Almost everything you need to know about...

Applying satellite SAR data in the insurance sector

GEOFEM

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INSURANCE SECTOR CHALLENGES

- Climate change
- Customer experience
- Claims handling
- Labour shortage

"We are seeing today changes globally in the frequency and severity of perils."
Chubb, 2021

"The number of properties affected by clay shrink-swell will increase from 3% (1990) to 6.5% in the next 10 years due to climate change."
British Geological Survey, 2020

INTRODUCTION

Insurance is one of the largest global industry sectors, generating more than $5 trillion in annual revenue. Yet, this industry is often perceived as complicated and slow moving. While the insurance sector has become more resilient financially, it has also let a significant portion of risk go uninsured. The evolution of natural disasters and a changing climate require increasingly sophisticated catastrophe models and pricing.

Climate change

Insurance companies face the challenge of addressing escalating climate change risks. According to Deloitte, a majority of US state insurance regulators expect all types of insurance companies' climate change risks to increase over the medium to long term – including physical, liability and transition risks.

An increase in local extreme weather will in turn impact the susceptibility of different regions to geohazards such as landslides, coastal erosion and sinkholes, exacerbating the damage and cost to insurers. For example, researchers estimate a 30-70% increase in landslide activity due to climate change.

Figure 1: Damage caused to property and infrastructure following a landslide after a severe rainfall event.

Moreover, the climate crisis is very likely to put millions of homes at increased risk of subsidence. Subsidence can cause considerable damage to property and infrastructure and is likely to prove expensive to repair and remedy. The Association of British Insurers (ABI) states that more than 35,000 claims are made in an average year for domestic property alone, with total settlements in the region of £250 million. Following especially hot and dry summers – particularly in regions experiencing drought conditions – these figures escalate to as high as 50,000 claims and pay outs for insurers of up to £400 million. For example, in the summer of 2018 there was a 400% surge in subsidence claims. The frequency of extreme weather events is increasing due to climate change, so the higher claims level is likely to become the norm.

Customer experience

Technological advancements in other consumer sectors have changed customer behaviour and expectations. The insurance sector struggles to keep up with the technological revolution. A recent survey of over 15,000 policyholders in 30 countries for the World Insurance Report indicated that only 40% of property claim customers had a positive experience. The two most important factors contributing to a positive experience were the speed of the settlement and the transparency of the claims process. More investment in real-time data and digital platforms is important to improve operational efficiency and increase customer satisfaction while reducing risk to exposures.

"Consumers are expecting the level of product delivery and service from their insurers that they are accustomed to from tech companies like Amazon, Netflix and Uber."
CoreLogic, 2021

Figure 2. Quick, easy and transparent claims management increases customer satisfaction.

"Subsidence claims will reach £600 million a year by 2050." Association of British Insurers, 2018

Claims validation

After a claim has been made, in order to validate it, physical inspections take place. This can be a hassle: scheduling conflicts, weather, travel and the intrusive nature of inspections can create problems for the home or infrastructure owner, inspector and carrier, according to CoreLogic.

One of the most common but complex examples of claims is subsidence. Subsidence is normally covered by property insurance whereas settlement is not. Subsidence cases require expert evidence and technical data. It's very difficult for policy holders to prove the property hasn't already had a history of the problem, while it's even more difficult for insurers to prove that it did.

