Data analytics for the identification of developing instabilities in open pit mines, waste dumps and TSFs.

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Routine data analytics tools

Terabytes of monitoring data are collected every week at mine site by modern monitoring systems (InSAR, radar, prisms, GNSS, geotechnical sensors, microseismic netwtorks, etc.).

Experience shows that data under-exploitation is common in most of mine site.

Monitoring data can be routinely analyzed to identify anomalous behaviors potentially indicating approaching failure conditions on the slope.

Monitoring data can be analyzed as follows:

- **Analysis in time domain**: to highlight areas prone to *progressive displacements* through a systematic multi-temporal inverse velocity analysis of InSAR and radar dataset
- **Analysis in horizontal (planimetric) space domain**: to calculate *strain parameters* (angular distortion β and horizontal strain ε_H) for the Identification of areas of strain accumulation (differential settlements, as well as tensile or compressive strain), typically corresponding to areas where ground fissures and trenches may appear from InSAR.
- **Analysis in vertical (altimetric) space domain**: to draw cross sections with vector geometry in sensible areas to better understand the *deformation mechanism* from vectors (InSAR, prisms, GNSS).

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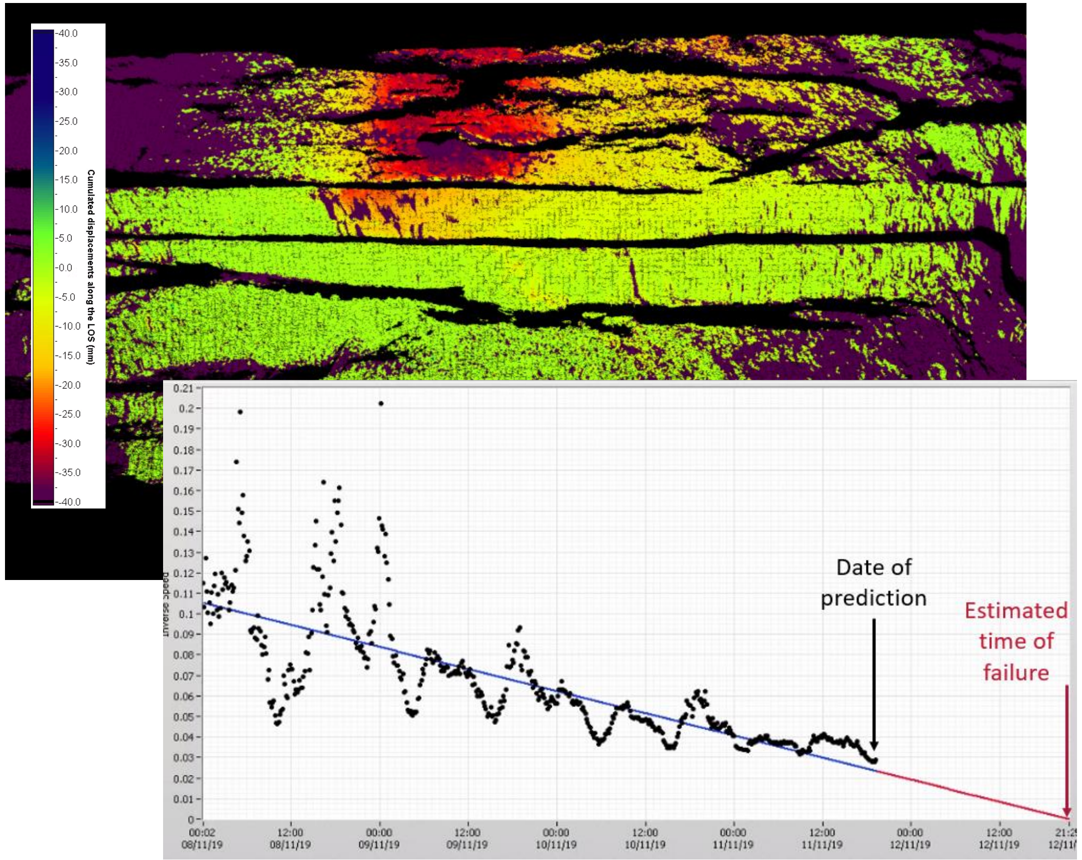
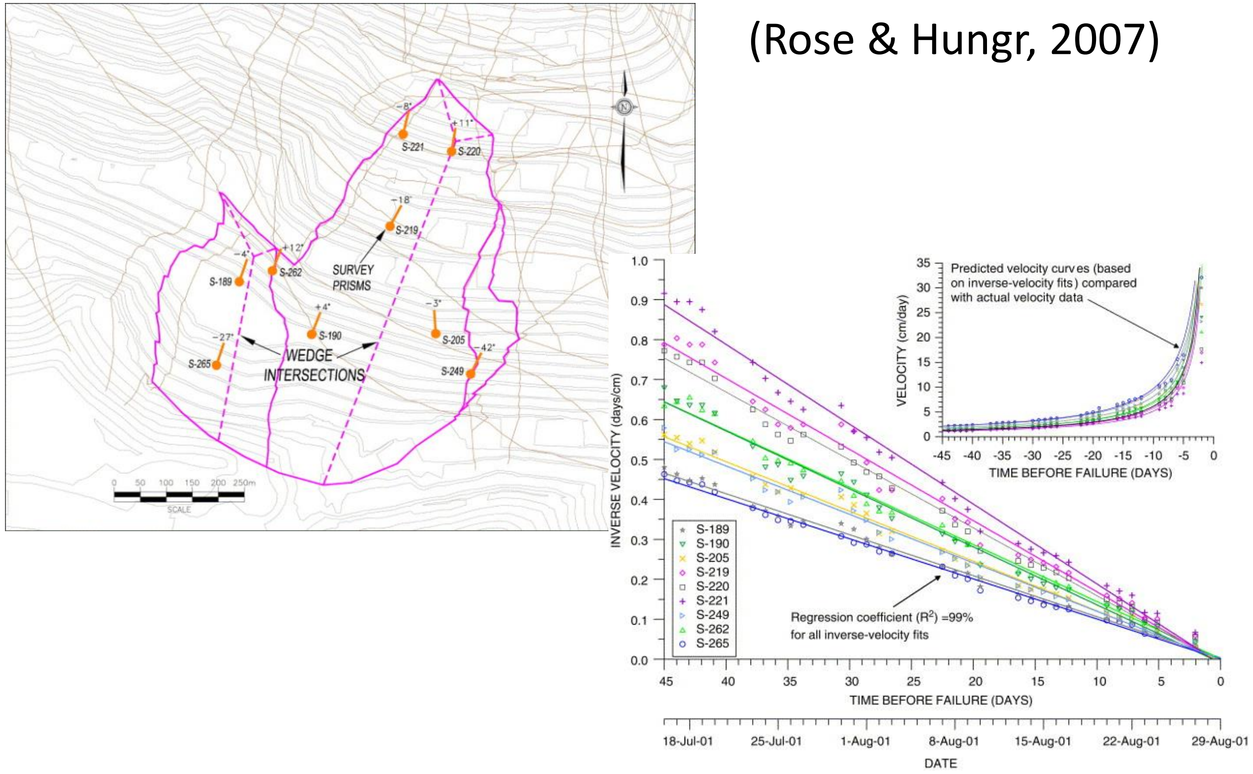
Prediction of the time of failure

- Inverse velocity in the mining industry is mainly used on radar data and, to a lower extent, on prisms, laser and geotechnical data. Recently a few cases published based on InSAR back analyses.



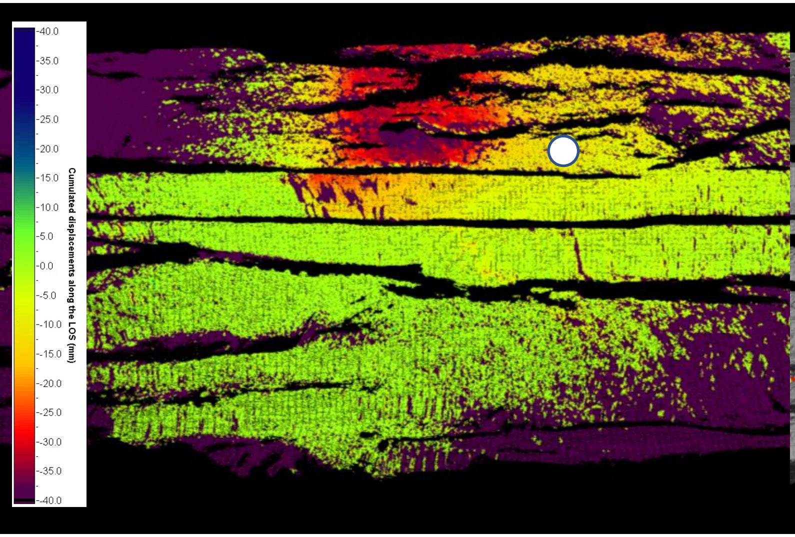
(Rose & Hungr, 2007)



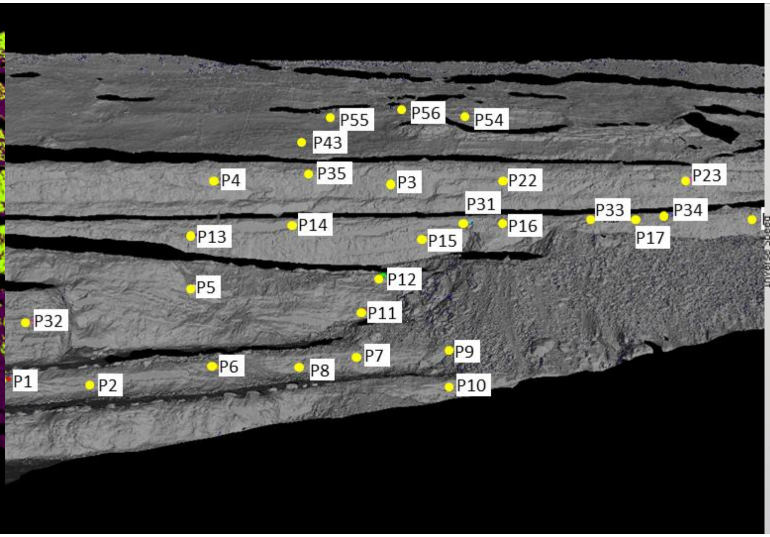
Current Inverse velocity process

- Nowdays Inverse Velocity is typically performed:

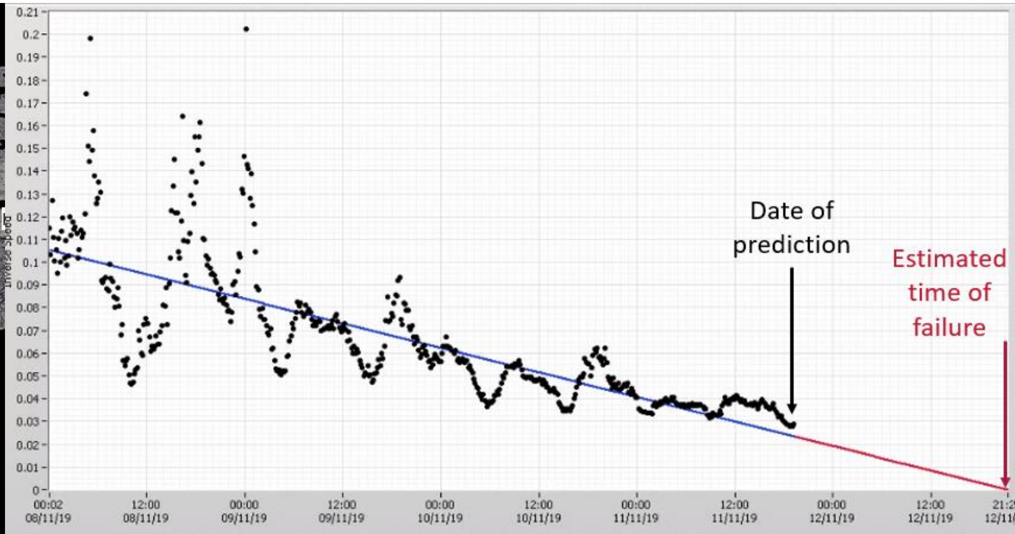
- on single manually selected points (radar, prisms, geotechnical sensors) where accelerations have been previously identified, thus not allowing to take advantage of “spatially distributed” monitoring datasets, such as InSAR, radar and laser thus limiting the possibility to automatically identify “critical” areas



