The Use of Advanced Geohazard Management Software to Incorporate Real-Time and Near-Time Data into Decision Making

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1 ABSTRACT

The increase in available real-time or near-time weather and earth sensing data and the expanded use of remotely accessed geotechnical instrumentation has resulted in a step change over the last decade in how pipeline operators can manage the integrity of their pipelines related to geohazards. The age-old techniques of watching SCADA readouts combined with periodic line inspections by helicopter or fixed-wing aircraft have now been supplanted by the use of real-time flood monitoring and seismic alerting, the ease of obtaining highly precise ground monitoring through lidar and satellite-based interferometric synthetic aperture radar (InSAR), and the use of new geotechnical and geophysics tools with significantly reduced costs of remote telemetry.

To effectively use this wealth of real-time and near-time data, leading pipeline integrity and geohazard management professionals have evolved geohazard management software for pipelines to integrate and visualize this data in ways that drive better, faster insight and perform automated analytics to highlight change dynamically. With the newer generation of geohazard management software, operators can efficiently leverage immense amounts of data while still focusing their attention on the most important areas of their pipeline system. Across a pipeline network, for example, the newer generation of software can highlight areas where snowpack or precipitation is greater than normal, identify watercourse crossings where flooding is likely to or is occurring, outline where forest fires have recently occurred, or alert on areas where the ground surface has moved. Realtime instrumentation can be remotely interrogated to determine when the situation started to change, how fast it is changing, and can be analysed with other data sources such as from Inline Inspection (ILI) tool strain data and lidar change detection – all in one place.

This paper will present case histories demonstrating how these newer technologies can be successfully incorporated into geohazard management programs through software that provides continuous data integration, insight and analytics, and active monitoring and alerting of geohazards.

2 INTRODUCTION

Over the last two decades, geohazard management programs have started to become standard practice as part of overall pipeline operations. These programs are typically a part of the integrity management group's area of responsibility and utilize the expertise of external consultants to provide specialty support, although for some operators who are subject to frequent geohazard impacts, in-house experts and teams dedicated to geohazards may also be present. Early geohazard management programs heavily relied on Geographic Information System (GIS) software to gain an understanding of the spatial extent and location of hazards, overlaying points of interest with archived satellite or aerial imagery. The main component of these geohazard programs were reports that summarized individual geohazards or provided an overview of a pipeline system. This reporting method lacked the geospatial connection and understanding of these hazards which is a critical component of these programs and at most they would have an associated a point in the GIS workspace to a feature name in a report or a rough overview image. These systems were often unique to each operator based on their perceived needs at the time and often had different categorization of the geohazard types managed and each with their own criteria for identification, varied field data parameters being collected, and follow-up recommendations (if any) would be undertaken at operator-specific timing intervals. This method of standalone programs did not allow for repeatability between inspections or consistency between operators as the inspections were based on subjective assessments by teams that were not necessarily the same personnel year to year. As geohazard management began to mature in the early 2000s, the first generation of geohazard management software was developed with the intent to provide a single repository for geohazard information, allowing visualization in a GIS-like interface but also allowing for basic information from databases to be associated with identified geohazards or locations. Importantly, however, the development of dedicated geohazard management software allowed for repeatability, scalability, and consistency to occur as subjective assessments were replaced with factual data and calculation methods, thus allowing for formalised qualitative rankings or quantitative assessments to occur using geohazard-specific algorithms programmed directly into the software (Baumgard et al., 2014).

Advancements in collection methods have improved the quality and quantity of many data sets and have made them less cost prohibitive and easier to incorporate into geohazard management programs. Real-time weather (flood, precipitation and seismic), remote sensing data (lidar, InSAR, photogrammetry, satellite), geotechnical instrumentation (strain gauges, piezometers, shape accel arrays), geophysics surveys (electrical resistance, seismic, magnetism), inertial measurement unit (IMU) data are just some examples of the types of data that can be incorporated into a geohazard management software. To effectively use this wealth of real-time and near-time data, geohazard management software for pipelines has evolved to integrate and visualize this data in ways that drive better, faster insight and perform automated analytics to highlight change dynamically. With the newer generation of geohazard management software, operators can efficiently leverage immense amounts of data while still focusing their attention on the most important areas of their pipeline system. Across a pipeline network, for example, the newer generation of software can highlight areas where snowpack or precipitation is greater than normal, identify watercourse crossings where flooding is occurring, outline where forest fires have recently occurred, or alert on areas where the ground surface has moved. Real-time instrumentation can be used to monitor subsurface movements and identify new or changes in movement rates and can be analyzed with other data sources such as Inline Inspections (ILI) tool strain data and lidar change detection (LCD) – all in one place.

