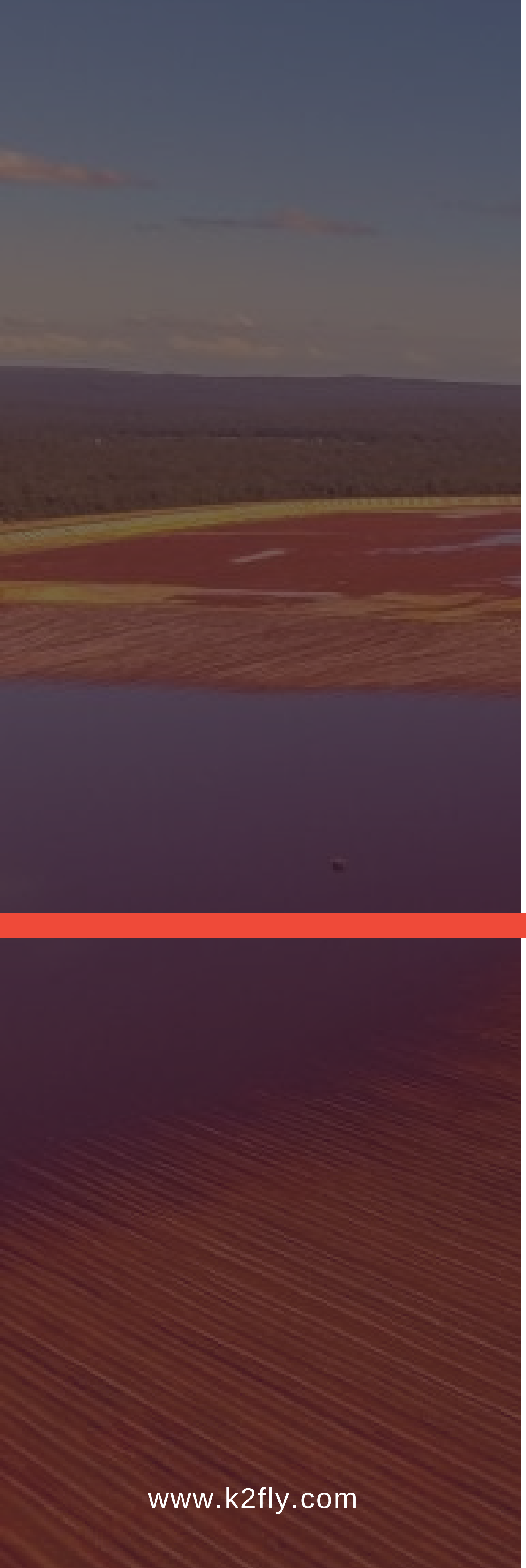