Radar displacement map →



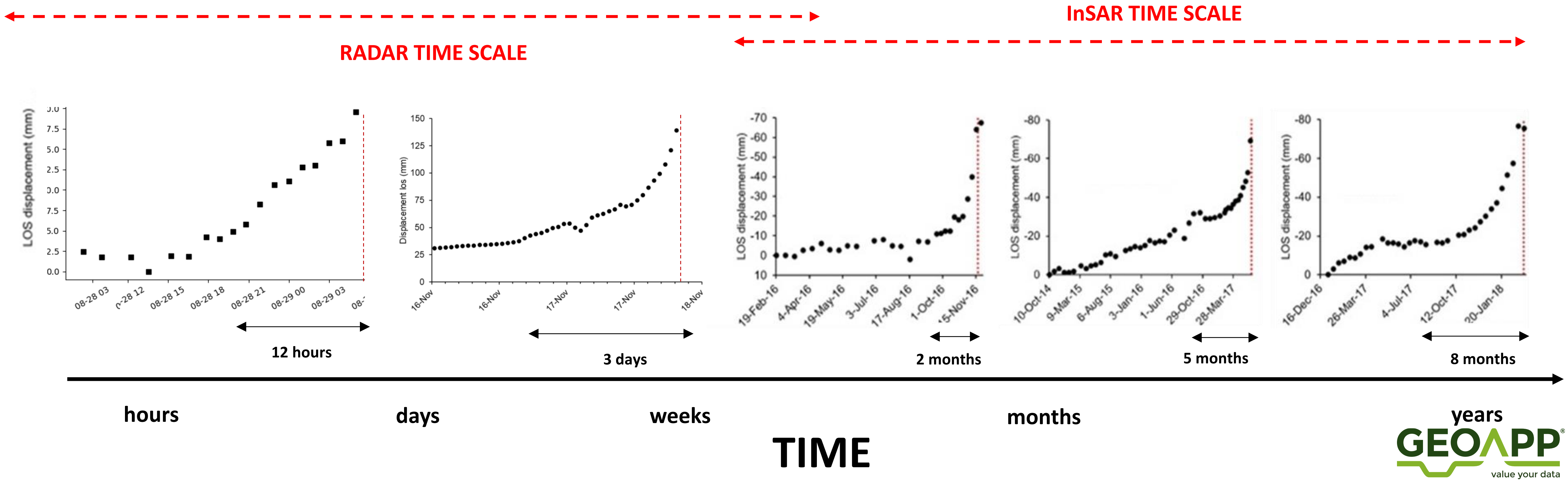
Manually selected points →



Point wise inverse velocity prediction

Inverse velocity challenges

- Nowdays Inverse Velocity is typically performed:
- over short term (radar) and over pre-defined temporal intervals used to calculate the regression coefficients of the linear interpolation of inv velocity values, thus not allowing to early identify progressive trends over long temporal scales.



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Spatially distributed Inverse velocity

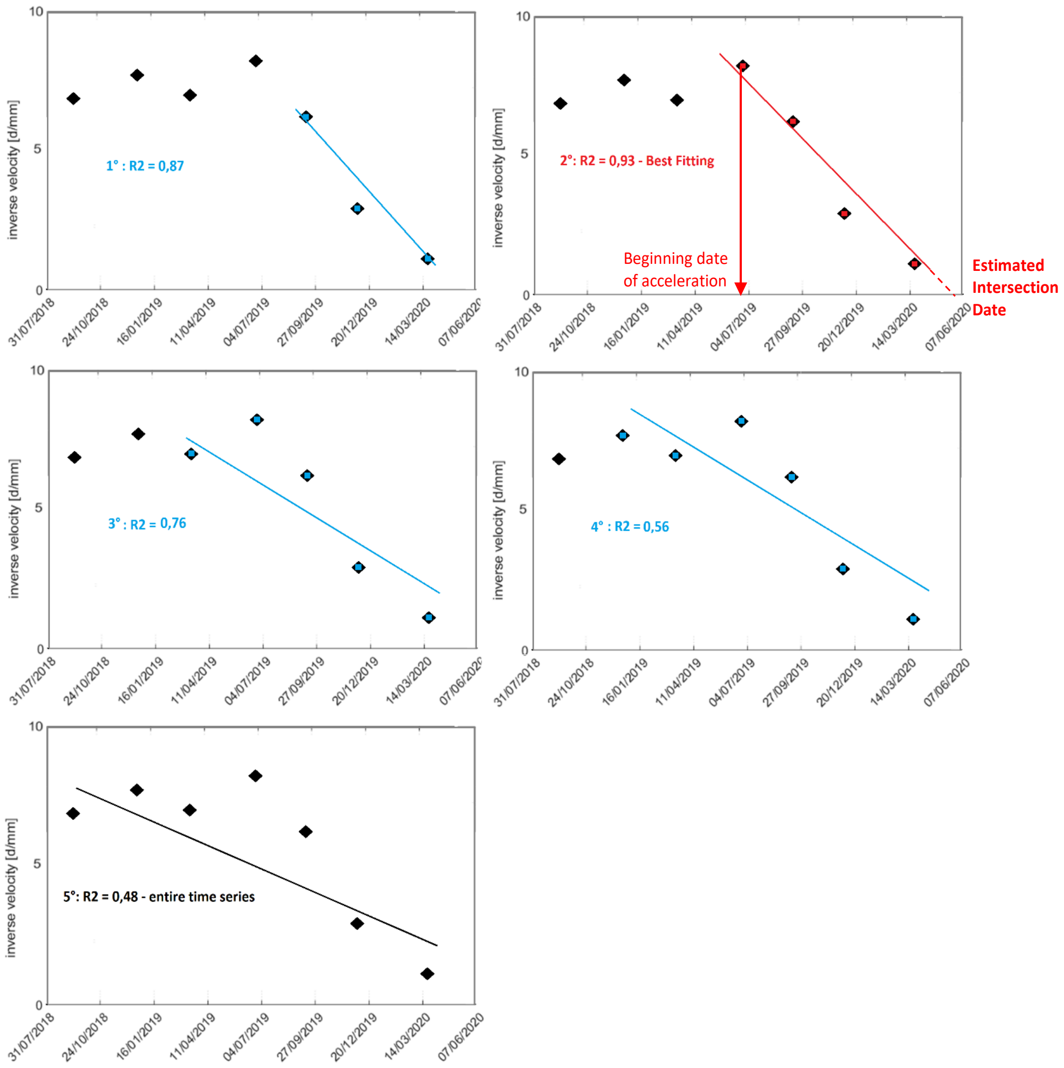
- The spatially distributed inverse velocity analysis is carried out after a prefiltering of the data, both on long term data (full time series) and on the last part of the time series to intercept both long term progressive trends and short term accelerations.
- The inverse of velocity series is calculated and analyzed by means of two different approaches:

- the R^2 analysis target long term analysis,
- the R^2 Best Fitting (R^2BF) search for short term phenomena in the last part of the monitored time interval.

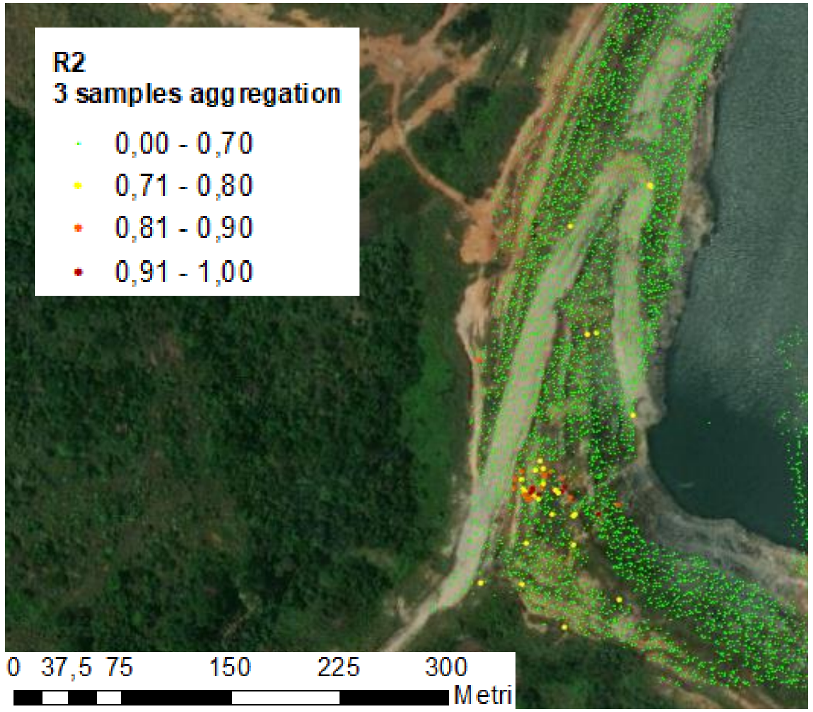
- The outcome of the analysis are R^2 and R^2BF maps and intersection date maps, as well as, for each measurement point, time series of displacement, velocity and inverse velocity.

Spatially distributed Inverse velocity

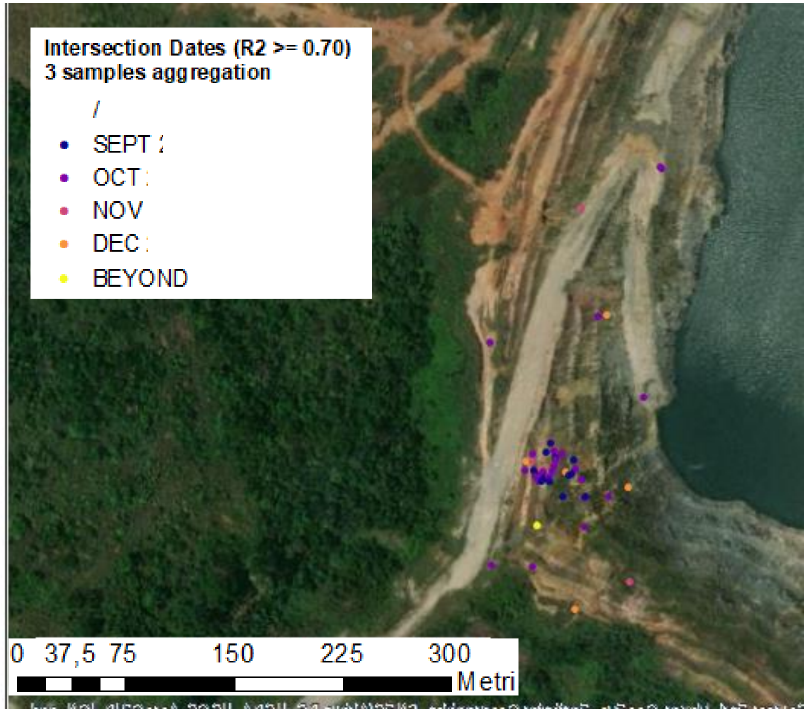
- The determination coefficient R^2 is calculated for the entire period covered by the dataset, but also by using the «best fitting» approach.
- The "best" R^2 is calculated through an iterative automatic procedure through several attempts on the time series. The outcomes of the process are represented by the beginning date of the acceleration and by the intersection date of the linear extrapolation with the time axis.



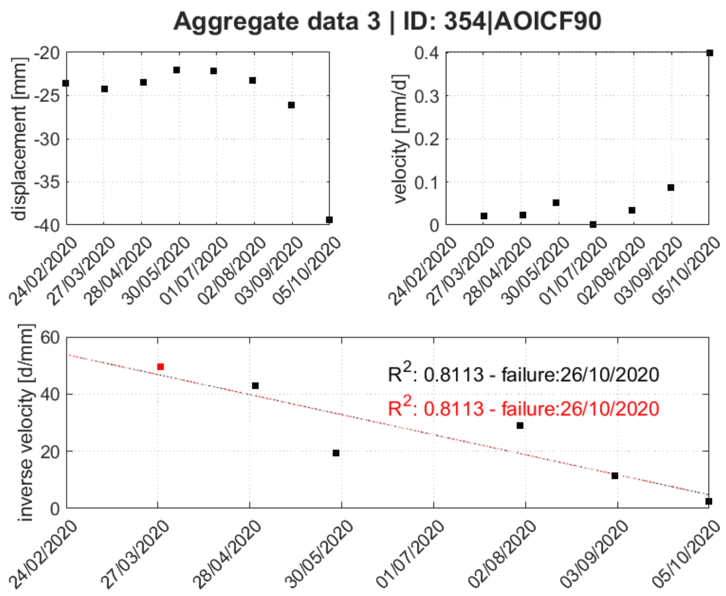
Spatially distributed Inverse velocity



R^2 or R^2 BF maps



Intersection date maps



Displ/vel/inv velocity time series

Gamsberg open pit case

- Occurred on the 17th of November 2020 in the Gamsberg zinc open pit (South Africa).
- 1.6 million ton of material. Ten members of staff trapped at the bottom of the pit. Eight rescued, but other two were killed.