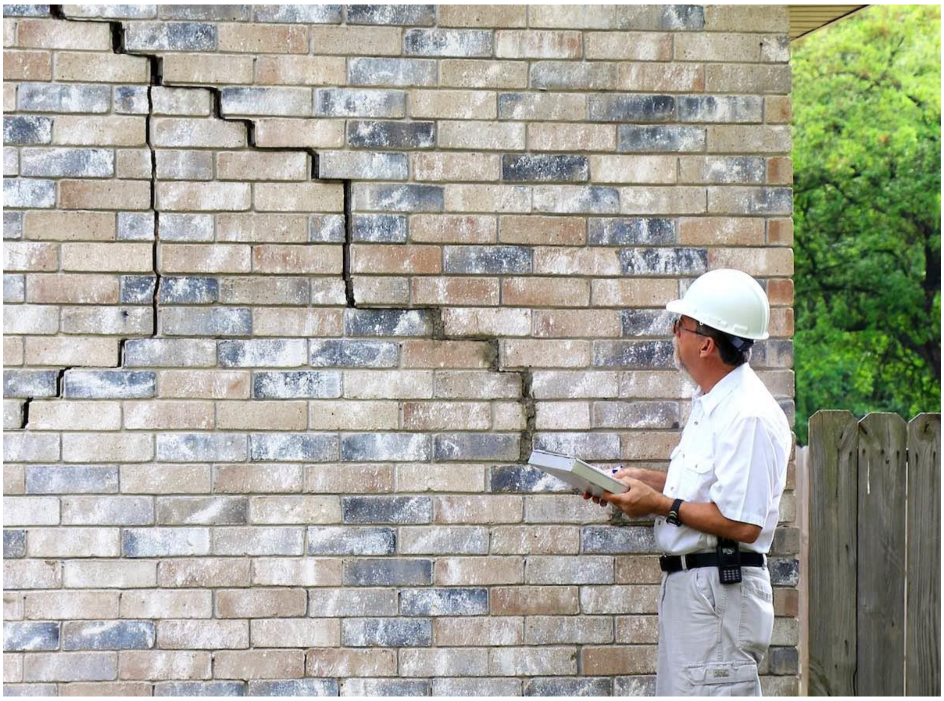


Figure 3. Technology providing real-time data improves the efficiency of claims validation and handling.

> *"There's a growing skills gap that insurers are struggling to close."*
> PWC, 2021

Labour shortage

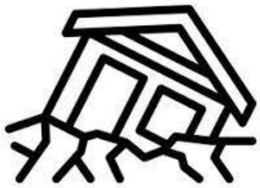
Studies indicate that 25% of professionals in the insurance sector have retired or are about to retire, while in the US alone, a quarter of workers in the sector are expected to retire in the next few years, leaving a projected 400,000 vacancies unfilled by 2020.

According to CoreLogic, a shortage of such magnitude limits the sector's ability to respond to claims, especially in the aftermath of a natural catastrophe. The 2018 Insurance Industry Employment and Hiring Outlook Survey noted that talent is required in five key areas: sales, underwriting, customer services/admin, technology and claims.

GEOHAZARDS

Geological hazards (or geohazards) are the result of natural, active geologic processes, often exacerbated by man-made activities and may lead to widespread damage to property and infrastructure.

They are unusual in nature since damage occurs due to movement of the ground supporting a building or infrastructure, or even the impact of debris falling from surrounding areas. Simple damage repairs do not remove the root cause of the problem and so damage may reoccur. Geohazards do not respect property boundaries, so the root cause may lie in adjacent properties or further afield.



"Shrinking and swelling of the ground (often reported as subsidence) is one of the most damaging geohazards." (British Geological Society)

Subsidence

Subsidence is the term used by the British insurance industry to group insurance claims arising from ground movement, whatever the cause (e.g. collapsible soils, mineworks). However, the vast majority of subsidence claims are the result of shrinkage and swelling of clay soils. Such soils can undergo large volume-change as moisture levels vary seasonally. Increased soil moisture during the wet months causes heave or uplift, while during the dry months, shrinkage causes subsidence. The changes in soil volume between the wet and dry seasons is unevenly distributed which causes distortions and damage to property and infrastructure.

Even though subsidence does not receive the same public attention as other natural hazards, the cost from the resulting damages exceeds those caused by floods, landslides and earthquakes combined. An estimated $12 billion is spent annually repairing damage due to swelling clays alone. Unsurprisingly, many countries, such as the UK and France, have integrated this geohazard into their insurance systems.

"The impact of a landslide can be extensive, including loss of life, destruction of infrastructure, damage to land and loss of natural resources." (FAO)

Landslides

A landslide is defined as the movement of a mass of rock, debris, or earth down a slope. In contrast to earthquake risk, landslide risk of loss is rarely quantified, due to the localised nature of the risk and the fact that the probability of occurrence is hard to define. To cover property damage, a separate insurance coverage for landslides known as a difference in conditions, or DIC, policy is required.

Landslide susceptibility maps take into consideration the topography and geology of the area (e.g. steepness of slope and rock or soil strength) as well as prior failure (from a landslide inventory).

"No property is immune to sinkholes, even the lawn of the White House in Washington, D.C., which developed a sinkhole in May 2018." (International Association of Certified Home Inspectors)

Sinkholes

A sinkhole is a depression in the ground that has no natural external surface drainage. This means that when it rains, water stays inside the sinkhole and slowly percolates into the subsurface. Sinkholes are dramatic because the land usually stays intact for a period of time until the underground void gets too big. When there is insufficient support to the land above, a sudden collapse of the land surface can occur without warning. Catastrophic ground collapse coverage protects a home if it falls into a sinkhole and the foundation is damaged beyond repair.

