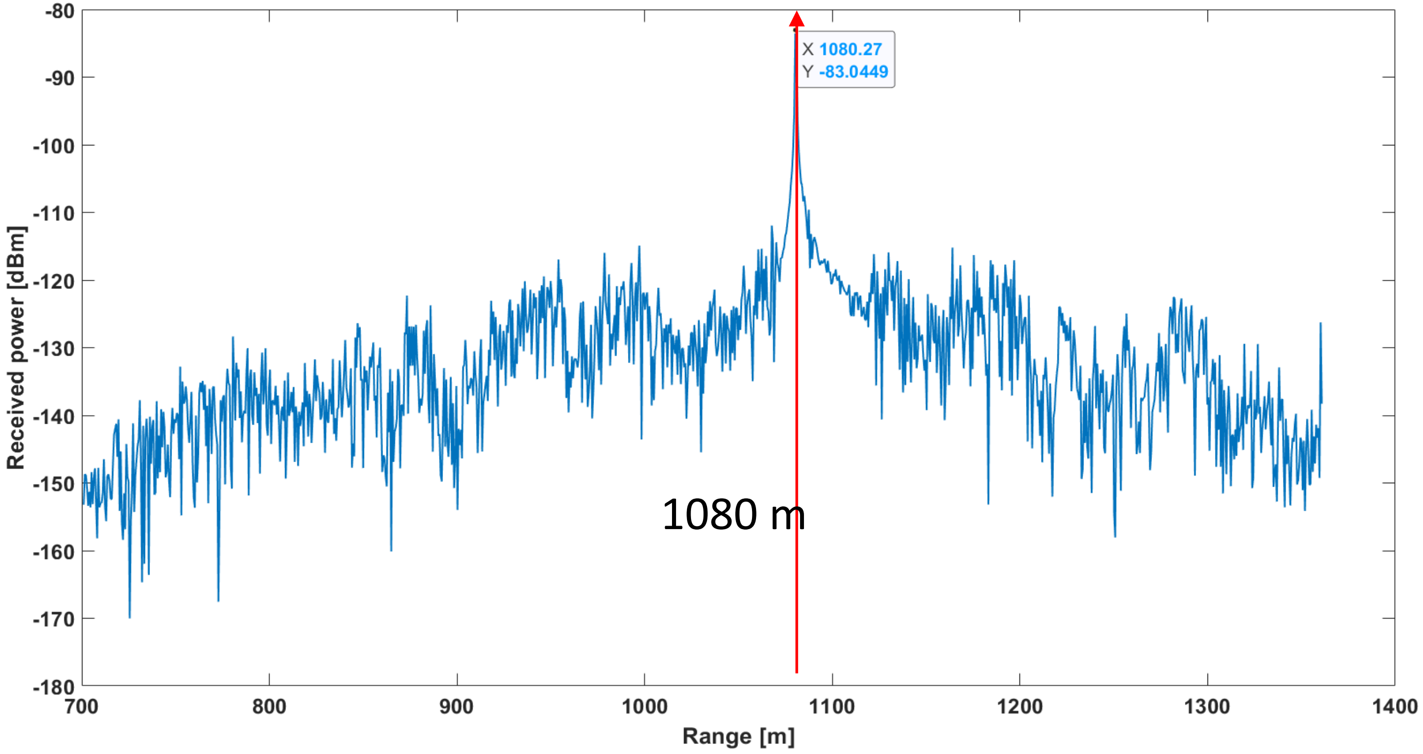
Fringes due to topograpy



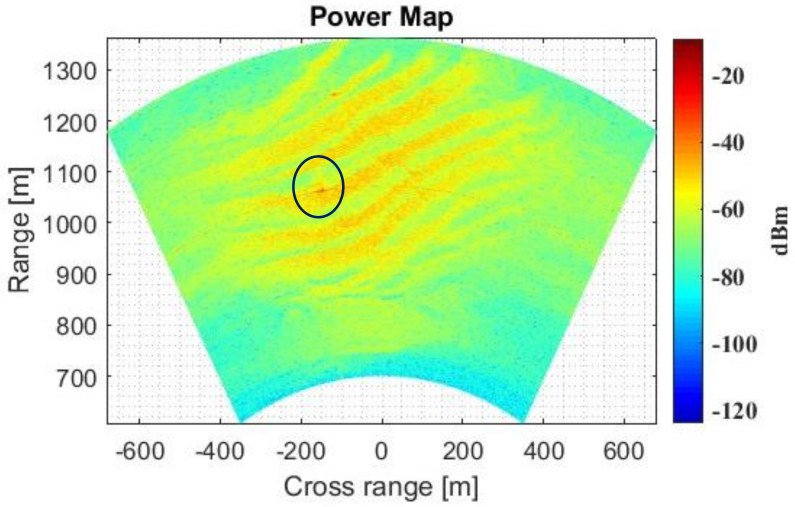