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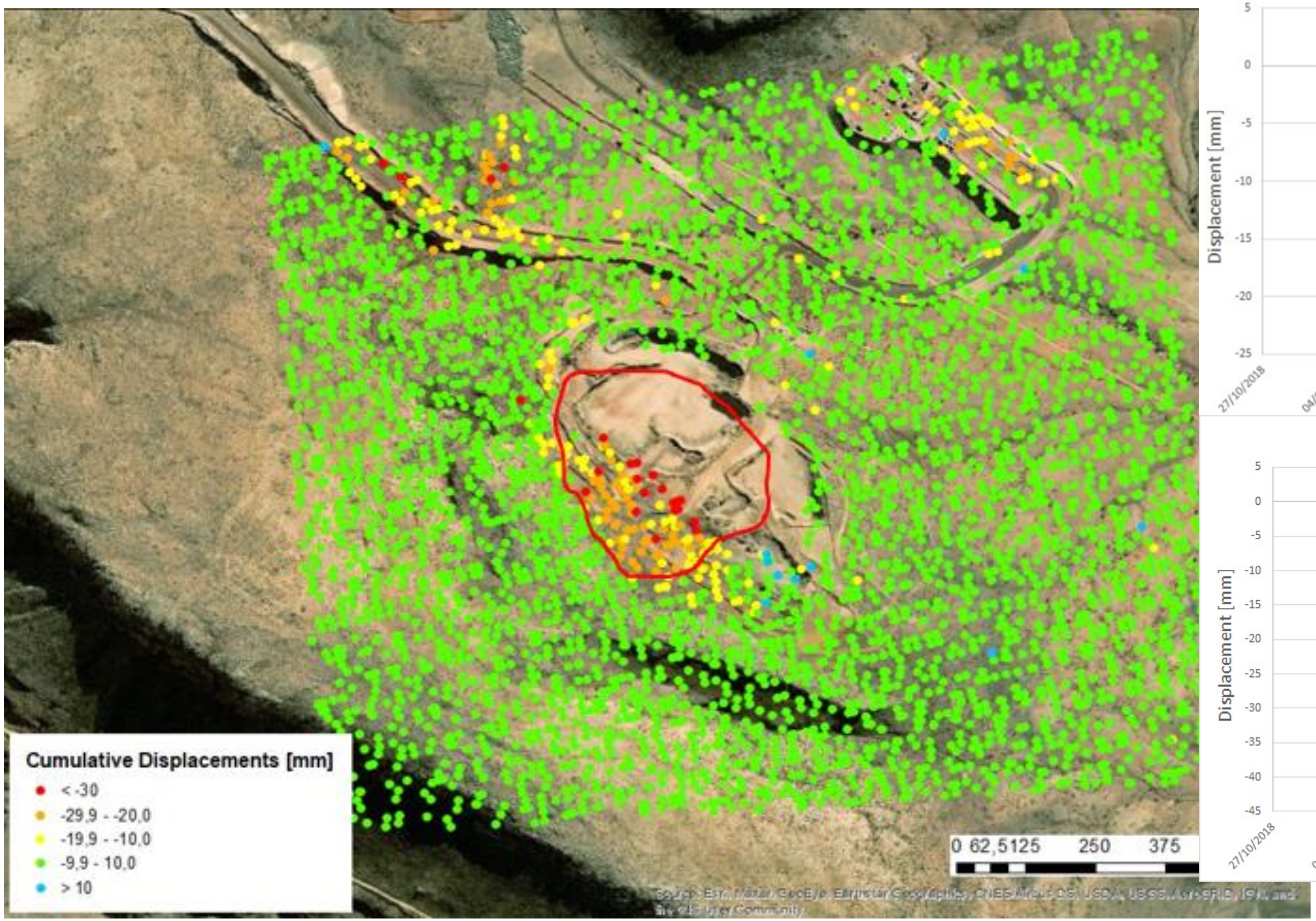
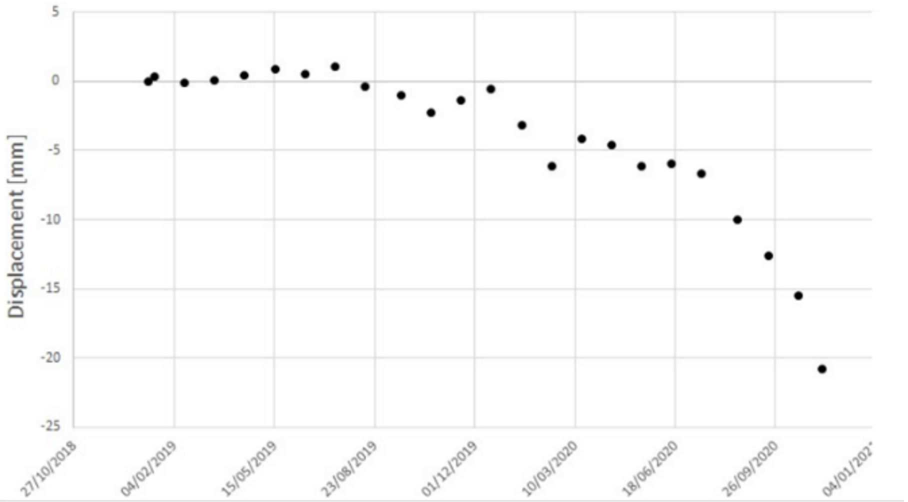
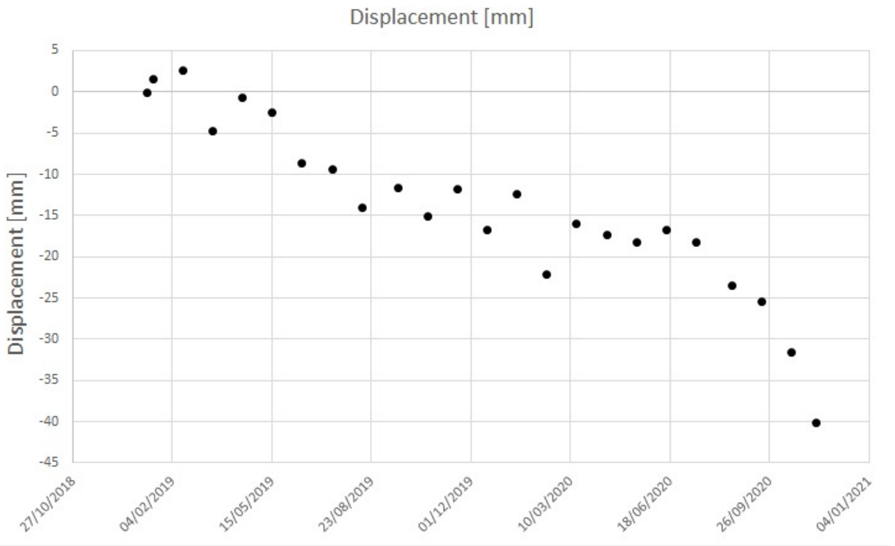
Gamsberg open pit case