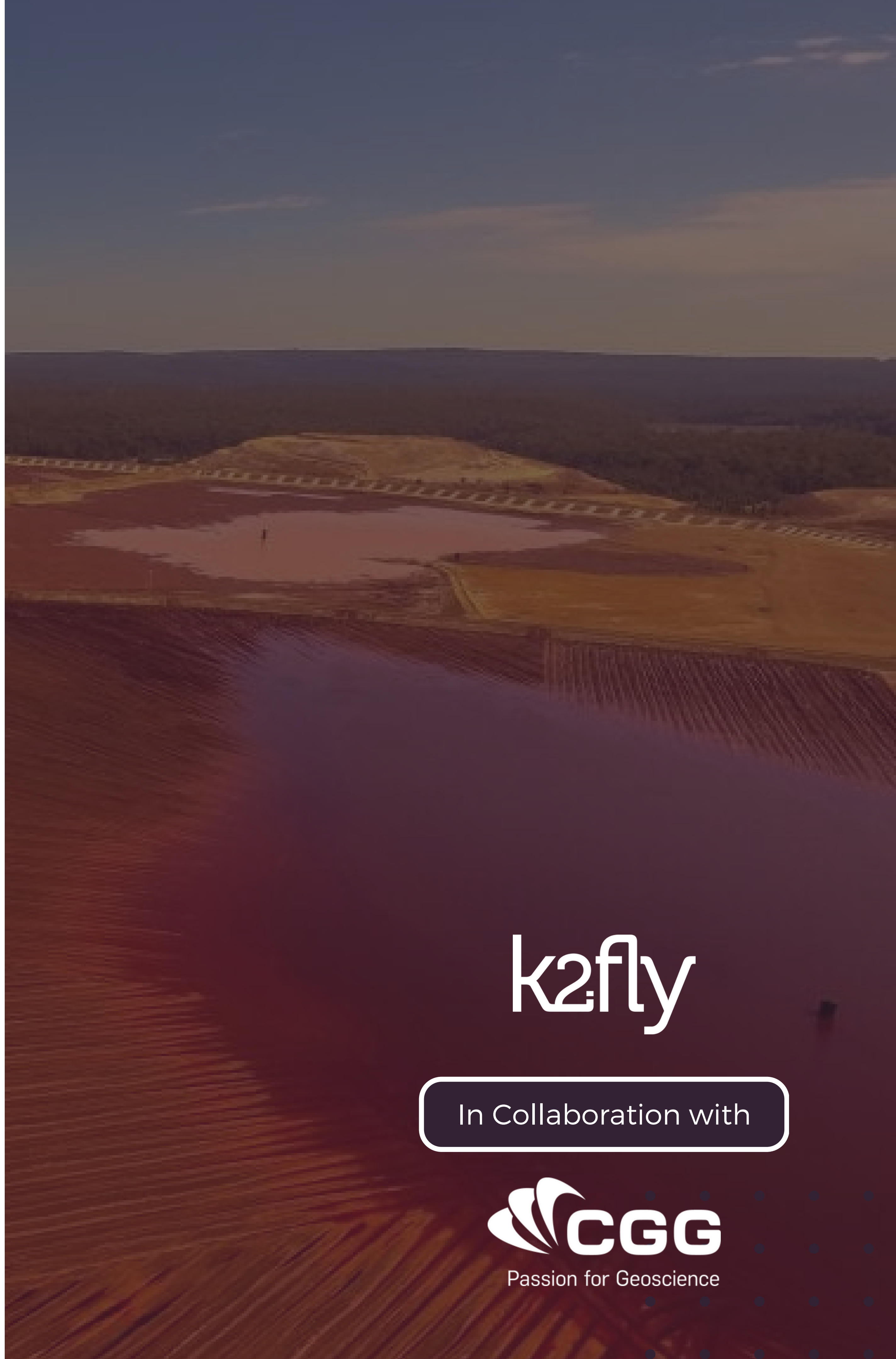