Figure 4: Collapse of four garages into a sinkhole caused by the dissolution of gypsum at Ripon, North Yorkshire, 1997 (BGS).

"Of all natural disasters, earthquakes pose the greatest threat to life and can cause enormous financial losses." (MunichRe)

Earthquakes

This type of hazard depends on the degree of seismic activity, along with factors such as local topographic and built features, subsurface geology and groundwater. If an earthquake generates a large enough shaking intensity, structures like buildings, bridges and dams can be severely damaged, and cliffs and ground destabilised. Stronger earthquakes frequently cause knock-on effects with high loss potentials such as landslides, sinkholes and tsunamis. A post-earthquake displacement assessment can be used to measure ground deformation following an earthquake, providing an indication of the extent of damage to the structures in the area.

Figure 5: Photos before and after an earthquake in Italy in 2016, showing immense damage to property and infrastructure.

"Coastal erosion threatens property and businesses and puts people living near cliffs and shorelines at risk." (Geological Society of London)

Coastal erosion

According to the British Geological Survey, coastal erosion is defined as the removal of material from the coast, resulting in a landward retreat of the coastline. Across England and Wales alone 113,000 residential properties, 9,000 commercial properties and 5,000 hectares of agricultural land are within areas potentially at risk of coastal erosion, which translate to a capital value of assets at risk of approximately £7.7 billion (DEFRA, 2001). Climate change and rising sea levels will have a huge impact on coastal stability and are likely to increase the areas associated at risk and the investment required to protect these areas.

The severity of this hazard depends on factors such as the topography, geology, climatic and oceanographic processes and human intervention. The removal of material from coasts by any means, can cause secondary hazards such as flooding, rock falls and landslides, as well as loss of land and damage to pipe networks, property, and infrastructure. Surveying and monitoring of coastal areas helps to gain better understanding of the physical processes involved, as well as identifying susceptible locations at an early stage.

SATELLITE BASICS

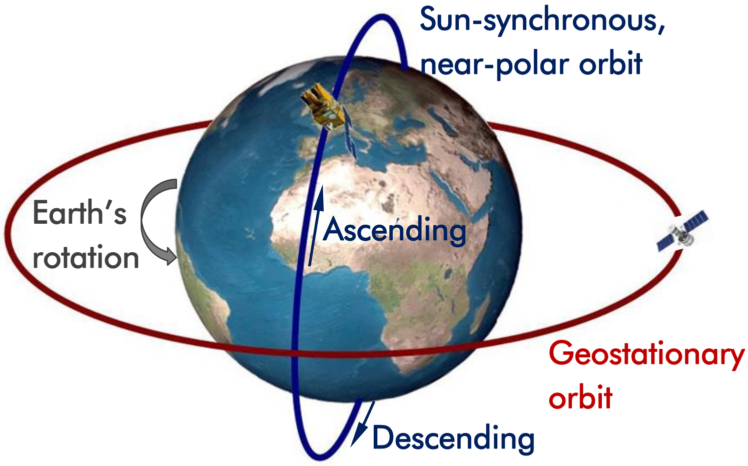


Figure 6: Satellite orbits

Satellite orbits

Most people know the geostationary orbit (at about 35,800 km altitude) that keeps a satellite over the same point on the Earth's surface by taking 24 hours to complete each orbit. Most SAR satellites, however, are in a lower (600-800 km altitude), near-polar orbit which takes 96-100 minutes to complete (Figure 6). They are called sun-synchronous because as the Earth rotates below, the satellite passes over each latitude at the same time of day. This helps to reduce variability between successive images that might otherwise occur if they were taken at different times of the day. When the satellite is travelling north-south it is said to be in a **descending** orbit and when it is travelling south-north it is said to be in an **ascending** orbit. Both ascending and descending SAR images are taken at most locations on the Earth's surface.

Satellite views

Satellites view the Earth's surface either directly down (nadir view) or at an angle from the vertical (off-nadir or side-looking) as shown in Figure 7. All SAR satellites are side-looking and tend to point to the right of their direction of travel. This means that ascending and descending images of the same area are taken from the west and east respectively (Figure 8), but not at the same time. Some satellites are even pointable, so they view the Earth at a range of angles which allows them to be tasked to record images of an area at more regular intervals.