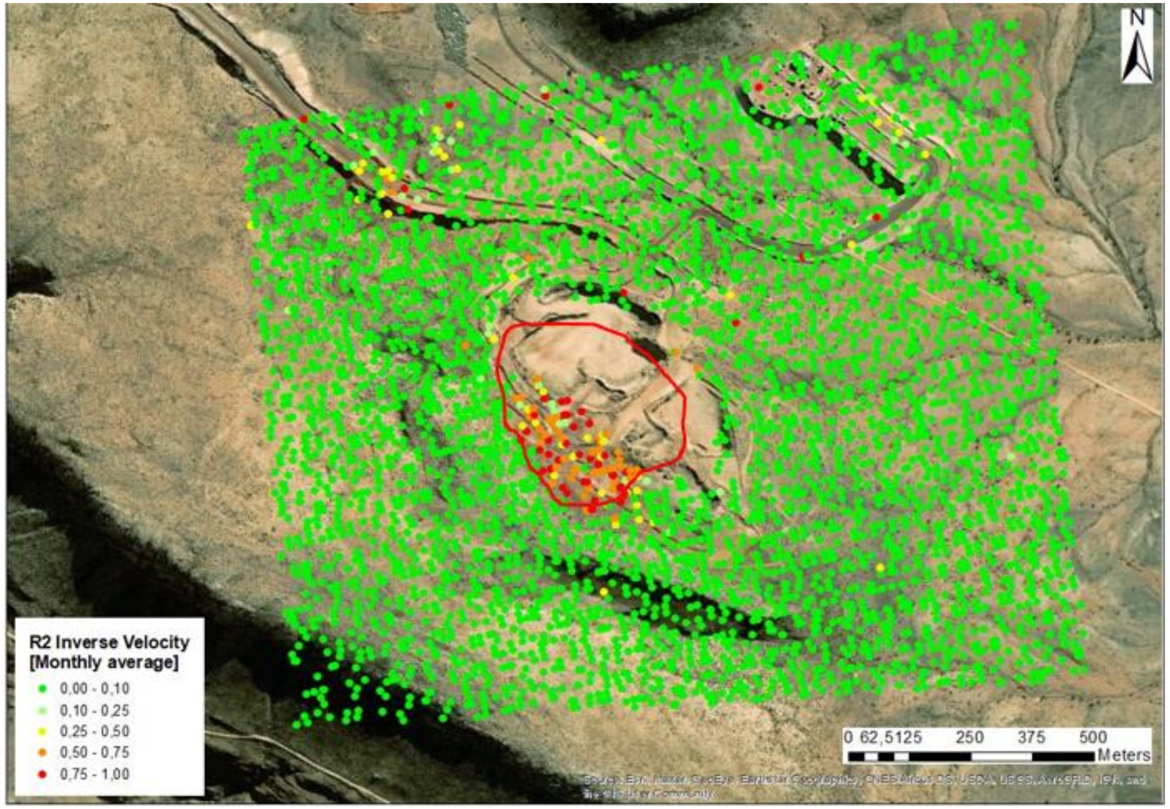






Cumulative displacement map from InSAR

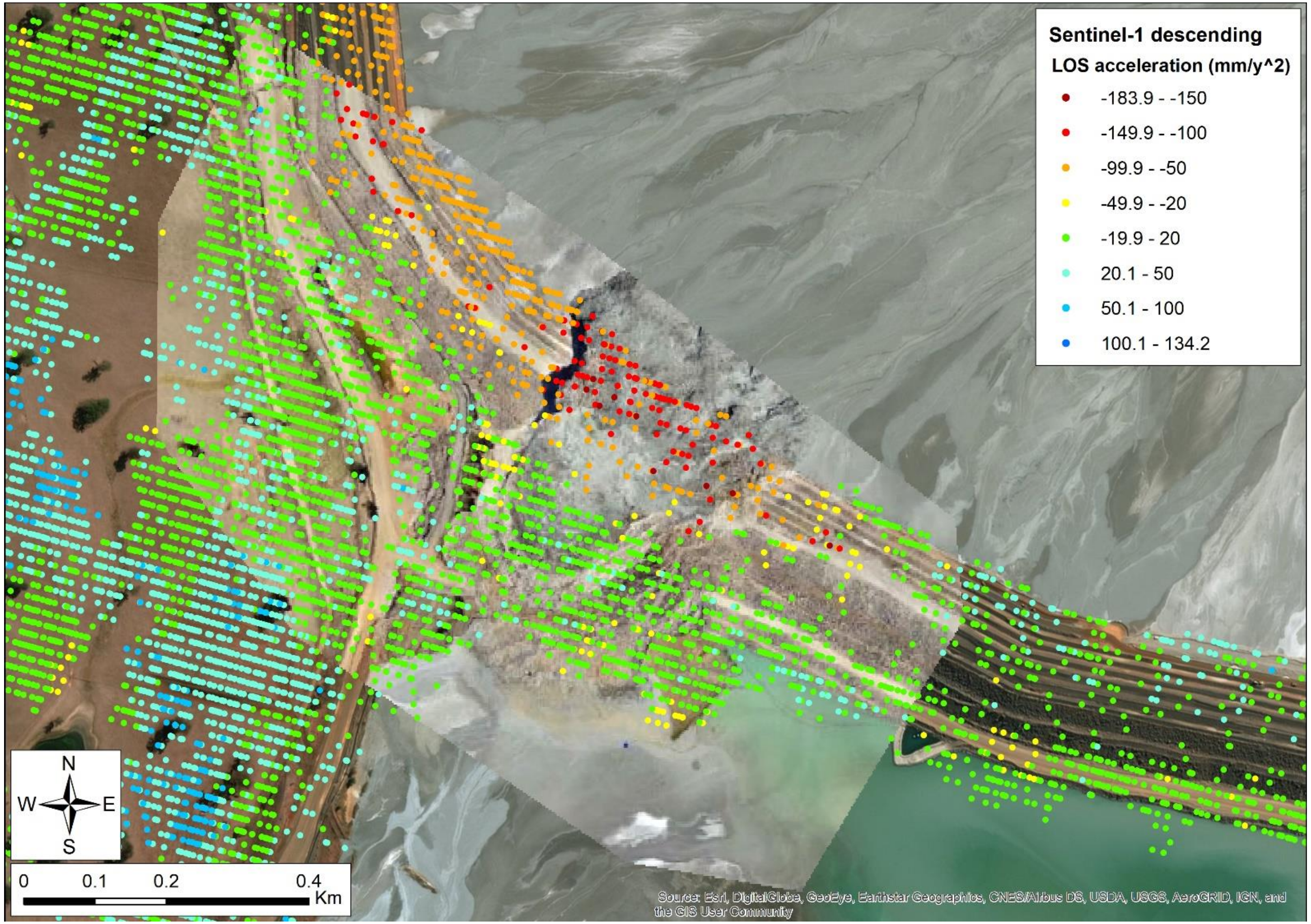
Gamsberg open pit case

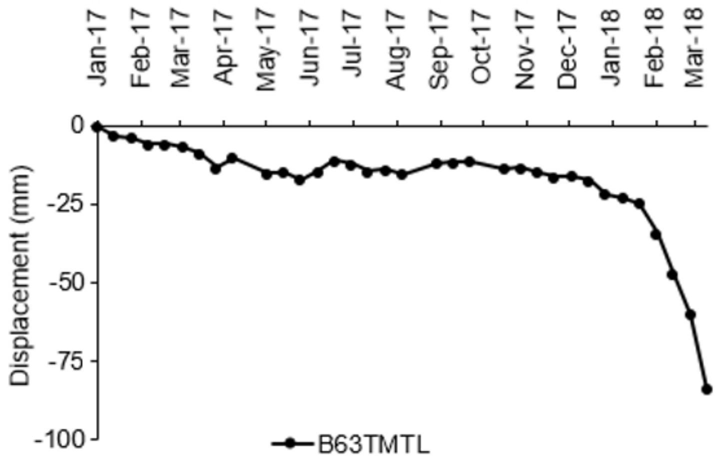


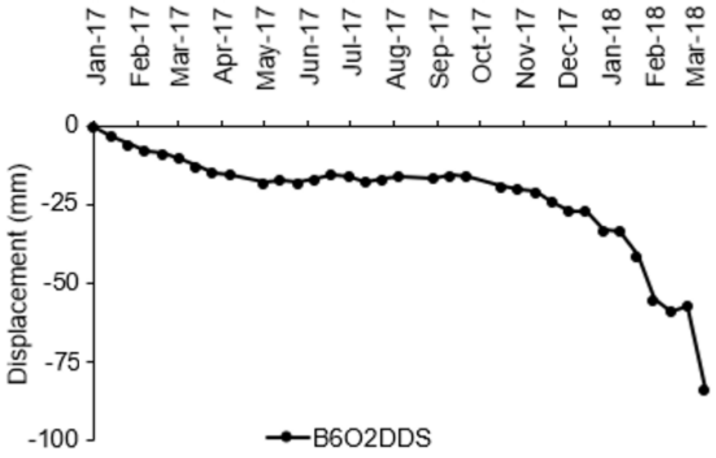
R^2 BF map

Intersection date map

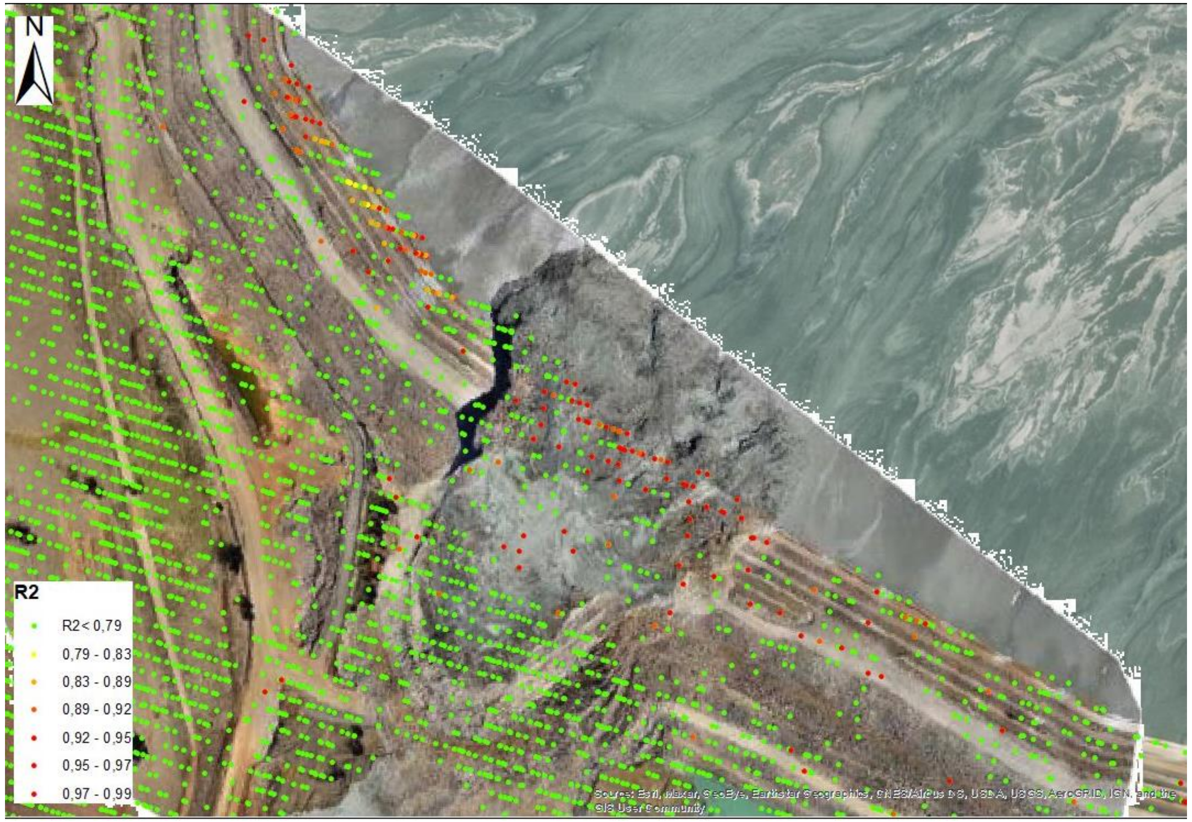
Cadia tailings dam case study



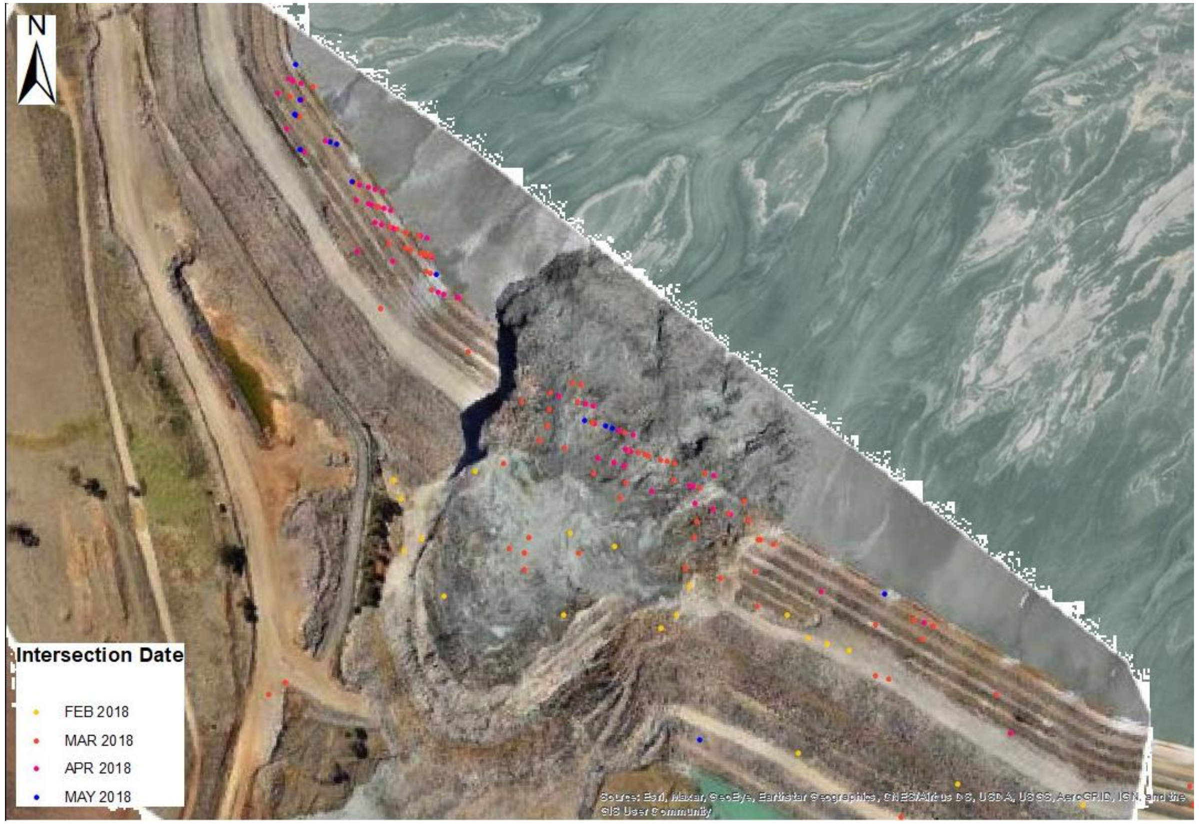




Cadia tailings dam case study

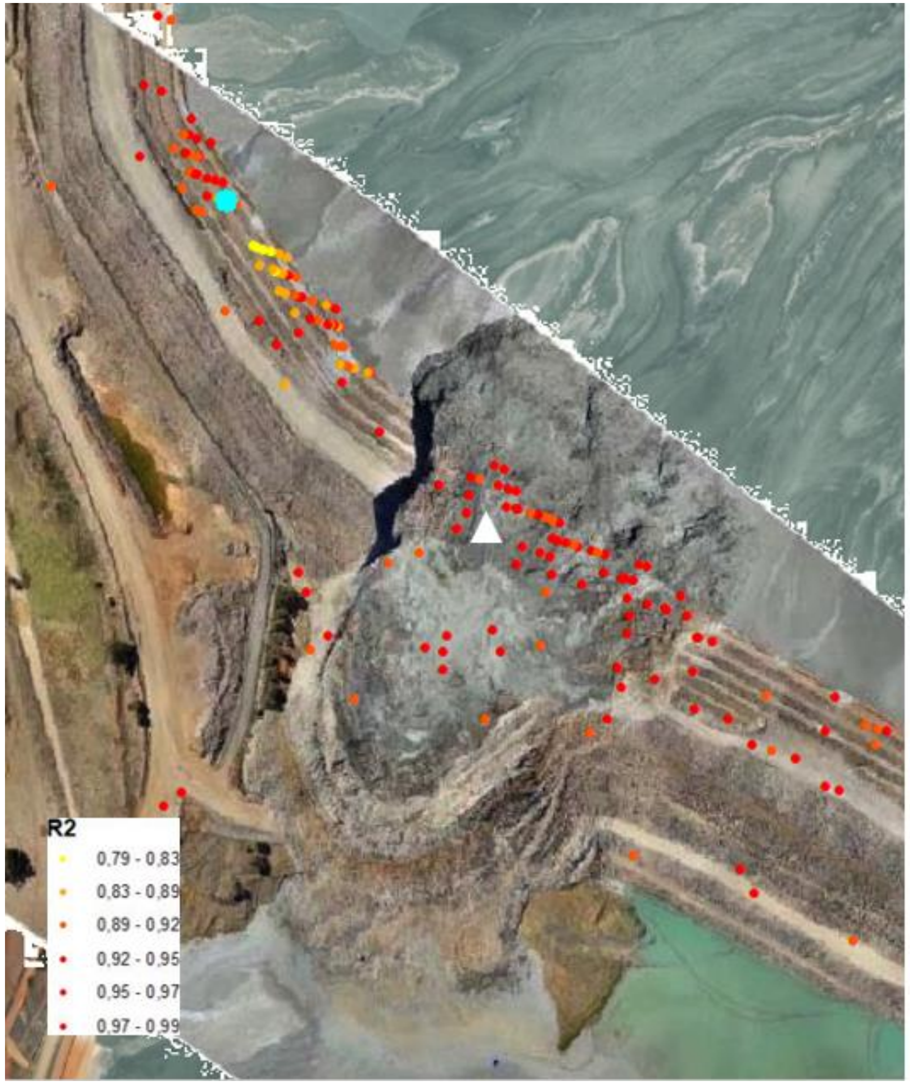


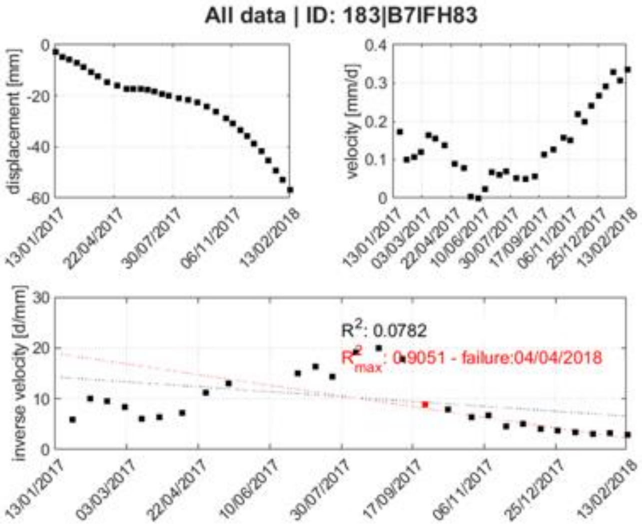