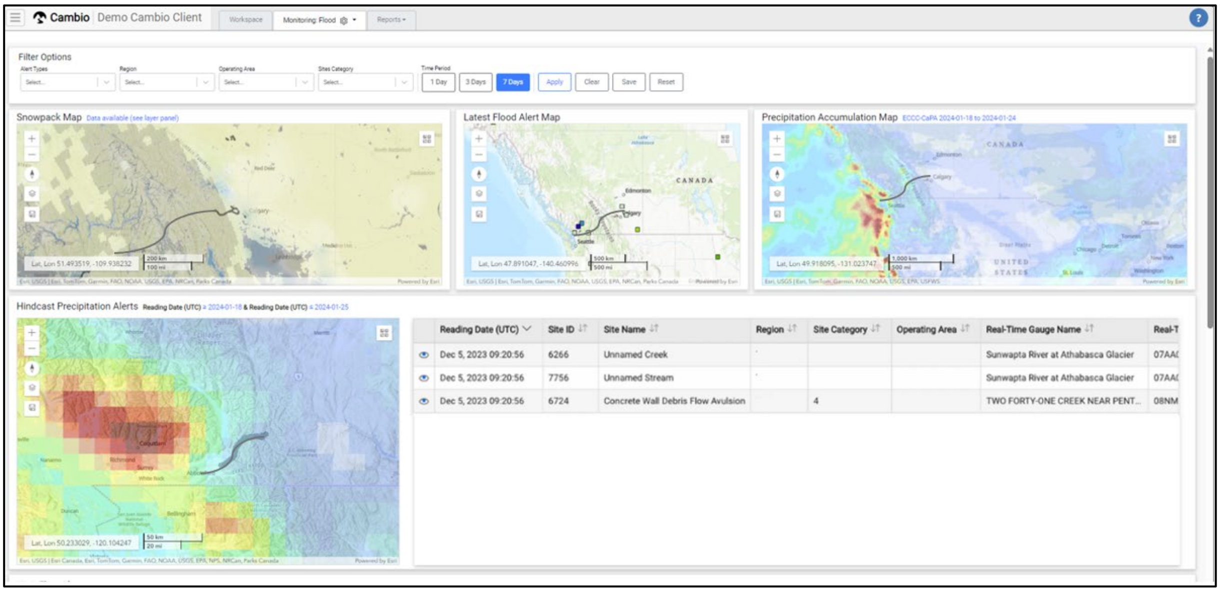
As data collection becomes easier, the effective and efficient management of the data becomes more challenging. With an exponential growth in available data both in terms of different sources and quantity of information that can now be used to better identify and monitor geohazards, a need for more advanced data management, processing, and analysis, has become increasingly more important (Johnson et al., 2022).

Nearly two decades after the first iterations of geohazard management software were implemented, a new generation of advanced geohazard management software is now being developed and utilised by many pipeline operators. Cambio™ produced by Cambio Earth Systems is an example of the latest generation of advanced geohazard management software that is now integrating massive amounts of data in real-time and near real-time. Software, such as Cambio, has been developed to centralize, manage, and utilize this data allowing project teams, including owners, contractors, and consultants, to access key data via a single source of truth. Centralized access to site data can provide an enhanced ability to work collaboratively to manage geohazards and turn data into actionable knowledge that can be used to inform decision making. The following sections will further discuss and demonstrate how advanced geohazard management software is being utilized to improve the overall effectiveness of geohazard management programs.