CR Installation on the Mine Dump

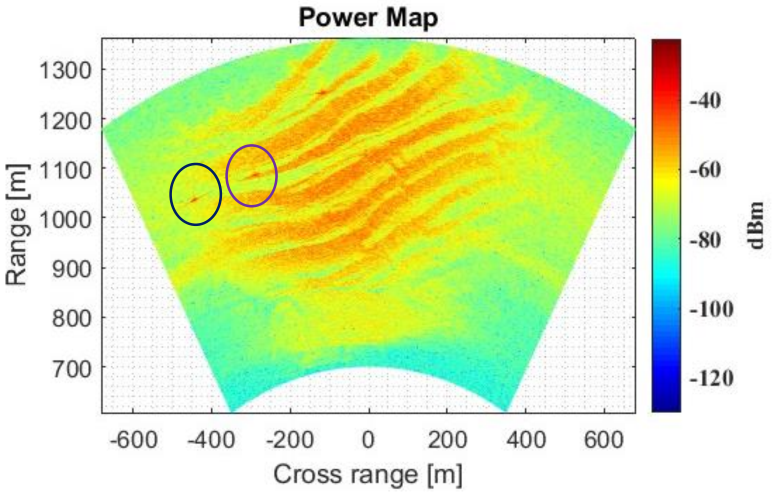
CR with 1 meter size and screw arrangement