R^2 BF map

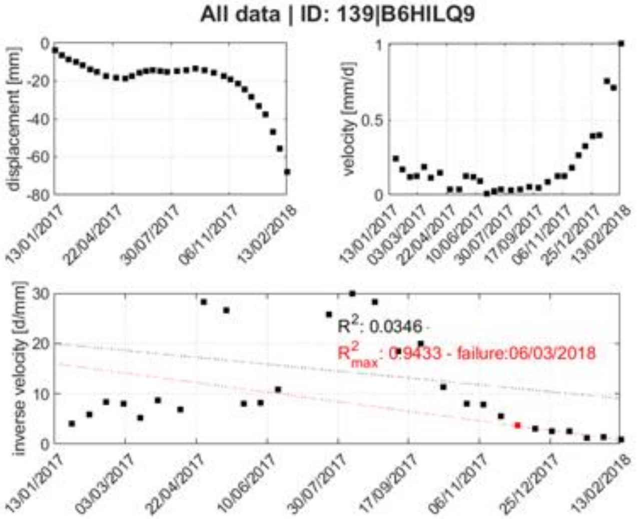


Intersection date map

Cadia tailings dam case study

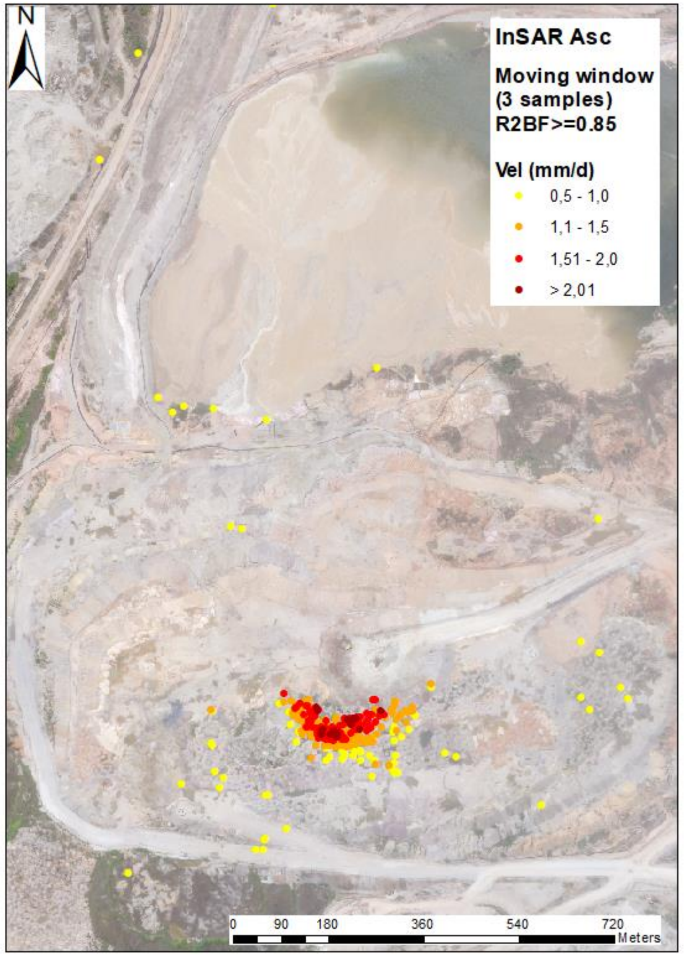






Waste dumps case study

12/06/2021



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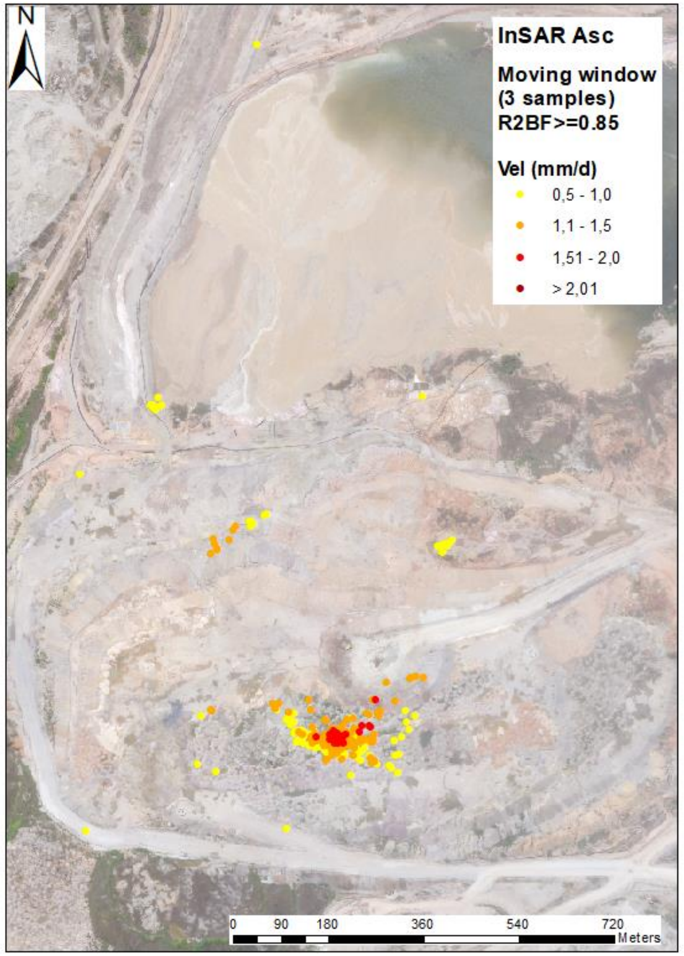

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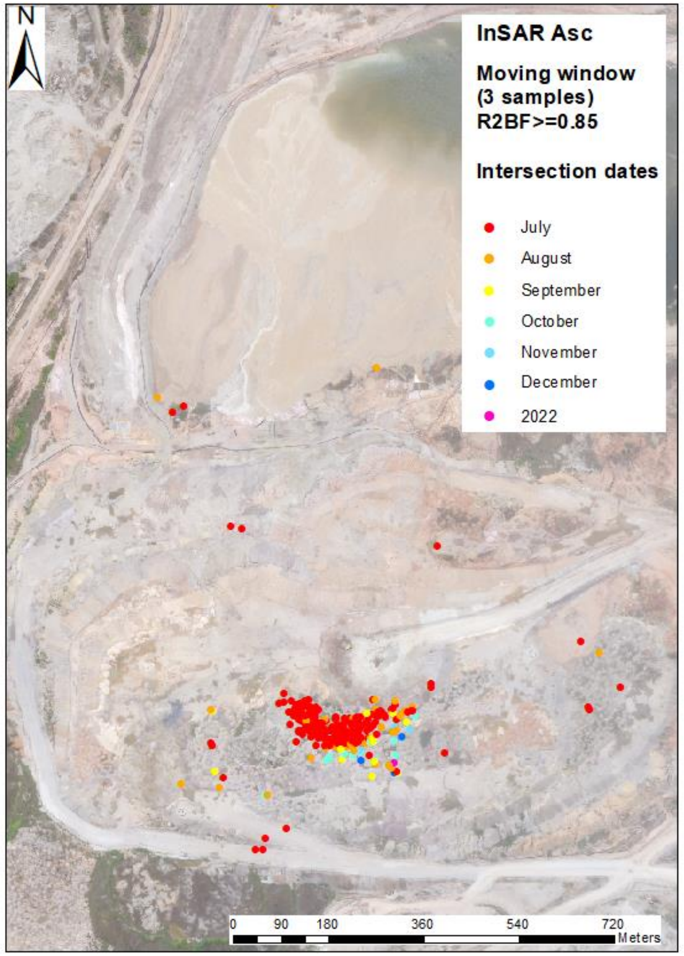

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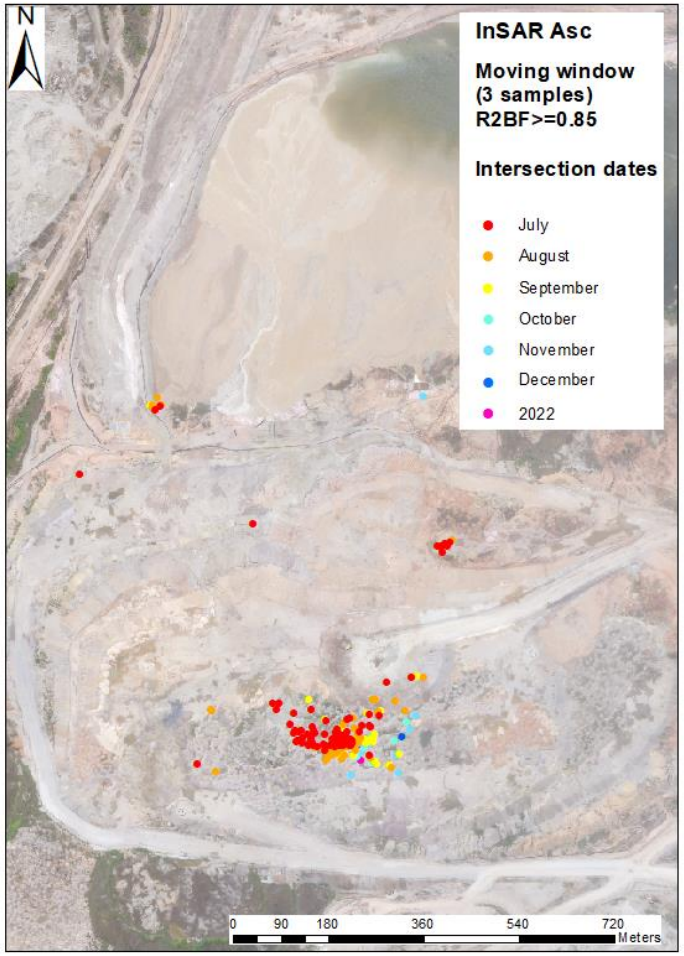