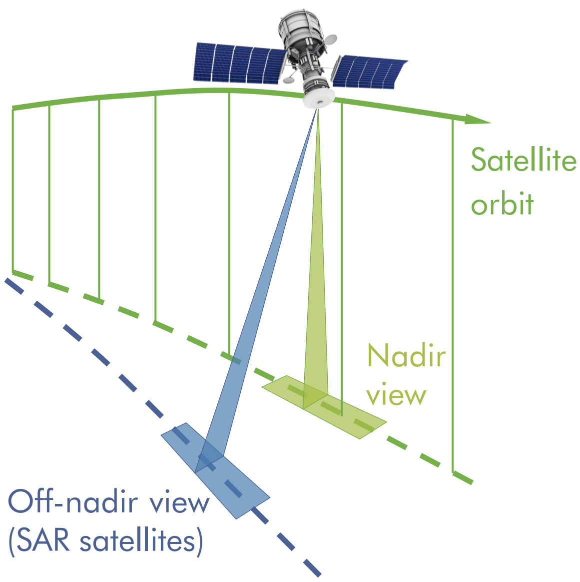


Figure 7. Satellite views

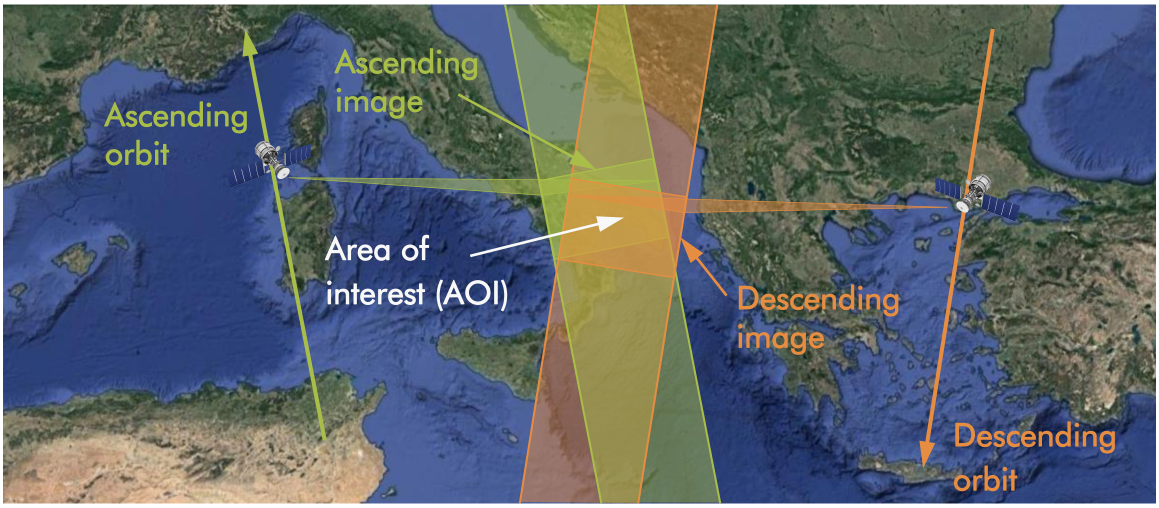


Figure 8. Acquiring ascending and descending SAR images of the same area of interest

SAR

SAR stands for Synthetic Aperture Radar. "Radar" because it transmits electromagnetic waves and receives reflections from objects to determine their distance or range (Figure 9). "Aperture" is another term for the antenna that transmits and receives the electromagnetic energy – the bigger it is the better the spatial resolution. The aperture size on satellites is restricted by practical considerations so in order to achieve sufficiently useful spatial resolutions, a "synthetic" aperture is employed meaning that a sequence of acquisitions from a shorter antenna as the satellite moves through space is used to simulate a larger antenna to improve the spatial resolution.