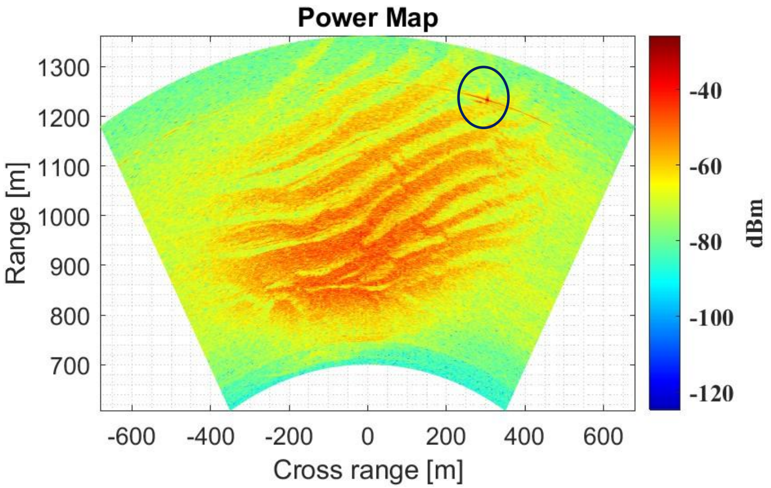
Range Spectra of point target



CR placement at different Locations

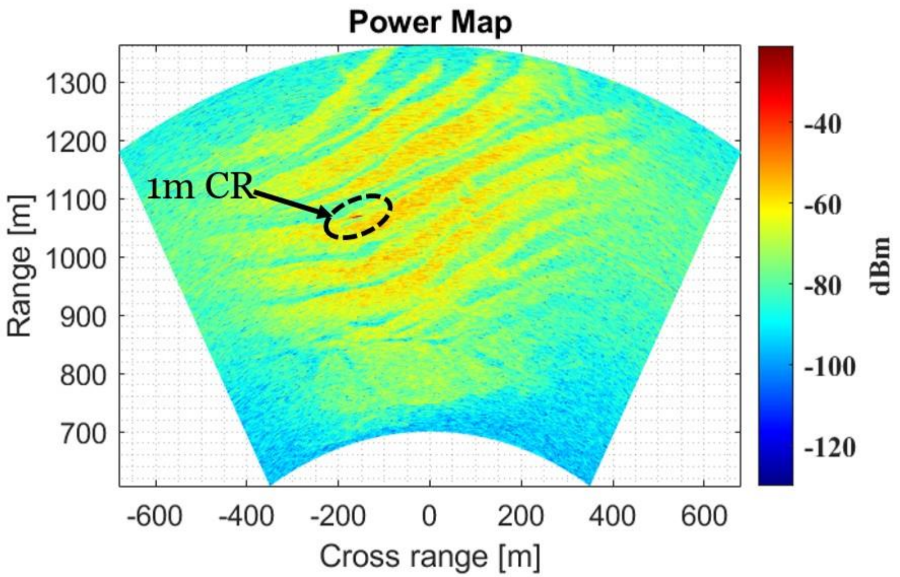






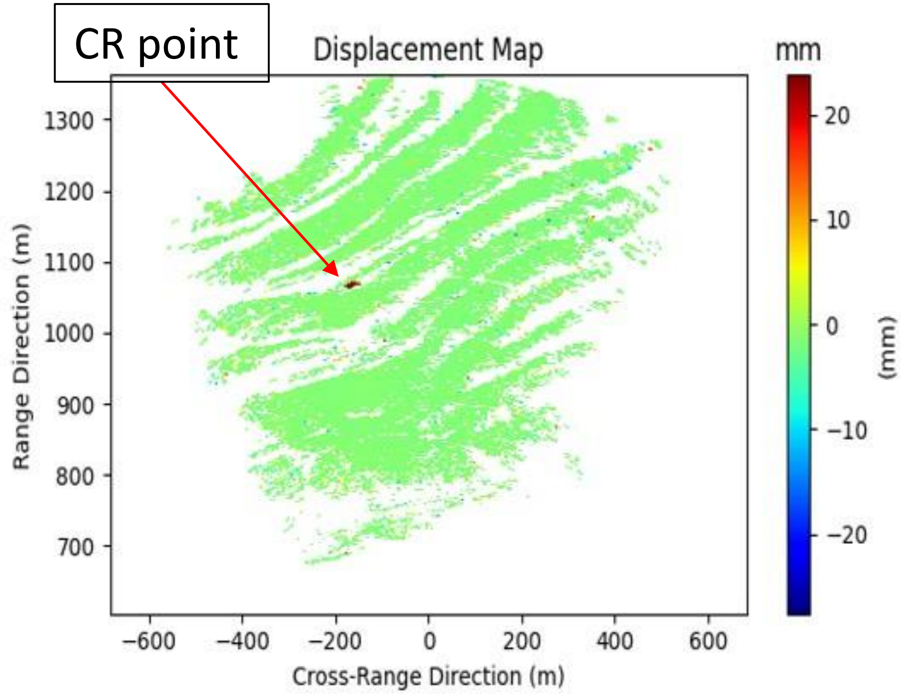
Corner reflector (CR) installed at the overburden dump at different locations