Leveraging InSAR to enhance Monitoring

How the world’s leading miners are leveraging InSAR for Tailings Monitoring and Management



k2fly

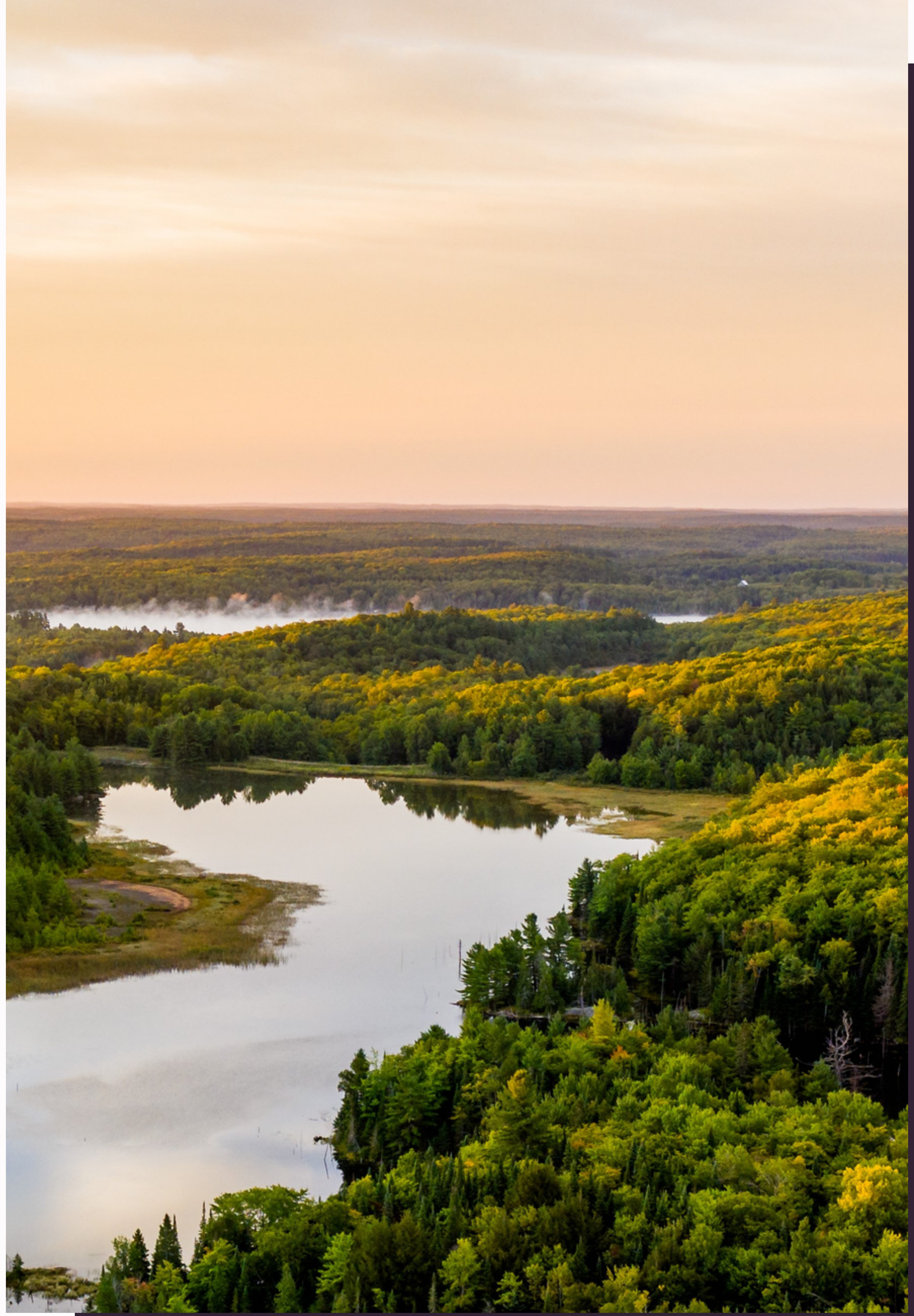
In Collaboration with

CGG
Passion for Geoscience

About K2fly

K2fly delivers enterprise-wide technical assurance software-as-a-service (SaaS) solutions for environment, social and governance (ESG) performance. Our Tailings Governance & Monitoring solution provides Environmental, Tailings, Geotechnical and Management teams with the tools to improve compliance, simplify data disclosure, and reduce the risks associated with tailings and dams.

This paper explores modern applications of Interferometric Synthetic Aperture Radar (InSAR) to the resource and energy industry, focusing on tailings storage facility monitoring and management. Data has been provided by CGG, a fully integrated geoscience company with world leading geological, geophysical, and satellite remote sensing capabilities, who have come together with K2fly to show what is possible to mining operators using leading technology.



Introduction

Interferometric Synthetic Aperture Radar (InSAR) is a remote sensing technique that uses geomatic processing on satellite radar captures over time to remotely detect movement in the Earth's surface with high degrees of accuracy.

Satellite-based InSAR is a well-established Earth Observation technique. It is becoming increasingly popular in larger-scale operations such as the resource and energy industry due to advances in satellite data availability and increases in geoprocessing capabilities, enabling it to be a more scalable and repeatable process. More specifically, InSAR is particularly wellsuited to monitoring Tailings Storage Facilities (TSFs). InSAR limitations of vegetation cover (for C-Band and X-Band sensors) and regular ground disturbance are not typically problematic at tailings facilities.

Tailings are the waste materials created as part of the Mining and Refining process and are stored in large dams – commonly referred to as TSFs or Impoundments. Due to the toxic nature of tailings, failure to adequately monitor and manage these facilities can result in catastrophic environmental, social and financial consequences, as evidenced by the devastating TSF failure in Brumadinho, Brazil, which killed 270 people.

The new initiative supported by broad mining sector participation, a Global Industry Standard on Tailings Management (GISTM), demands more data availability from mining companies, and the sharing of this data with relevant third parties such as the Independent Tailings Review Board (ITRB), Engineers' of Record (EOR), and Accountable Executives.

Data from satellite InSAR acquisitions and processed data stacks can provide support for a better appreciation of the site's overall stability and health status. At a macro and localised level, this data adds valuable context when combined with other monitoring data from the facility.

Through K2fly's ground-breaking use of cloud-distributed geo-processing of large datasets, users can interact with InSAR data and get instant feedback on displacement and subsidence over time with easy-to-interpret map visualisations and charts.
K2fly makes data easily available and reduces reliance on static reports, allowing expert users to provide oversight, share their experiences, and support staff training.