3 Real-time and near Real-time Monitoring

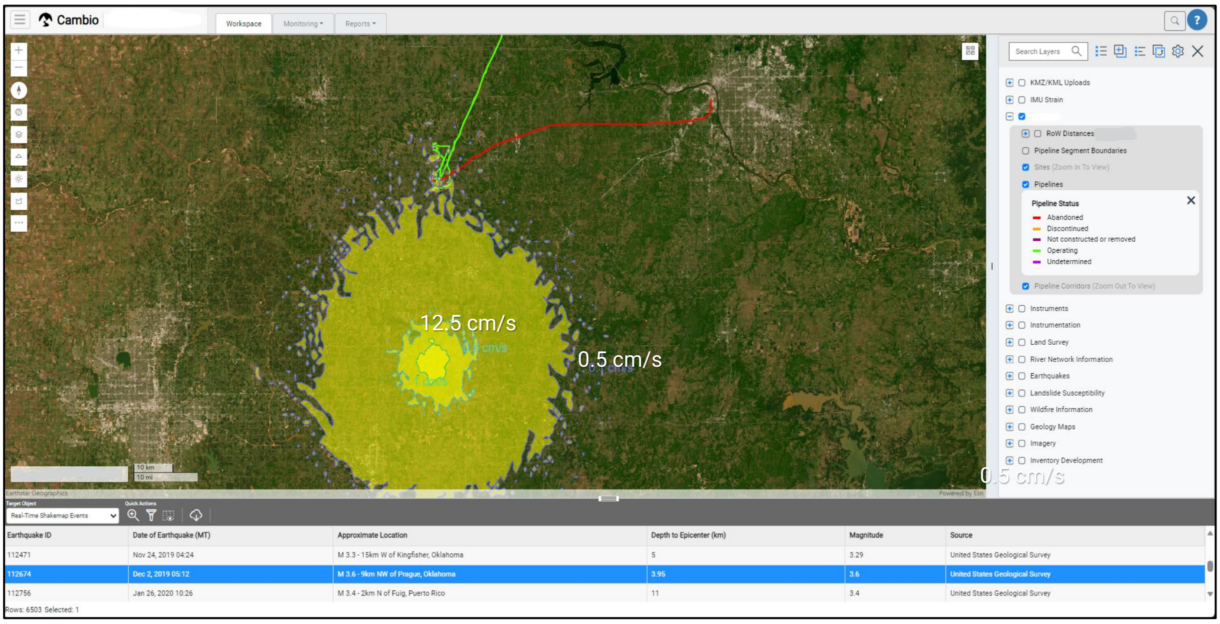
The effects of weather, and particularly those related to water, drive the majority of geohazards. This could be by initiating landslides and debris flows as intense precipitation, or flooding causing rivers to rapidly erode banks, scour their beds and avulsing to new paths. While weather forecasting has drastically improved over the last half-century through advanced computer modelling, its highest accuracy is still at the larger regional scale. For precise assessments of the current local weather conditions, real-time or near real-time monitoring is still essential. In areas where pipelines intersect watercourses and are susceptible to hydrotechnical geohazards, it is crucial to monitor increases in streamflow and predict the potential impact of ongoing events. This proactive approach is essential for effective management of a pipeline system. The United States Geological Survey (USGS) installed their first stream gauge in 1889 and now operates over 10,000 continuous-record gauges (USGS Streamgage Network, 2023). The United Kingdom operates a network of approximately 1,500 gauges (The UK Gauging Station Network, 2023), while Environment Canada operates over 2,100 real-time gauges (Water Level and Flow, 2023), and there are similar networks of stream gauges in most countries. Other large weather data sets are also frequently available such as snowpack and rainfall. When combined with stream gauges, these datasets contribute to a comprehensive understanding of specific locations where severe weather events may occur. However, understanding the current situation at the location of an installed gauge is not helpful when assets that need to be monitored may be kilometres away from the nearest gauge or even on an adjacent river or stream. Advanced geohazard management software can prorate data and interpolate for how these results are applicable to areas away from the data source. In Cambio, for example, a complex digital stream network consisting of over 10 million km of rivers, streams and creeks across North America can ingest real-time or near real-time data from the thousands of gauges operated by the USGS and Environment Canada and instantaneously prorate or interpolate readings to positions on almost any watercourse crossing in North America. This knowledge is crucial in assessing the potential for triggering geohazards. Utilizing such information enables active monitoring of pipeline systems, providing operators with the necessary time to implement appropriate management strategies in areas where hazards may be developing (Figure 1).

Figure 1. Real-time monitoring dashboard presenting the weather data, triggered alarms, and geospatial maps to allow for synthesizing essential information facilitate effective decision-making.