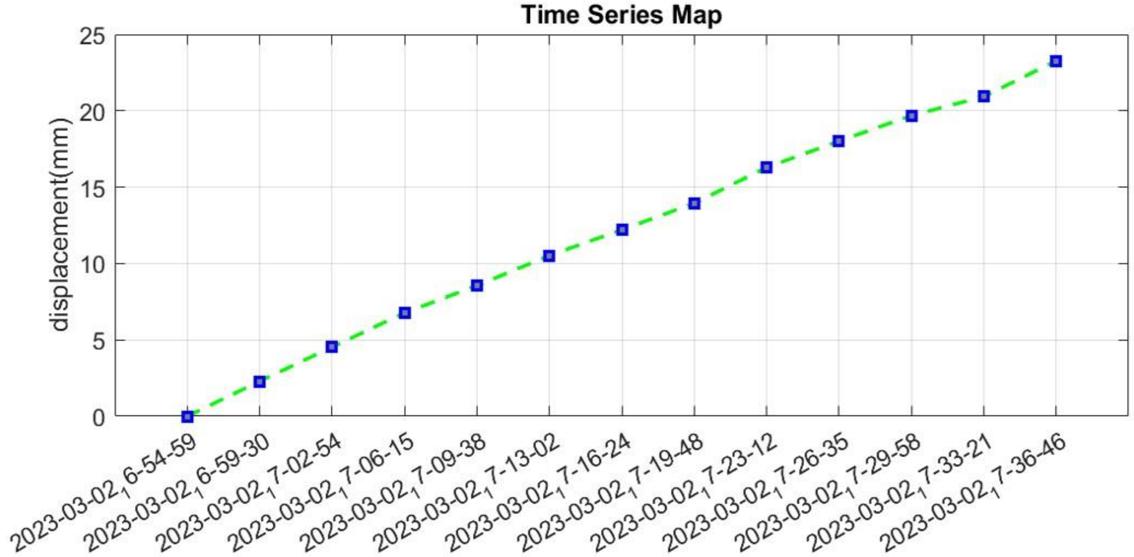
Controlled Movement of CR



CR is moved by 2 mm (< $\lambda/4$) for every new acquisition with the help a screw and two wooden planks.

Time Series Plot of CR Movement



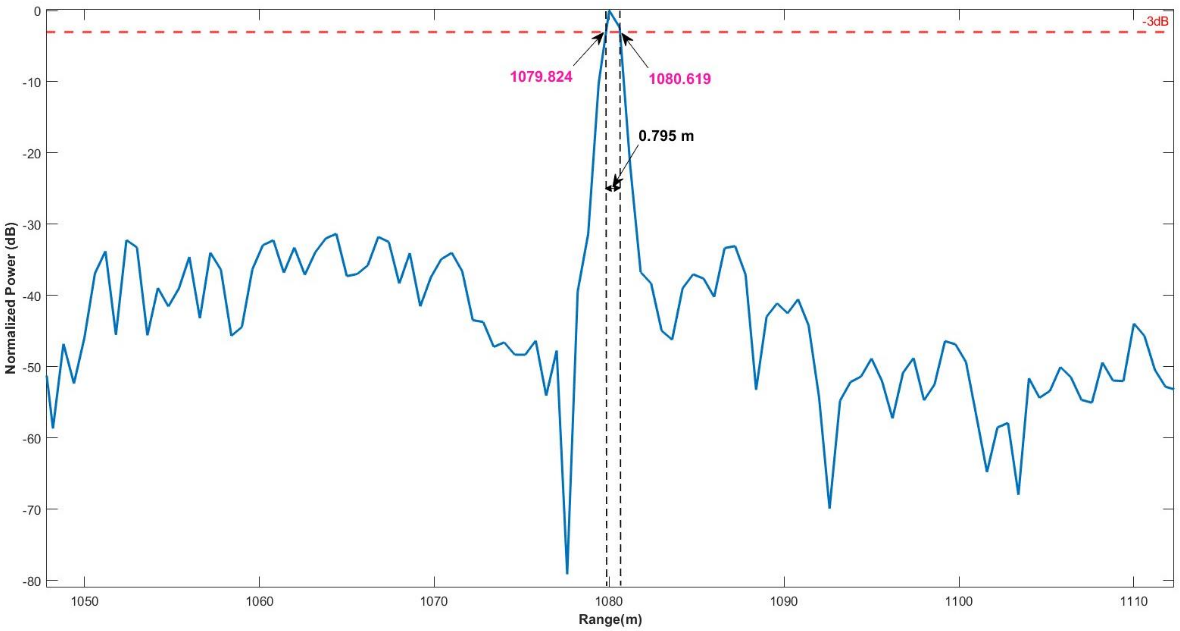


Displacement of CR over 40 min.