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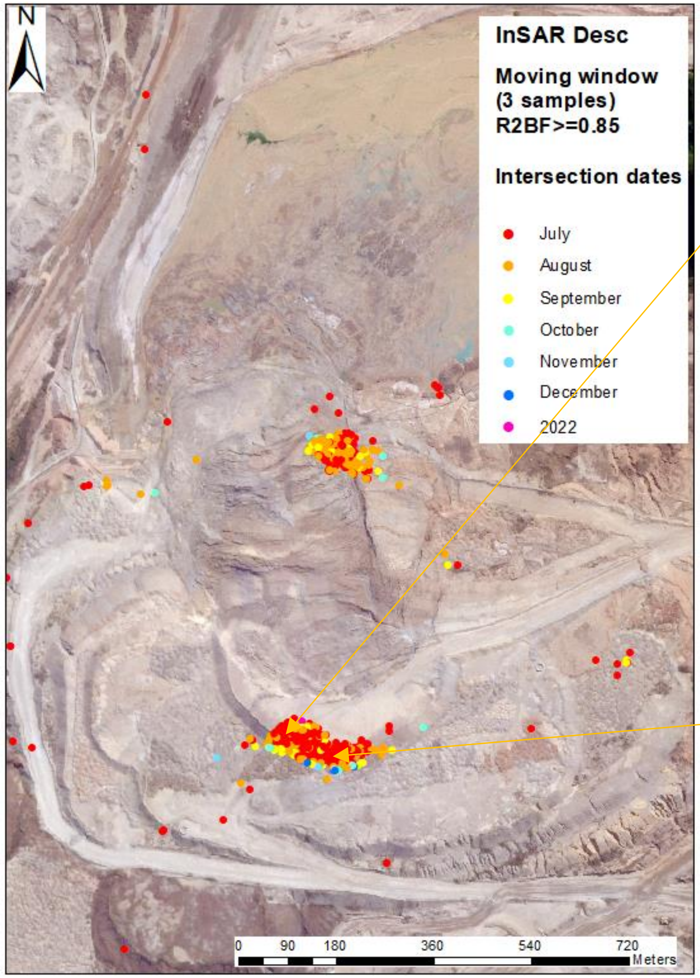
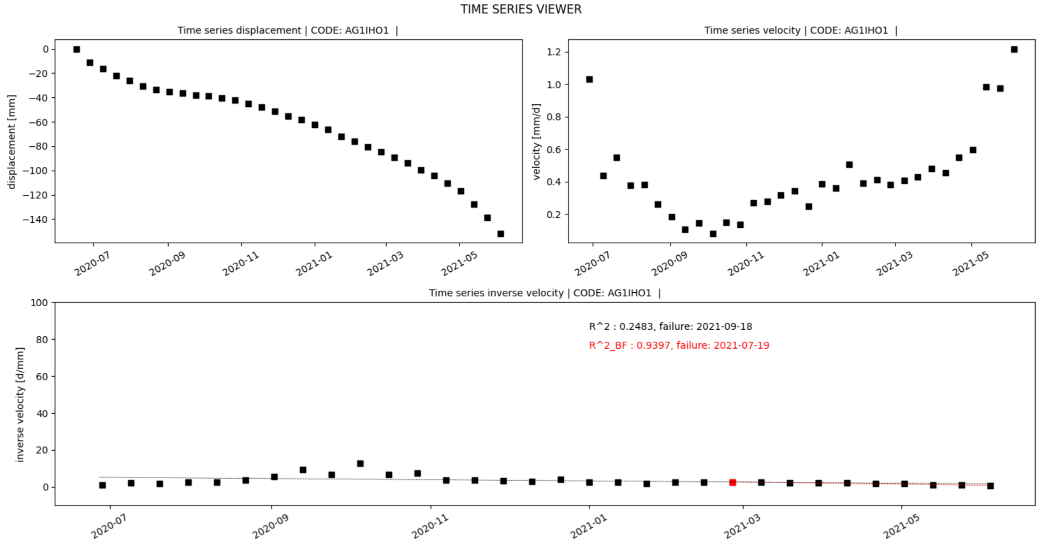
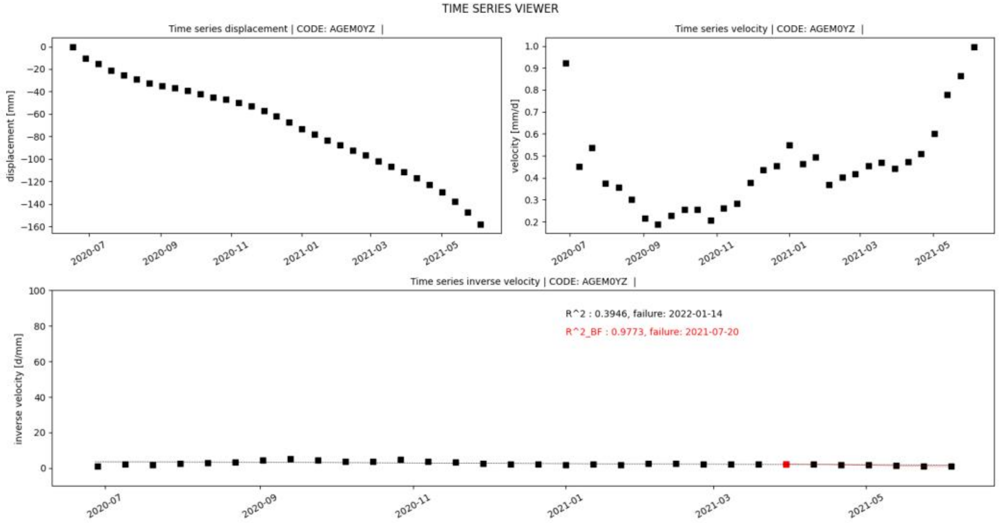
Waste dumps case study

15/06/2021







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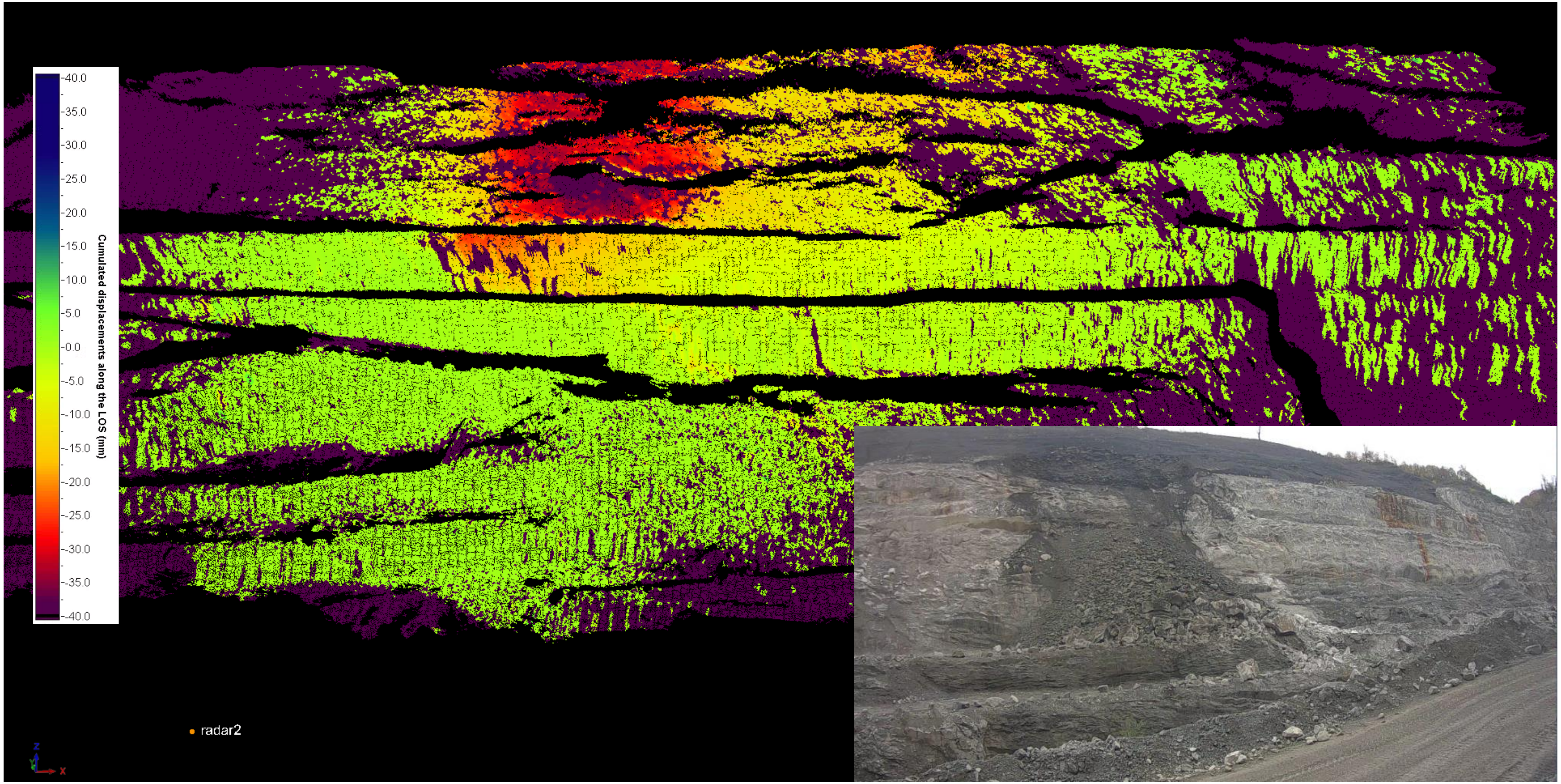
Quarry case study



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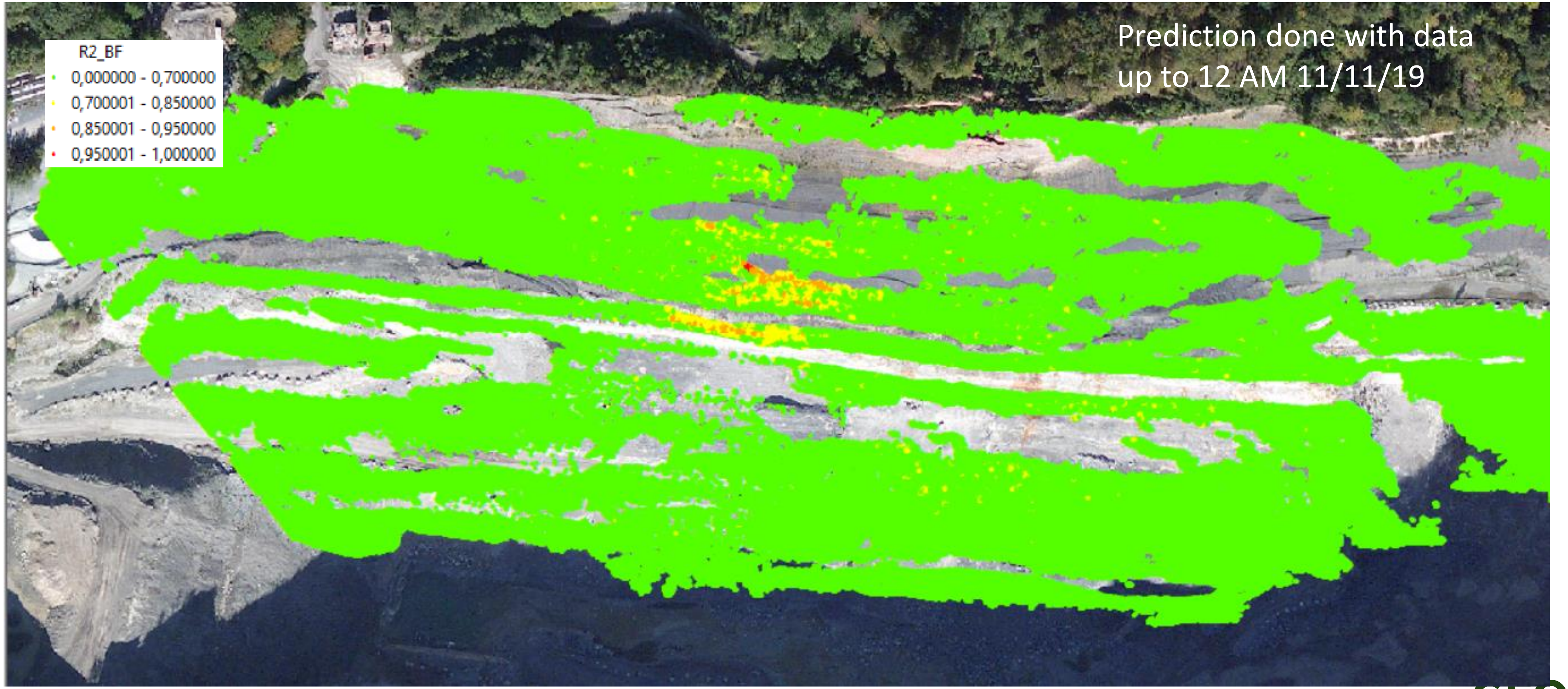
Quarry case study: R2 map 72 hours before collapse



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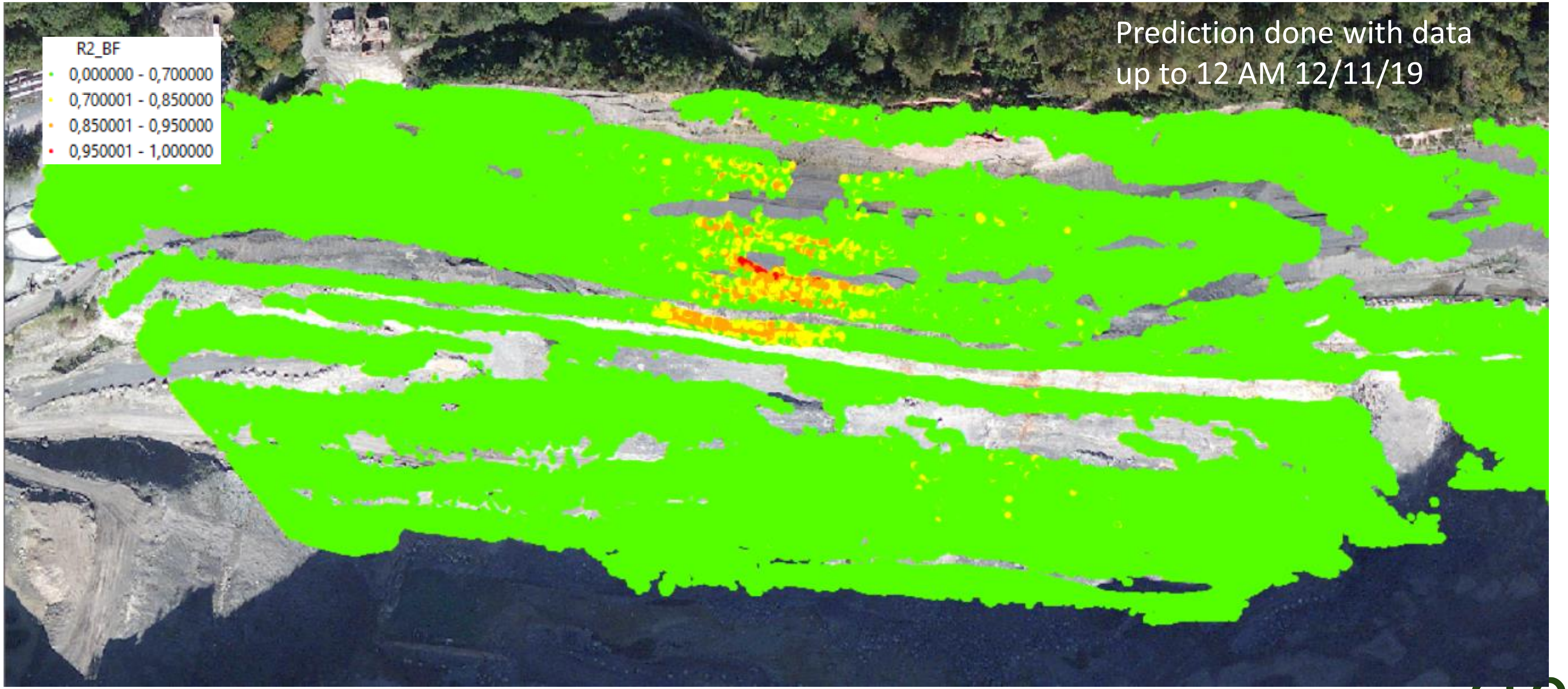
Quarry case study: R2 map 48 hours before collapse