Geohazards other than those generated by weather can also impact pipelines. One such example is from earthquakes where seismicity has the potential to directly strain pipelines through transient ground shaking during the event, as part of permanent ground deformation resulting from triggered liquefaction and lateral spreading of susceptible soils, or through initiating landslides. Organizations such as the USGS have significant expertise in monitoring global seismic activity. Over the last decade, these groups have increasingly made their data, both raw and processed, publicly accessible. Similar to the challenges faced with weather data, the key lies in effectively utilizing this information. In its simplest form, awareness of the earthquake location and magnitude provides pipeline operators with a preliminary understanding of potential risk exposure (Zaleski et al., 2018). Advancements such as the USGS's Shakemap offer more nuanced assessments by plotting predicted ground motion velocity contours around the seismic event. By incorporating these new tools into advanced geohazard management software, operators can overlay pipeline systems, liquefaction susceptible soils, and potential landslide sites with the velocity contours from Shakemap to allow for site-specific informed risk assessments to be made in near real-time (Figure 2). The ability to make data-driven decisions within minutes after a seismic event empowers operators to enhance both human and environmental safety while minimizing false alarms.

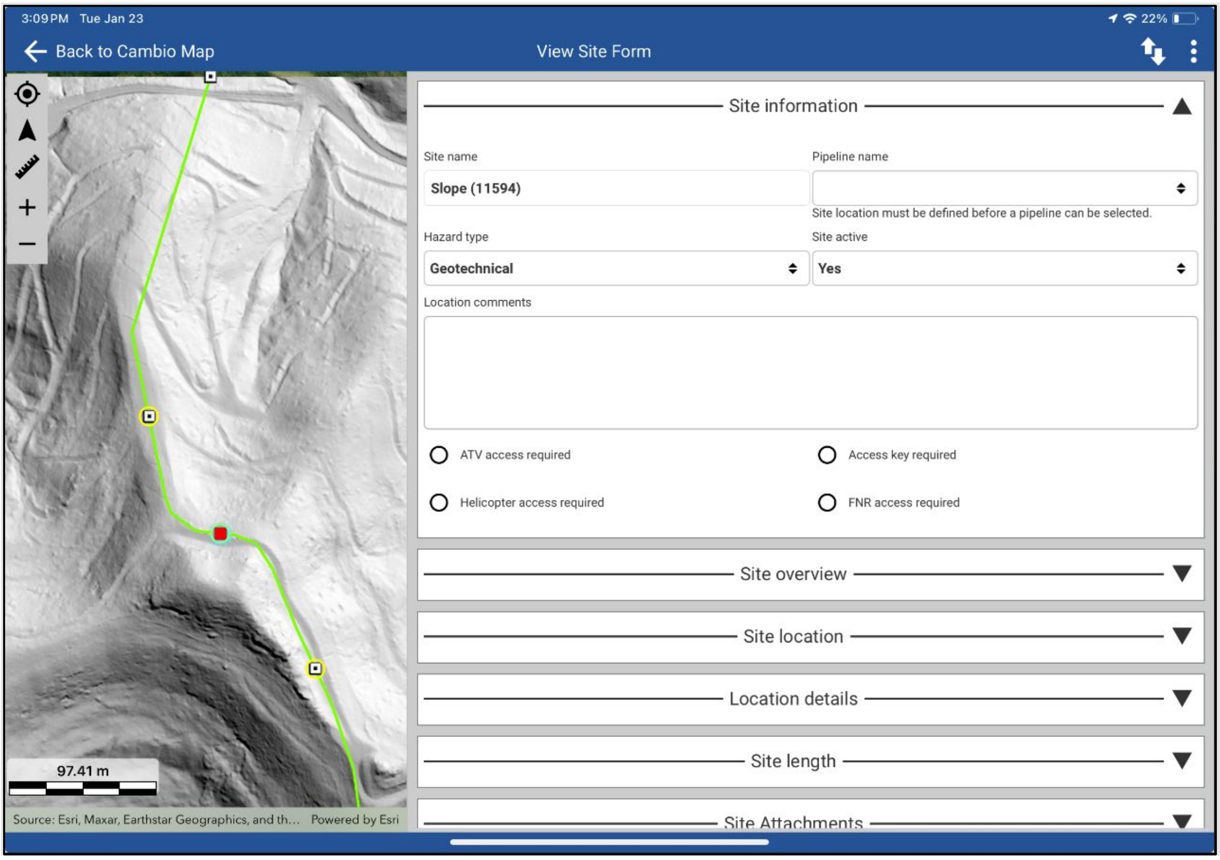
Figure 2. Visualization of the influence of seismic hazards on pipeline infrastructure through the integration of ShakeCast data over the pipeline centerlines.