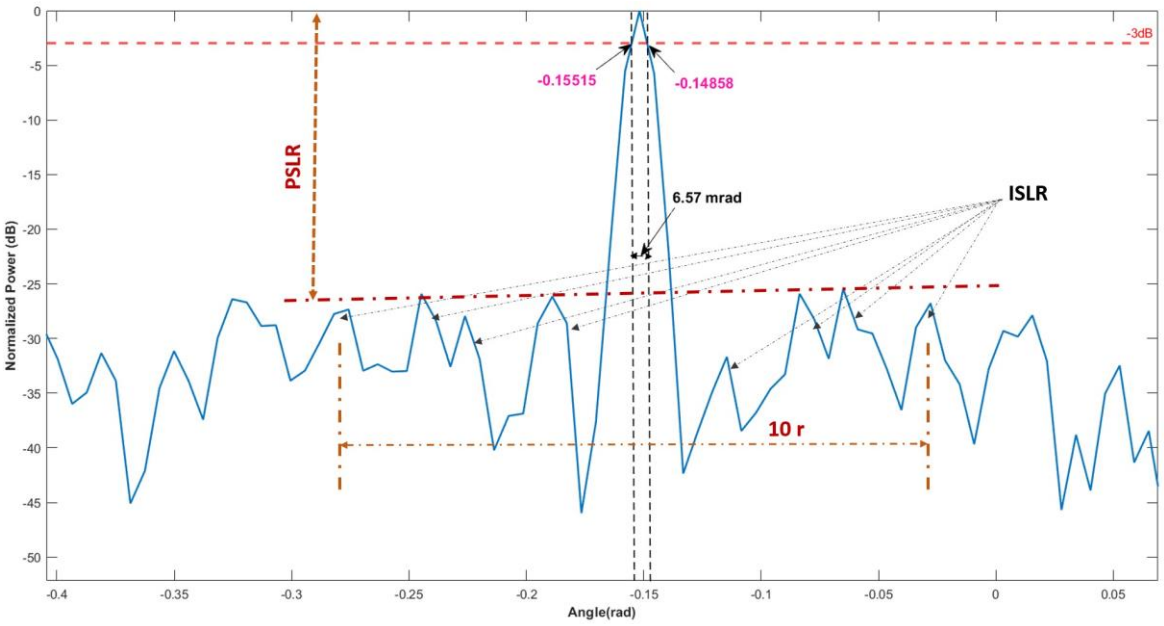
Total displacement 12 x 2 mm = 24 mm

RMSE = 0.5 mm

CR Impulse Response in Range and Azimuth



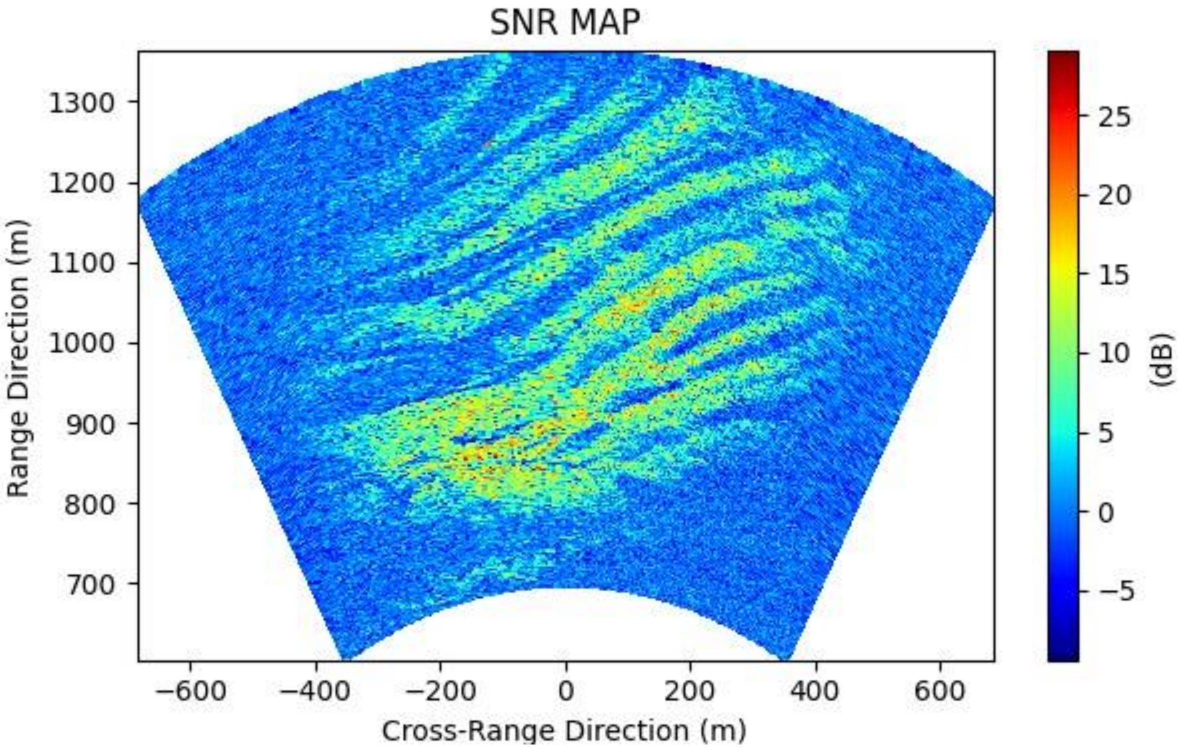
Range Impulse Response (RIR)



Azimuth Impulse Response (AIR)

Range PSLR/ISLR (dB)	Azimuth PSLR/ISLR (dB)	3 dB Width Range m / Azimuth (mrad)	System Specification Range m/Azimuth (mrad)	Difference (m) (Range m/Azimuth mrad)
-33 / -26	-27 / -17	0.79 / 6.57	0.60 / 5.98	0.19 / 0.59