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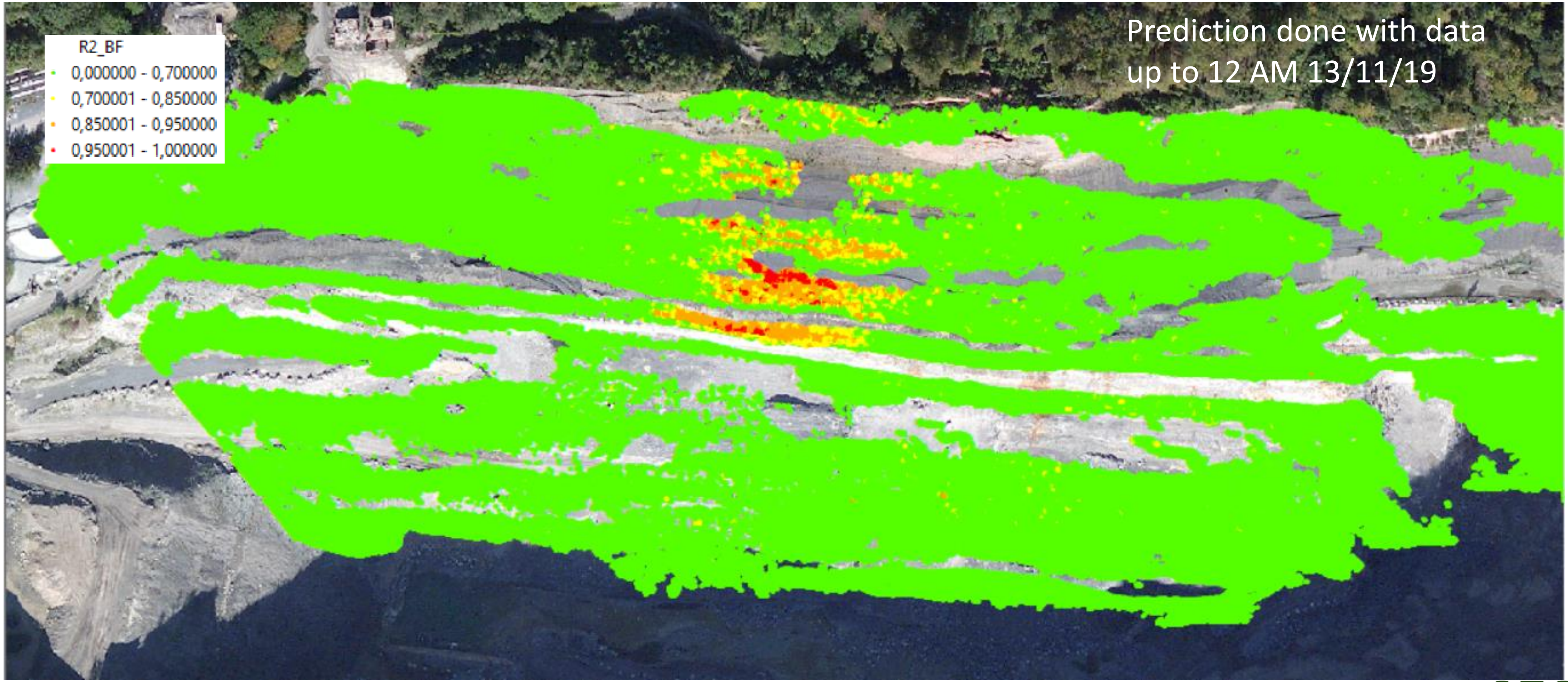
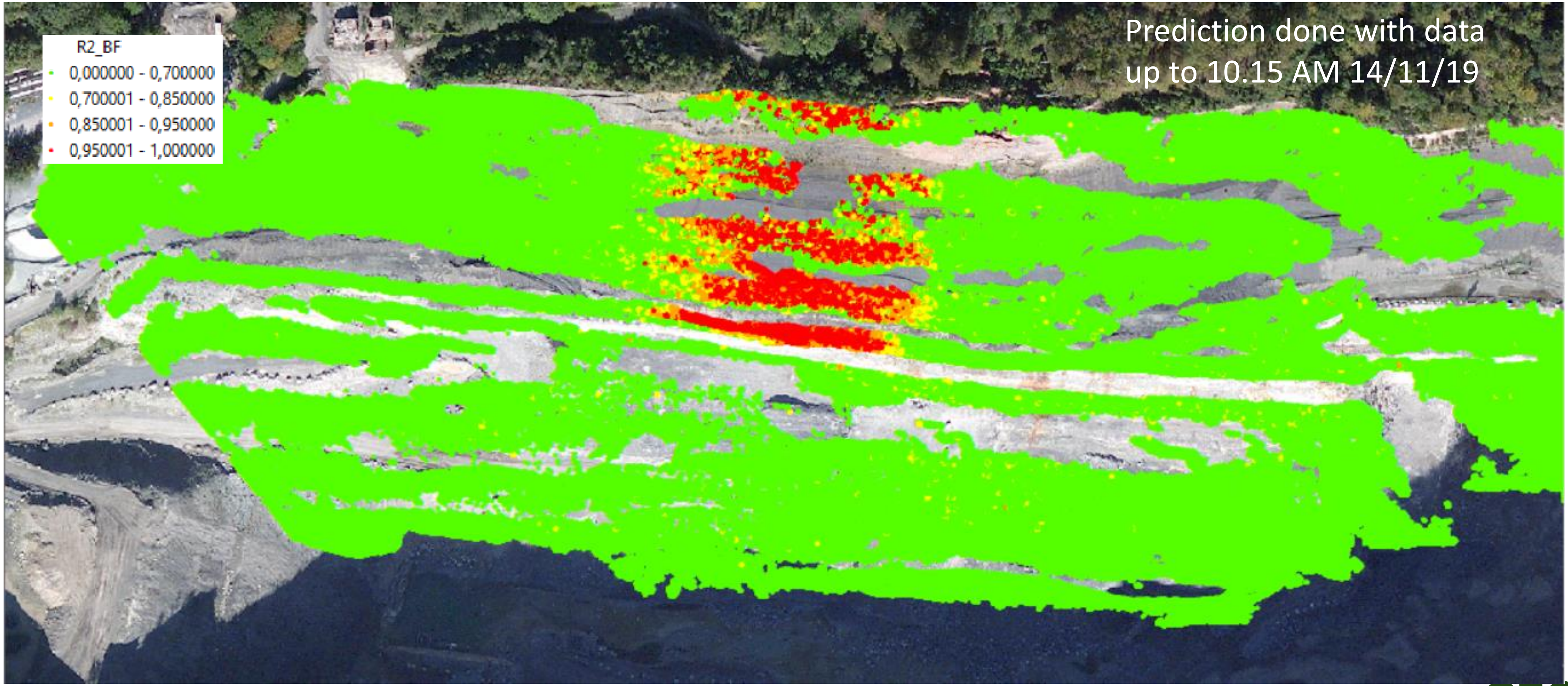
Quarry case study: R2 map 24 hours before collapse