4 CLOUD STORAGE AND ONLINE ACCESSIBILITY

Historically, specialized data, such as information gathered by consultants on topics like geohazards, has been maintained in the form of reports accompanied by occasional drawings and limited digital data. When digital data such as an outline of a landslide or an area of bank erosion was accessible, it was seldomly added to corporate enterprise databases and GIS systems alongside conventional data such as pipeline centerlines or construction, maintenance and repair information. Although the inclusion of geohazard data with other datasets is beneficial, corporate enterprise software is typically confined to office use, requiring connection to an organization's network. With the progression of personal devices such as tablets, geohazard management systems are increasingly adaptable for field use. These field-ready systems typically feature a streamlined version of the desktop internet-enabled version of the software, allowing users to either download data for a specific area to be visited or maintain connectivity through wireless/cellular systems (Figure 3).

Figure 3. Display of lidar data, inspection data, and pipeline information on a mobile device, with the capability to prepare the data for offline use, ensuring accessibility even in remote locations.



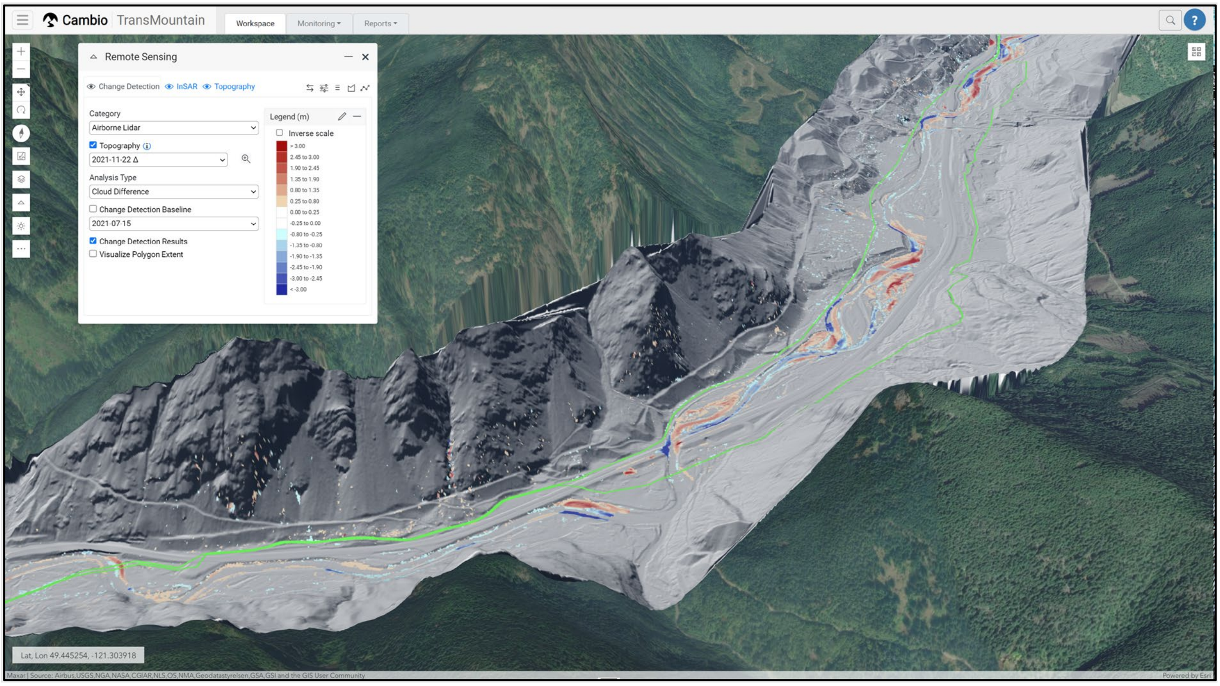
The quantity of available data is increasing faster than ever before. Storage on local network servers on-premises is becoming increasingly expensive to acquire and maintain, and an increasing number of corporations are recognising that storage offsite by Cloud Services can provide secure access to data with built-in redundancy as a cost-effective solution. For those completing activities in the field, having data stored off-premises in the Cloud has a significant advantage with the ability to potentially access data in a remote environment. With wireless/cellular carrier data available in urban and some rural locations, as well as recent affordability of satellite data services such as Starlink™ that cover even the most remote areas, accessing data in the field is no longer a problem. Combining cloud storage, online accessibility and mobile devices, data is now readily accessibly as needed. This capability enables geohazard management systems to store all data in a central location that can be accessed at any time which means that, should an issue occur or when large data analysis is conducted to identify trends data, it can be efficiently retrieved and reviewed.