SNR and NESZ



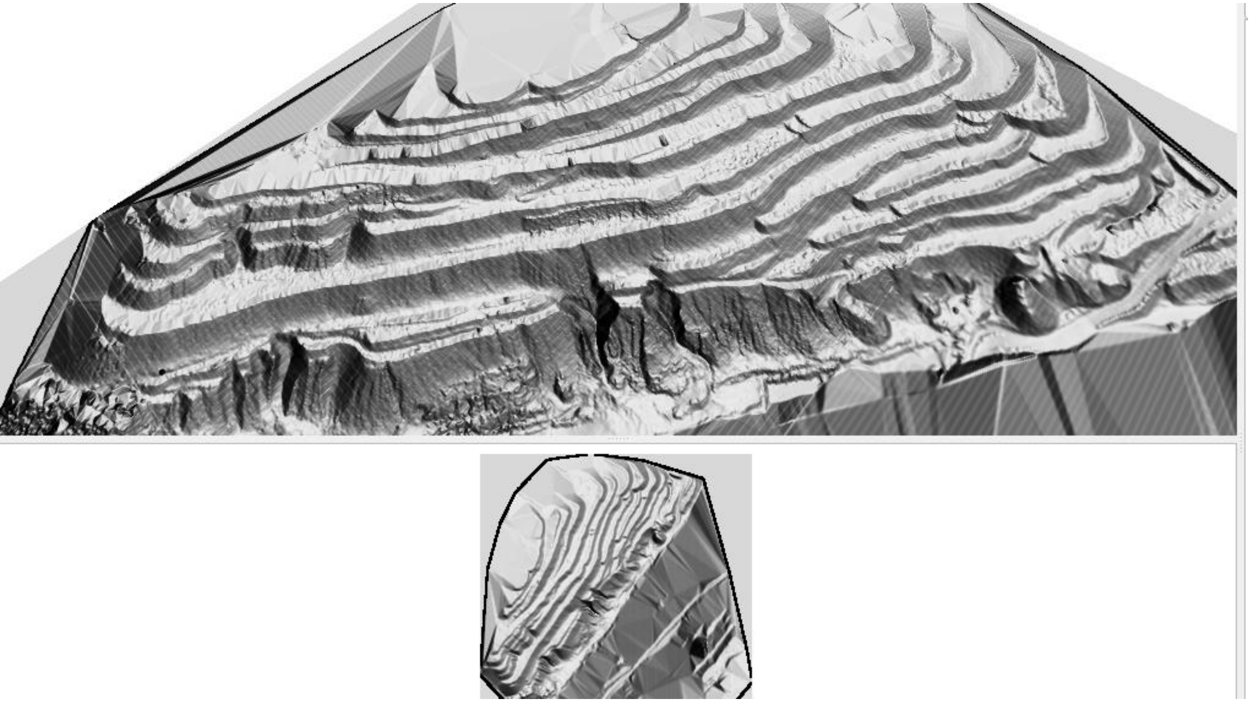
Target type	SNR (dB)
Point Target (C R)	67
Soil or Rock	15
Vegetation (on bench no 4)	15
Road (between bench)	0