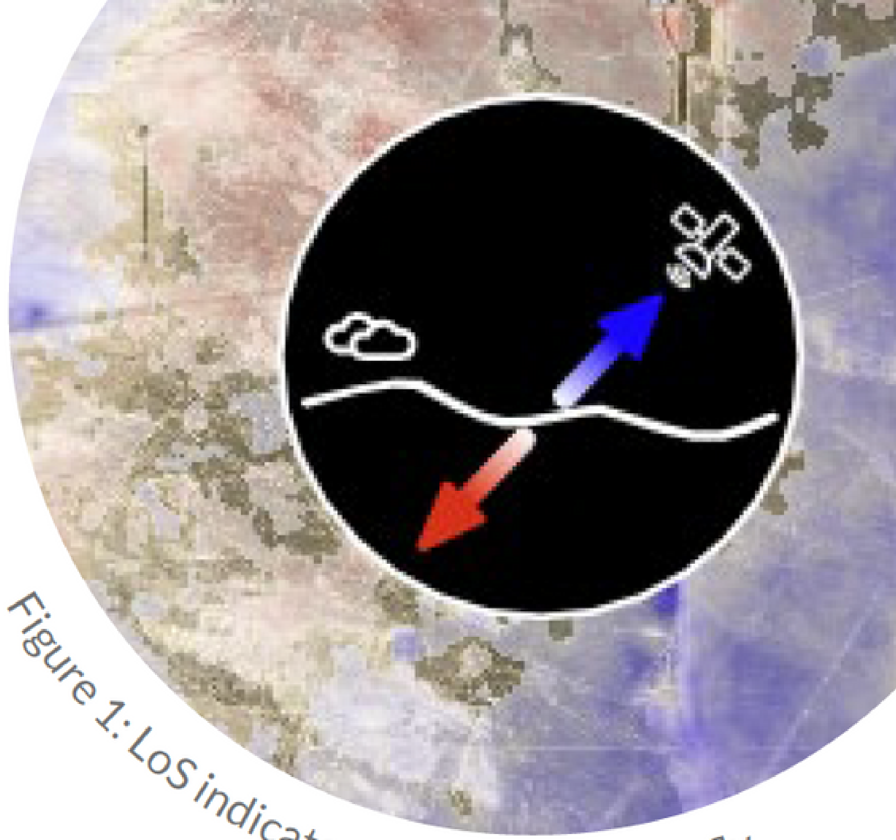


Figure 1: LoS indicator information in K2fly

> "K2fly makes data easily available and reduces reliance on static reports."

Through the K2fly InSAR module, users can build visualizations of displacements at a facility. Line of Sight (LoS) displacements are standardised to a cm/yr measurement, and periods of progressive displacement and tolerance exceptions are highlighted on maps and charts.

Analysis can be conducted on multiple stacks with dynamically rendered map layers and LoS indicators (see Figure 1), providing important context to the user on how InSAR displacement data relates to other monitoring data visualisations, from piezometers, other IoT devices, ground-based monitoring programs, and more.

Limitations of InSAR

Measuring ground displacement with InSAR is a precise and efficient way to remotely monitor a large area, such as a mine site. InSAR data does have some limitations due to the nature of the data acquisition. Satellite data acquisitions are made, ideally, from a pair (ascending and descending) of orbits. Some locations may only have a single orbit available. Dual orbit acquisitions allow for the decomposition of displacement in an East and West, and Vertical result. This is always preferred. However, any component of ground displacement oriented North-South will not exhibit displacement towards or away from the satellite. InSAR data is not sensitive to this motion.

Single orbit acquisitions are valuable but may only exhibit a portion of an area of interest (AoI) due to the orbit's inclination. Instrument revisit times over an AoI currently range from four to forty-six days. This will be a dynamic area of change in the near future as multiple companies launch X-Band constellations. Some of them hope to obtain four or even one-hour revisit times.