5 Remote Sensing Data (Lidar, InSAR)

One of the most significant advances to the earth sciences profession has been the evolution and availability of remote earth sensing technologies including lidar and satellite-based InSAR. These two technologies have allowed for rapid and accurate assessments of ground movement at scales that in the past would have been impossible to achieve. Tens or hundreds of kilometres of pipeline route can be assessed to determine where movement of millimetres may be occurring, and this can be repeated to gain an understanding not just of the rate of change but even if it is accelerating or slowing down.

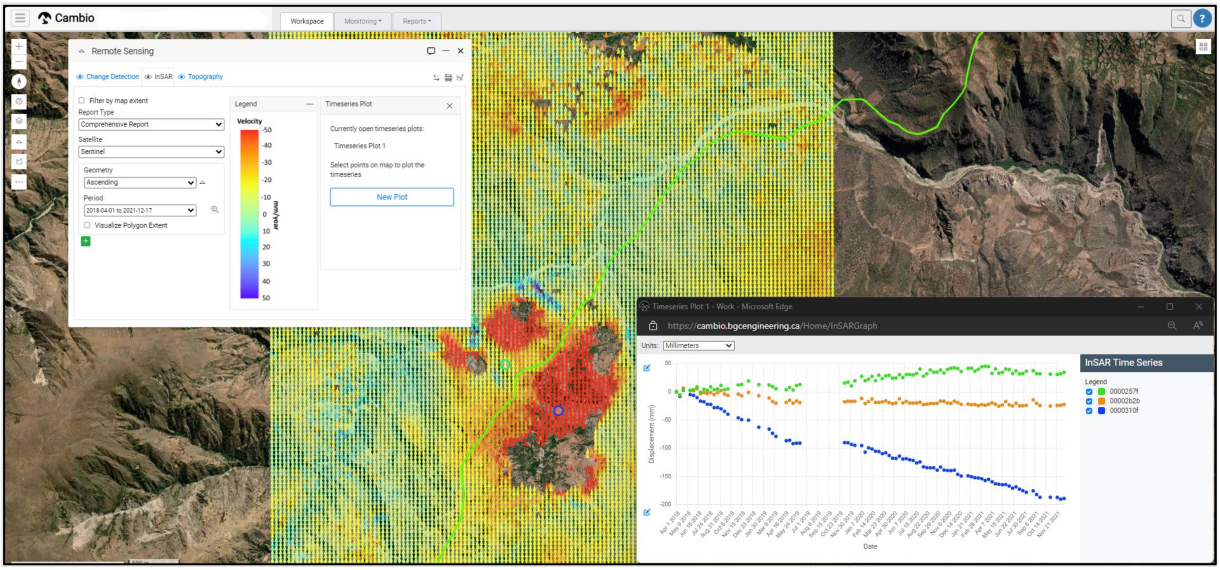
Lidar data is most frequently collected from airborne platforms (planes, helicopters and less frequently from remotely piloted aerial system) referred to as airborne lidar scanning (ALS) but can also be more locally collected with terrestrial lidar scanning (TLS). With its ability to penetrate vegetation, lidar can be used to “image” the ground surface in challenging terrain and with a density of points orders of magnitude greater than what a conventional surveyor would be able to achieve. This provides a unique visual that makes identifying features such as landslide scarps, seismic faults and old river channels easily observable. By comparing multiple lidar data sets, the positional change in the datasets can be assessed over time in a process known as lidar change detection (LCD). Changes analyzed between lidar datasets are reported as positive or negative relative to the baseline or initial lidar survey. Positive model differences can be interpreted as material accumulation or bulging, and negative model differences can be interpreted as a loss of material (e.g., material removal, erosion, or slumping) or settlement. Figure 4 illustrates a simplified example of riverbank erosion and how this process is reflected in LCD results. LCD provides insights into the development of potential geohazards and depending on the rate of movement, proximity and relative position to a pipeline, operators can now more effectively assess whether intervention is necessary at a particular site. Recent advancements in ALS data collection and LCD processing have increase both efficiency and quality of results (Weidner et al. 2023). These advancements have enabled high accuracy LCD to be performed over very large areas, such as entire pipeline corridors or networks, which was previously computationally prohibitive. (Lato et al., 2022).