Quarry case study: R2 map 0.5 hours before collapse



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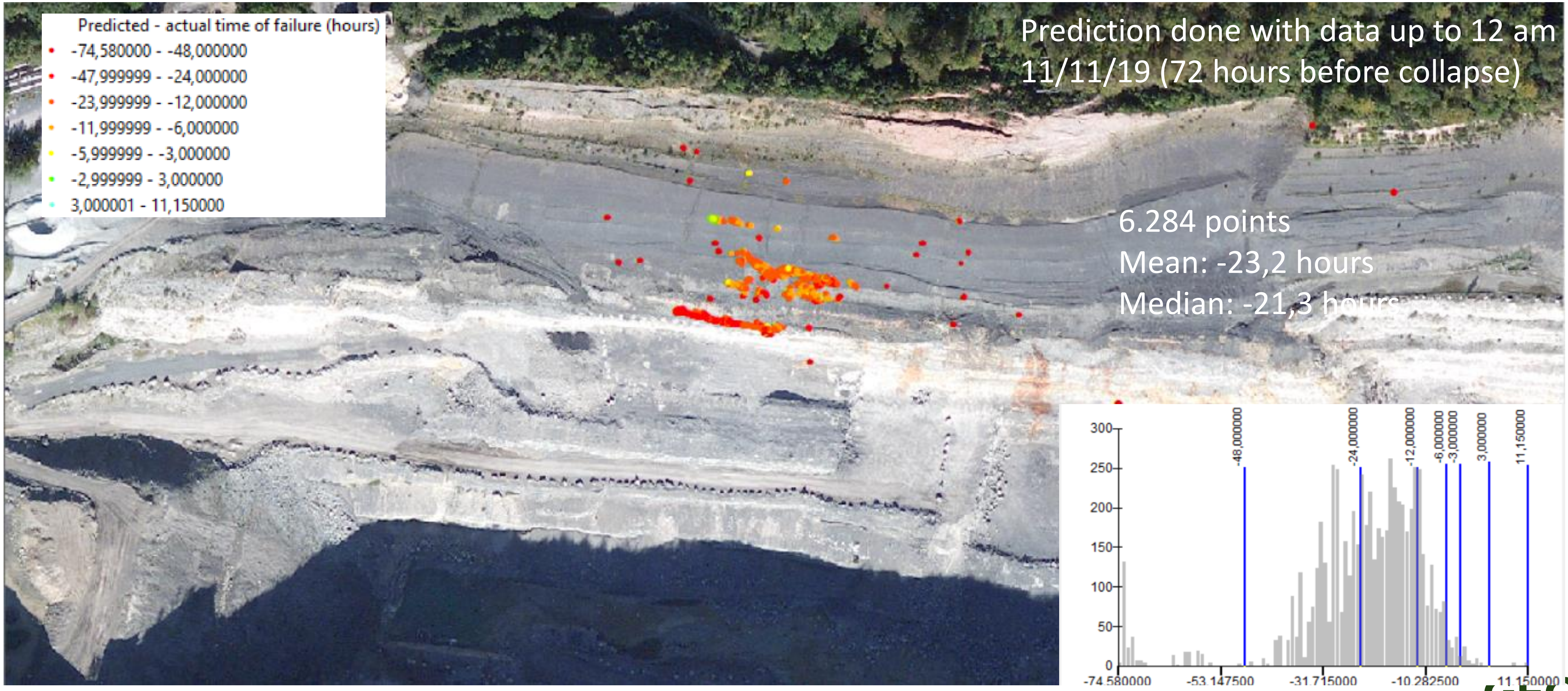
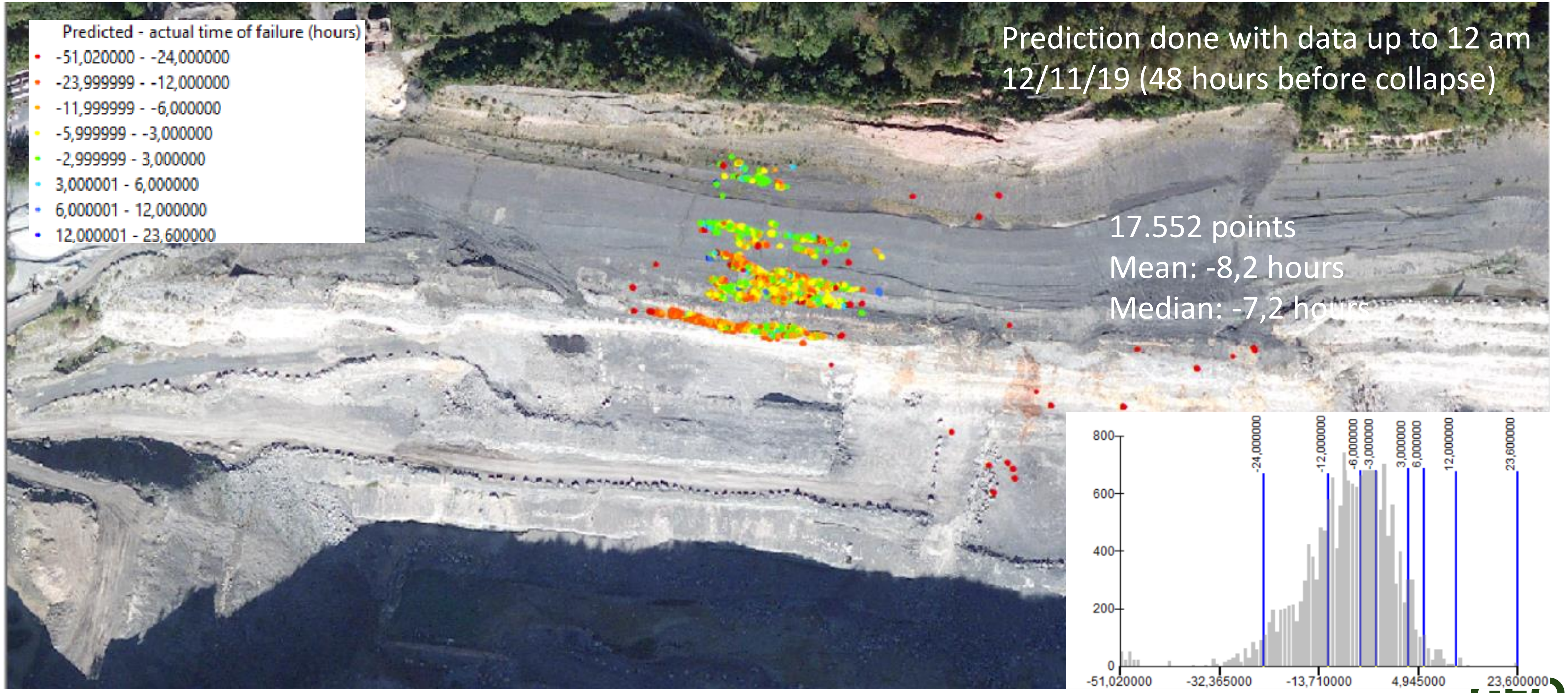
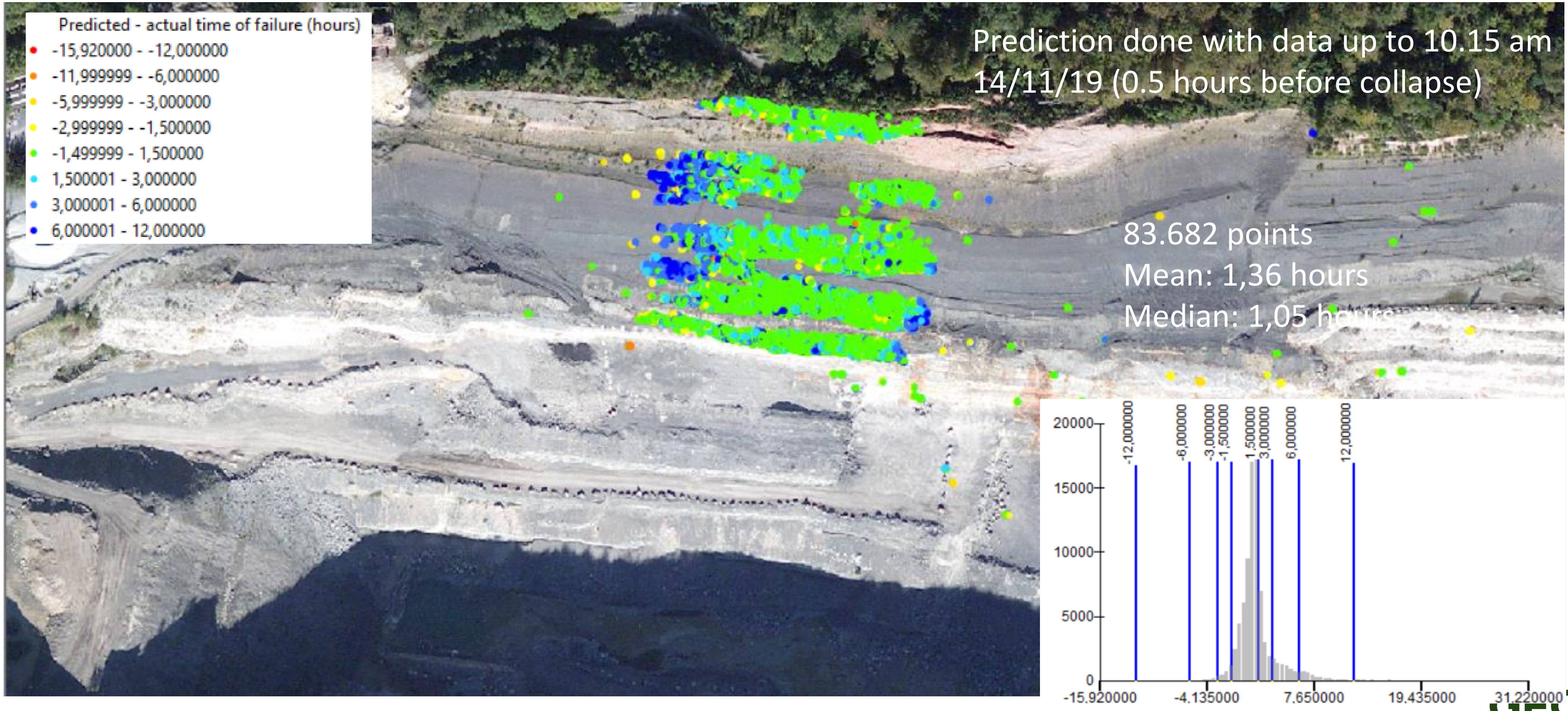
Quarry case study: Predicted – actual time of failure 72 hours before collapse



Quarry case study: Predicted – actual time of failure 48 hours before collapse



Quarry case study: Predicted – actual time of failure 30 min before collapse



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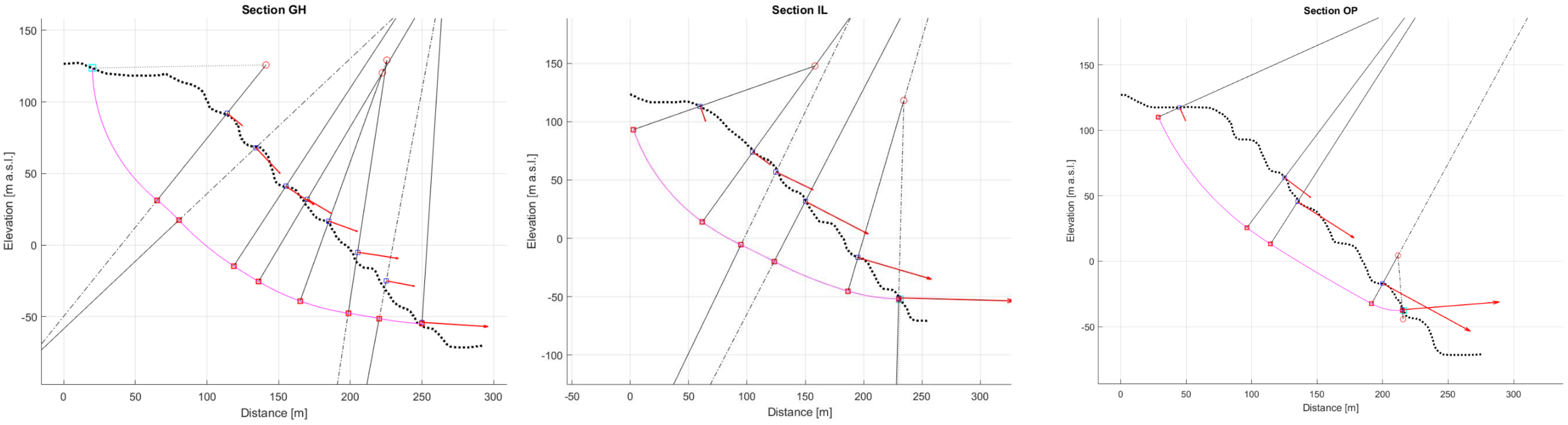
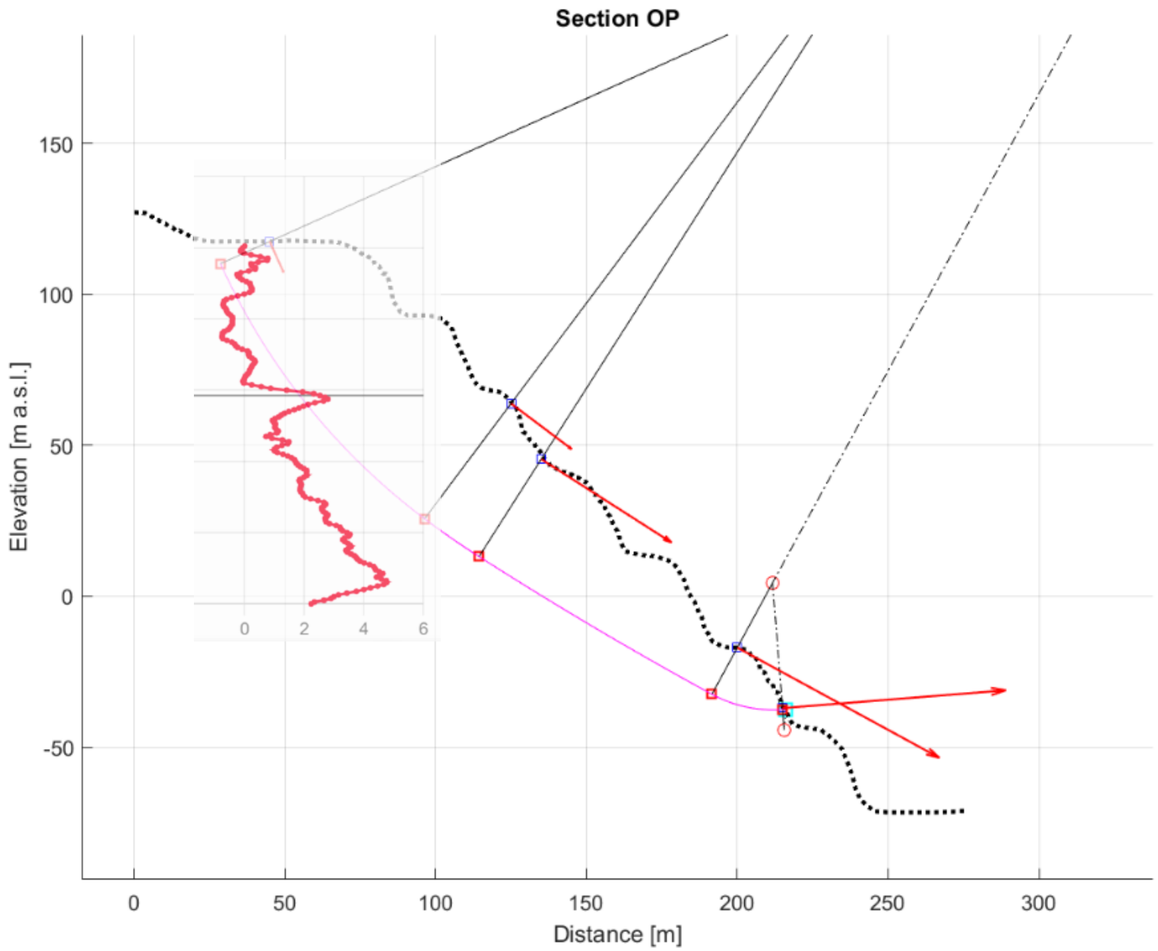
Estimation of the sliding surface



- The inversion of the surface displacement vectors done using the method proposed by Carter and Bentley (1985) first and then Cruden (1986) indicate the presence of a rotational sliding surface (rock mass failure) with an average depth of 55-65 m.

SAA vs estimated sliding surface

The described analysis led to the installation of a SAA inclinometer on the top of the slope. After a few weeks from the installation a clear shearing zone was identified at 60 m of depth.



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CONCLUSIONS

- Slope monitoring systems used in the modern mining industry are generating Terabytes of data, not always easy to be fully exploited by users with the scope of anticipating approaching failure conditions.

- A possible strategy to routinely analyze monitoring data has been presented, based on the following steps:

  a) time domain analysis: to highlight areas where progressive trends are present

  b) horizontal (planimetric) space domain analysis: to highlight areas with anomalous strain

  c) vertical (altimetric) space domain analysis: to understand the deformation mechanism

- The application of the proposed strategy to different mining assets, including open pits, tailings dams, waste dumps, solution mining and block caving has been presented.