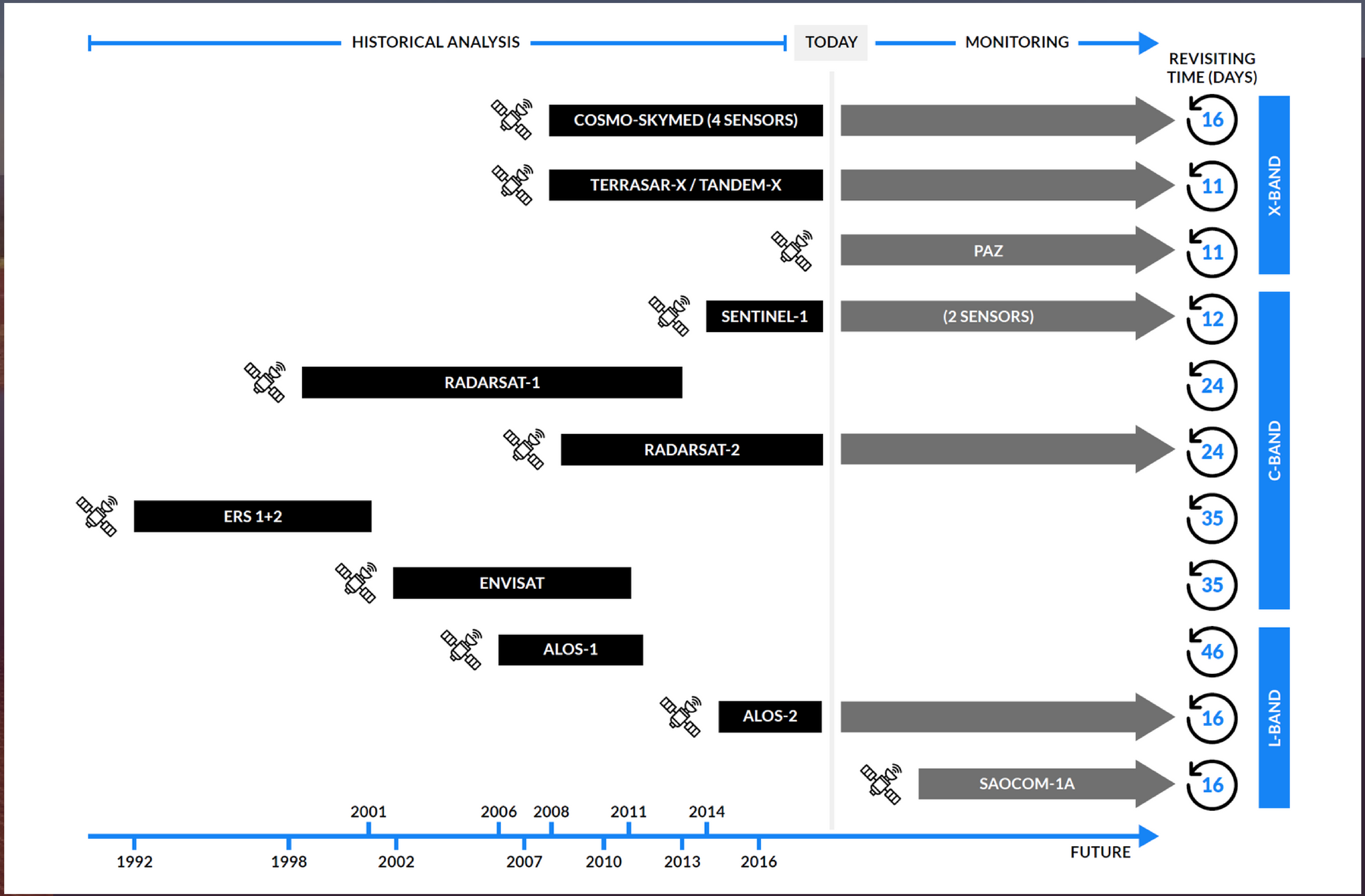
Also considered are any significant variations in topographic height; these may highlight distortions in SAR images because of the SAR instrument's oblique viewing geometry. Hilly terrain and ridge slopes facing the SAR satellite can exhibit distortions and act to obscure areas from view when facing away from the satellite. This is commonly known as shadowing. A rapid surficial displacement may go undetected if movement exceeds wavelength limits or elevation thresholds. Where site or AoI revisit times are infrequent or challenging, mine site users may have additional monitoring instruments on site. Terrestrial radar (RAR, GbSAR), or LiDAR instruments can provide valuable tactical or localised data acquisition.