Figure 4. Lidar change detection of a pipeline corridor following an atmospheric river event, aiding in prioritization and identification of high-concern sites for effective risk management though Cambio.



InSAR is a technique for mapping deformation using high resolution radar images tens of square kilometres in area. By comparing stacks of multiple images, ground movement can be identified, similar to lidar. InSAR data has historically been very expensive, primarily due to the high cost of acquiring raw data, and it requires a lot of images for analysis. However, in the last few years, international space agencies have increasingly adopted open-access data models. For example, the European Space Agency's Sentinel-1 satellites have been capturing data since 2015 all over the globe and the raw data is freely available. This makes using InSAR based on the Sentinel-1 data much more cost-effective. However, Sentinel-1 is a short wavelength sensor that is not ideal in areas with dense vegetation. In the first half of 2024, a launch window opens for a satellite called NISAR which is a collaboration between NASA and the Indian Space Research Organization. This satellite will provide open-source access L-band data which will have global coverage at a high resolution, providing additional options for InSAR measurements in vegetated areas. These developments will continue to lower the overall costs, making InSAR programmes accessible for regional ground movement or hydrotechnical hazard monitoring (Schueder and Engelbrecht, 2002). Figure 5 illustrates how InSAR data can be brought into advanced geohazard management software, highlighting areas of ground movement as well as providing details on long-term trends of that data.

Figure 5. Example of a pipeline crossing a ground movement feature identified through InSAR. Repeat measurements from identified points can indicate a progression of displacement over multiple years.



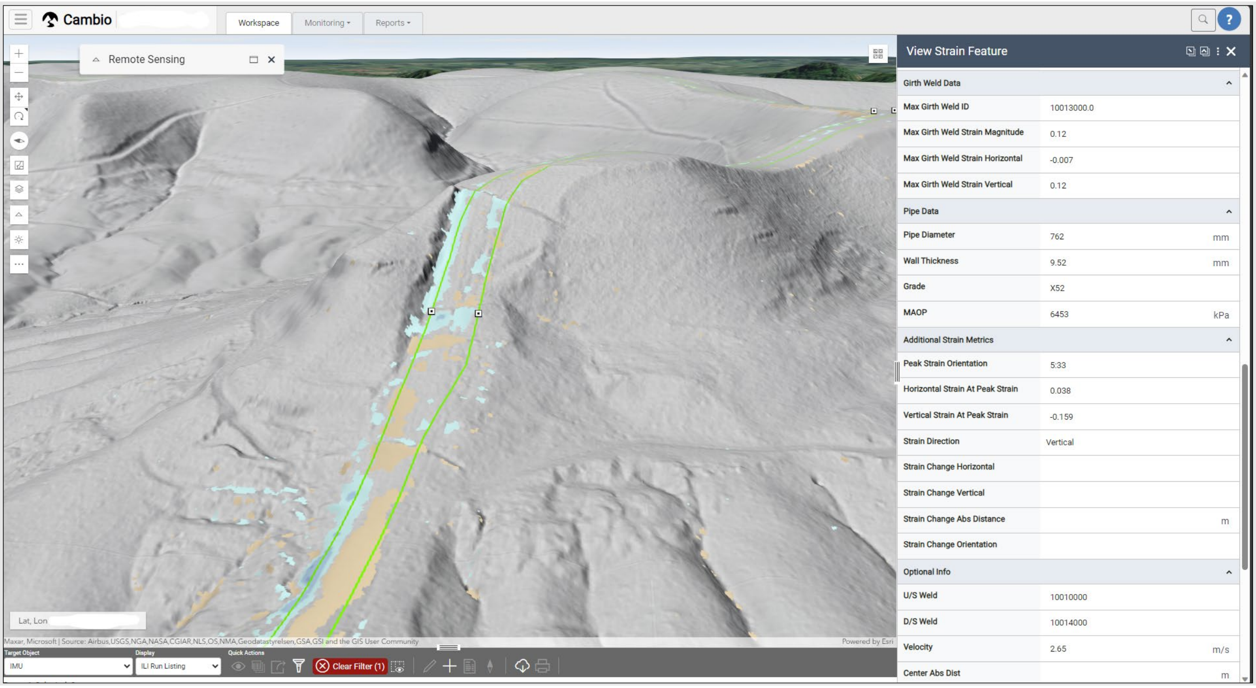
6 Artificial Intelligence and Machine Learning