$$NE\sigma^0 = \left(\frac{4\pi R_0}{\lambda}\right)^3 \frac{Loss \cdot kT2v}{P_{av}G^2 r_d}$$

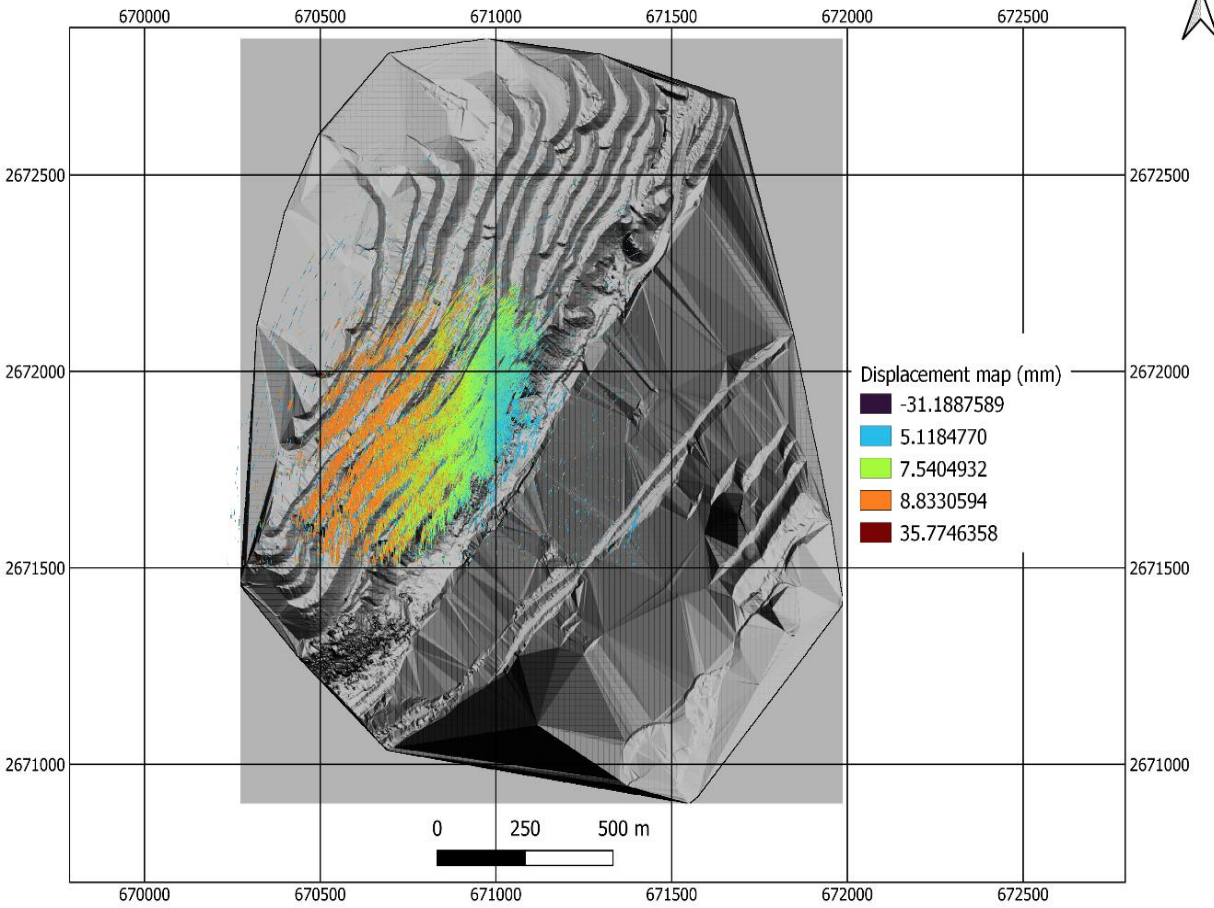
Noise Equivalent Sigma Zero (NESZ) = – 67.80 *dB*