Visualisation of InSAR Results in 2D

“The currently active SAR satellites provide interferometric SAR data at different wavelengths, spatial resolutions, and revisit times”

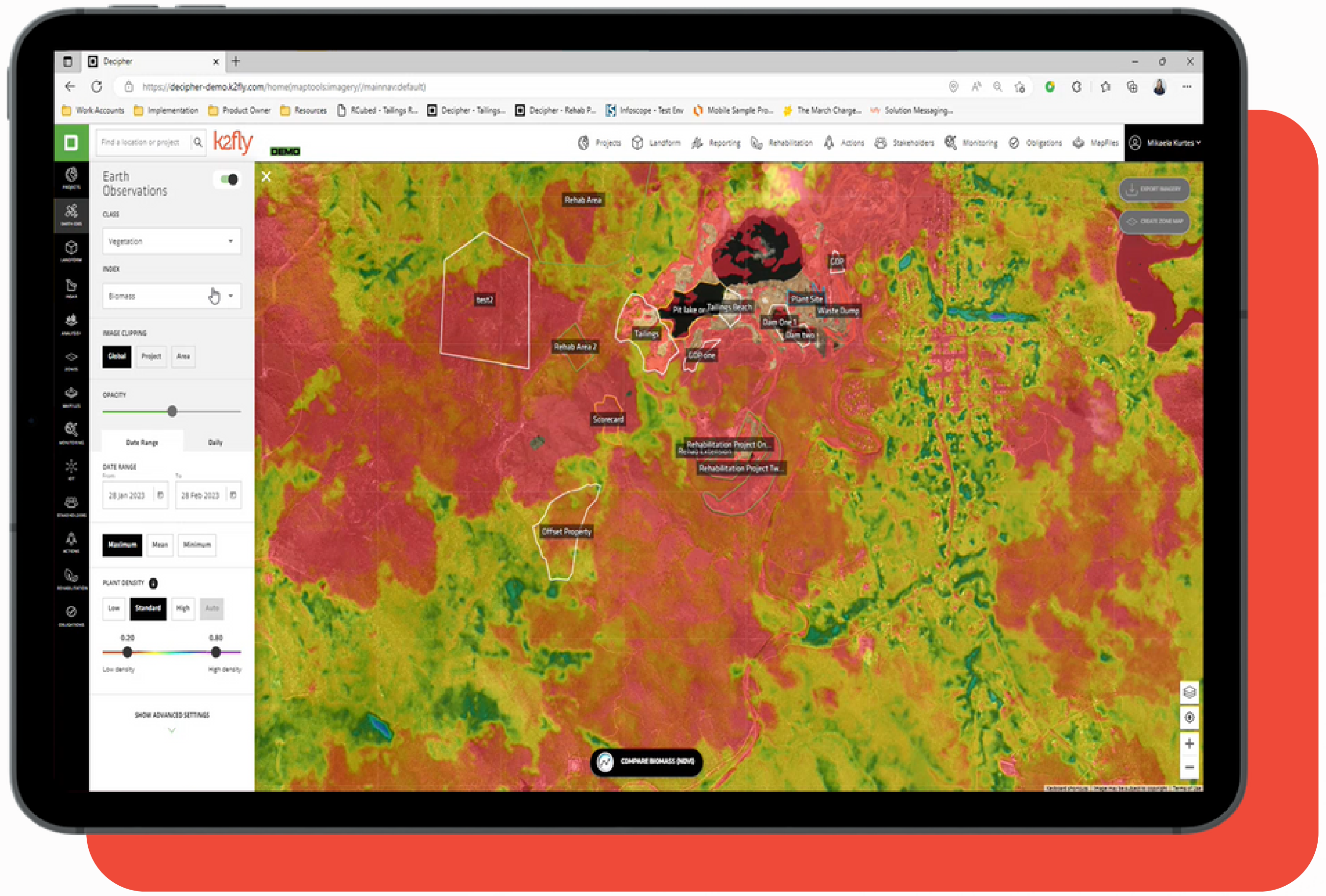
Since the first Synthetic Aperture Radar Satellite ERS-1 began orbiting in 1991, several satellite missions have been launched, especially since 2000. Today, numerous SAR satellites are available, and as mentioned previously, many others are scheduled for launch in the next five years. Some of the older SAR satellites have been decommissioned. The currently active SAR satellites provide interferometric SAR data at different wavelengths, spatial resolutions, and revisit times. High-resolution X-Band SAR sensors, such as the COSMO-SkyMed (CSK) and TerraSAR-X (TSX) constellations, acquire data with spatial resolution reaching sub-meter values and provide revisit times of up to a few days.