As described previously, governments and other third parties in numerous countries have accumulated extensive datasets of historical climate data spanning several decades. While these large datasets are currently utilized to enhance the precision of regional weather forecasts, they also serve as training data for Artificial intelligence (AI) and Machine Learning (ML) models to help deliver more accurate predictions regarding the intensity of local weather-related events. For example, AI and ML models can be trained to predict rate of rise of downstream river flows or the probability of landslides based on rainfall rates. By having this data available and integrated into an advanced geohazard management system, when these triggering conditions are recognised in weather forecasts, operators can be alerted of areas where increased attention or cautionary actions may need to be initiated. Likewise, with all of the digital data being gathered by pipeline operators annually (including ILI data, field observations and measurements at geohazard sites, and operational data or the large amounts of available remote sensing data), AI and ML models can be trained to recognize patterns that may not be easily identified by humans and are far more efficient at reviewing large datasets. These models can test hypotheses on cause-and-effect and provide quantifiable results on prediction accuracy. The results can be used to more efficiently summarize data and highlight important information making risk informed decision making more efficient and effective. As AI and ML models become more popular their efficiency and accuracy will no doubt increase over the next decade.

7 IMPROVED VISUALIZATION

One of the most important features of advanced geohazard management software has been the ability to improve visualization and communication. Traditional GIS platforms rely on stacking layers and then making queries to those data sets in a highly generic framework. Early iterations of geohazard management software combined the attributes of a traditional GIS with basic database architecture to allow for basic metadata to be included. Advanced geohazard management software such as Cambio bring innovative ways to review and analyze data. They are designed to take complex and diverse data from multiple sources and combine them in context together with powerful analytics to enable robust and reliable decisions. For example, Figure 6 illustrates overlaying inline inspection data where strain anomalies have been identified by an ILI vendor with Lidar data to confirm if the strain is occurring within an area of ground movement. Without needing to change software, users can then dynamically compare years of Lidar data to see if the rate of movement of a landslide corresponds with the rate of growth of the strain anomaly when looking back at previous ILI vendor data. Using either of these datasets in isolation can lead to costly mitigation efforts that may not fix the problem. This way of presenting data sources in a visual way, makes it easier to see information essential to decision-making at a big-picture level. The aspect of having it be a centralized knowledge base allows a project team, including owners, contractors, and consultants to access one source of data, which provides an unprecedented ability to work collaboratively together to solve complex problems and turn data into actionable knowledge.

Figure 6. Example demonstrating the capability to simultaneously observe strain feature data and change detection results, enhancing comprehension of potential hazards at a site.



8 CONCLUSIONS

The availability of real-time and near real-time data has increased dramatically over the last two decades. This data has the potential to revolutionize how geohazards are managed by allowing for risk-informed decisions to be made using current information and to act as the foundation for predictive models. However, with all this data comes the need to ensure that the critical data can be recognised from within what could be considered background noise. Advanced geohazard management software is now capable of interfacing automatically with these datasets, highlighting locations where critical data is occurring (such as where flooding or ground shaking from earthquakes is occurring), and providing access to relevant information on these sites including historic records from site inspections, Lidar or InSAR data. By utilizing advanced geohazard management software, pipeline operators can better proactively manage against geohazards through an improved understanding of the status of their pipelines in real-time.

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