Geocoding and Overlay

Laser DEM with Terrestrial Laser Scan



Displacement Map overlayed on Hillshade Laser DEM

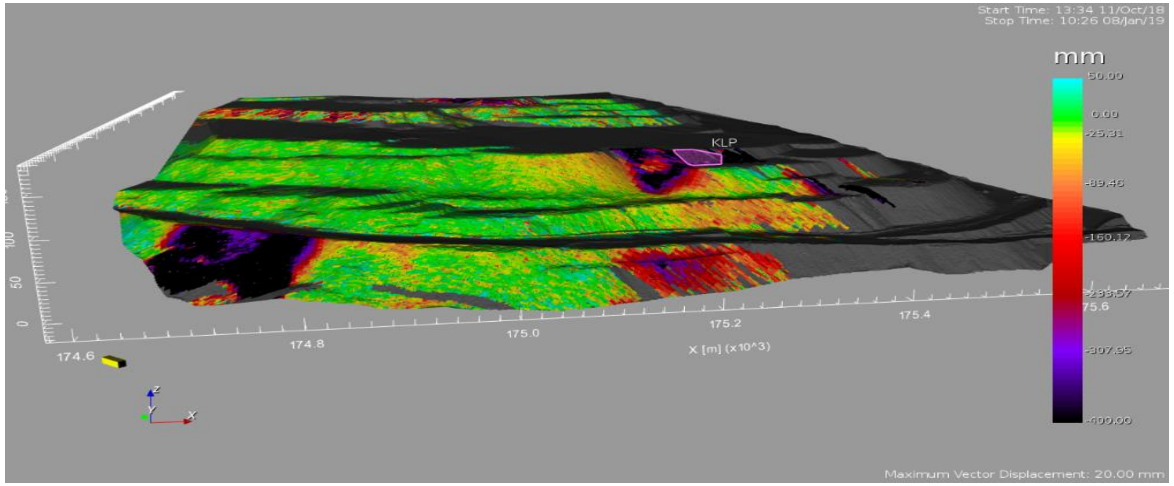


Conclusion

- **Strong return from soil/rock and CR is observed**
- **Many PS points are observed with 0.9 coherence up to a few hours.**
- **With long time series data, the loss of coherence is noticed**
- **CR movement is estimated with RMSE of 5 mm**
- **System is not yet fully operational**

IBIS-M Radar installed by Coal India at NCL

Thank You



Asansol, West Bengal, NCL