This allows for an increase in the density of data across the measurable targets. More significantly, frequent acquisitions allow for significant improvements in the detection of nonlinear displacements. Medium resolution C-band SAR data have been thoroughly exploited in the last two decades, using ERS-1 and 2 and ENVISAT-ASAR (ENV) missions and RADARSAT-1 and 2 (RSAT1-2). The European Space Agency (ESA) is providing the Sentinel-1 (S1) constellation, which has a spatial resolution comparable to previous ESA C-band missions and a revisit time of 6 – 12 days depending on the location of the target. Sentinel platform data is open access.


HISTORICAL ANALYSIS
TODAY
MONITORING
REVISITING TIME (DAYS)
COSMO-SKYMED (4 SENSORS)
16
TERRASAR-X / TANDEM-X
11
PAZ
11
X-BAND
SENTINEL-1
(2 SENSORS)
12
RADARSAT-1
24
RADARSAT-2
24
ERS 1+2
35
ENVISAT
35
C-BAND
ALOS-1
46
ALOS-2
16
SAOCOM-1A
16
L-BAND
1992
1998
2001
2002
2006
2007
2008
2010
2011
2013
2014
2016
FUTURE

InSAR data has been successfully used worldwide to assess specific events.

For example, the Grasberg mine in Paua, Indonesia, was a real challenge for monitoring with extreme terrain and turbulent tropical weather on top of natural geohazards a part of the daily environment. The 80km extended tailings area was monitored using dual-orbit TSX data at 11-day intervals, creating an excellent ground displacement history. This addition to the operational monitoring program deployed at this mine site enhanced the early warning systems and ongoing risk management.



Another example of a practical InSAR application was a study across the Cadia mine in New South Wales, Australia. This site experienced a localised TSF failure on 9 March 2018.

The InSAR results show that low-magnitude subsidence signals were observed across the TSF dam during the year preceding the collapse. In January 2018, a notable change in behaviour was observed, with a concentrated subsidence area focused on the region, which initially failed on 9 March 2018. Post-collapse InSAR measurements show an increased subsidence rate for regions on either side of the failure zone. A review of medium and high-resolution satellite images shows that the failure was in phases, with an initial failure and then a subsequent failure, at least two days after 9 March 2018. It also highlights what might be construction activity associated with a dam raise before failure. [3]

A post-collapse analysis was conducted on ten descending SAR images acquired by the Sentinel-1 satellites at 12-day intervals from 21 March until 19 July 2018.

The aim of this was to establish whether the dam had stabilised post-collapse or whether it was still deforming.

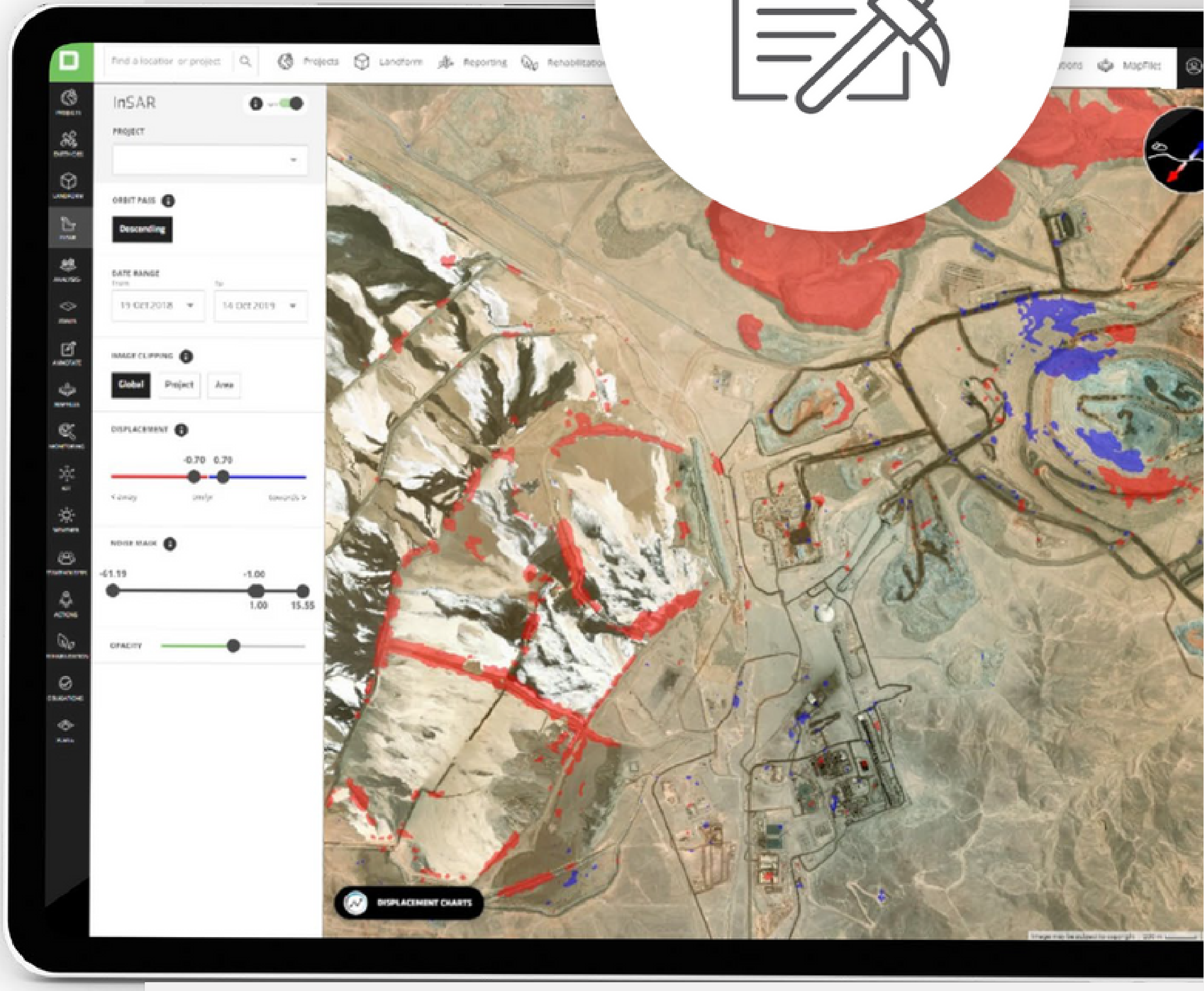
Figure 4 shows the mean displacement rate for the TSFs post-collapse in 2D view. The red and orange regions on the map show where the TSF dam was still subsiding following the collapse, with the greatest change occurring in the regions surrounding the failure. The greatest subsidence occurred in the region to the east of the failure (red area), with displacements of up to 40 mm over the period. This region of the tailings is notably subsiding more, from 21 March to 19 July 2018, than the pre-collapse event measurements, exhibiting that it could be under additional stress following the collapse.

Figure 4: InSAR Acquisition over Cadia Mine
The red circle shows the tailing dam collapse area© CNES 2018, Distribution Airbus DS. InSAR data contains modified Copernicus Sentinel data (2018), © CGG 2018

Visualisation of InSAR

Representation of geo-information allows a user to visually and vividly reflect a spatial dataset's physical context. K2fly's module allows users to combine different types of data in the same web GIS architecture, enabling compelling visuals and the ability to assess, understand, and solve problems.

Visualisation of InSAR data is a fairly novel concept and has previously been offered using overlays of Google Earth by some InSAR providers. Demand for visualisation has grown recently. To meet this, K2fly offers data with real-world background and contextual information with full control on the visualization, including InSAR.



In this collaboration, CGG and K2fly looked at a mining site using InSAR data from 19 October 2018 to 14 October 2019.

The "traditional" view highlights key areas of displacement: Red-coloured data areas are moving away from the sensor (e.g. compaction or subsidence), and blue-coloured data areas move towards the sensor (e.g. swelling or heave).

Augmenting InSAR with detailed monitoring

While not the aim of this collaboration, sensor data from the facility (such as weather, inclinometers, seismometers, and more) augment and enhance the story being told by the InSAR results. The K2fly solution integrates most of this sort of telemetry data from a facility. It presents it to an end-user in a user-friendly format so that determinations can be made. Lidar, radar, sensor, and satellite data (InSAR and Imagery) then work together for even further visualisation.

K2fly also tracks and manages actions within the system. This ensures that observations are acted upon and closed out as part of the management process.

Conclusion

In a world where Environmental, Social, and Governance (ESG) are gaining criticality rapidly, and TSF’s are being scrutinised by management more than ever, Visualisation of InSAR (and other) data is being requested by more and more consumers. The efficient collaboration by CGG and K2fly has shown that it can be effectively configured in a short space of time so that end users can benefit from the vivid and rich outputs the views can provide.

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