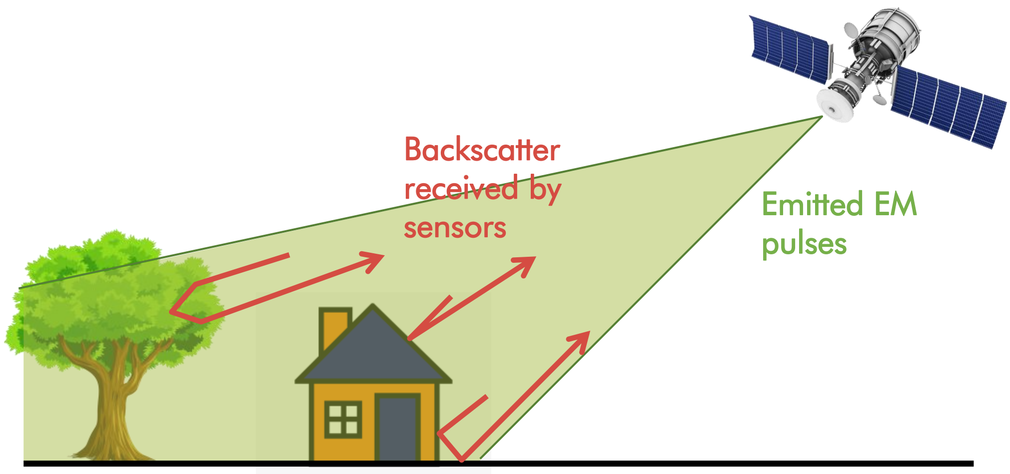


Figure 9. The all-important "radar" part of SAR

Wavelengths

Earth observation satellites have either passive sensors that detect reflected solar and infra-red energy from the Earth's surface or active sensors that emit their own electromagnetic energy and detect what is reflected back (backscatter – as shown in Figure 9).

Passive sensors operate in the ultra-violet, visible and infra-red portions of the electromagnetic spectrum. Active sensors (including SAR) operate at longer wavelengths in the microwave portion which allows them to operate in all weather conditions (including cloud cover), day and night.

What satellite SAR can do…

- Measure ground surface and structure displacements for a high density of points over large areas.
- Measure changes in soil moisture for a high density of locations over large areas.
- Determine historical values of displacement and soil moisture from archived satellite images going as far back as 1991.
- Do all this at reliable time intervals, no matter what the weather, day and night.
- Assess property and infrastructure asset condition across entire areas quickly, regularly, consistently.

What satellite SAR cannot do…

- Measure displacement and soil moisture of objects hidden from the line of sight of the satellite (e.g. deep below the ground surface or under a dense forest canopy).
- Measure displacement at specific, predetermined locations (unless corner reflectors are installed).
- Measure displacement and soil moisture accurately while surface textures are changing (e.g. during earthworks, snow cover or planting new vegetation).
- Measure displacement and soil moisture continuously (typical intervals are 1 to 6 days).

COMPARE APPROACHES

Insurers need to determine the risk related to geohazards to be able to make more informed underwriting decisions and assign the right premium to each asset. Moreover, data of past and present displacements can provide insight into the risk and act as a reliable validation for claims related to ground movement (e.g. subsidence and heave, sinkholes, landslides, earthquakes).

Risk estimation

Insurers need to be able to quantify the risk to geohazards for pricing as well as portfolio management. Depending on their risk appetite, they can decide whether to insure a property or asset or not, how much premium to assign or what terms to include in the contract. Reliable risk estimation is therefore essential and required for large areas to cover the whole portfolio.

In recent years, the insurance industry has been using models to assign the risk related to geohazards. The hazard is an estimation based on several physical factors. Traditionally, the assessment of these factors is based on rather regional and seldom-updated information sources such as geological and topographical maps. For example, areas of clay geology with certain properties and histories of damage may be identified as having a higher shrinkage and swelling potential. However, there will still be variations in damage within those areas due to a number of factors that are hard to determine in spatial detail.

In contrast to hazards such as flooding, hurricanes and even earthquakes, geohazards such as landslides and sinkholes are complex, with much more limited history and localised as well as evolving susceptibilities. This makes it very difficult to build models, due to the lack of relevant data. Typically, insurers will collect information from different sources and suppliers to understand the risk related to geohazards. This includes geological maps, rainfall data, reports of previous movement, as well as past claims. All this information is difficult to gather and include in a model, as they come from different providers, with a different format and timeframes.

Satellite SAR data provides actual measurements of the movement of the ground, properties and infrastructure, as well as other information such as soil moisture. It can be used to differentiate risk across small distances, even at a property-to-property level, while still covering large areas quickly and efficiently. Since the data is updated at regular intervals (bi-weekly), the changing geohazard susceptibility at a property-to-property level in response to climate change, and even weather events, can be assessed across large areas.

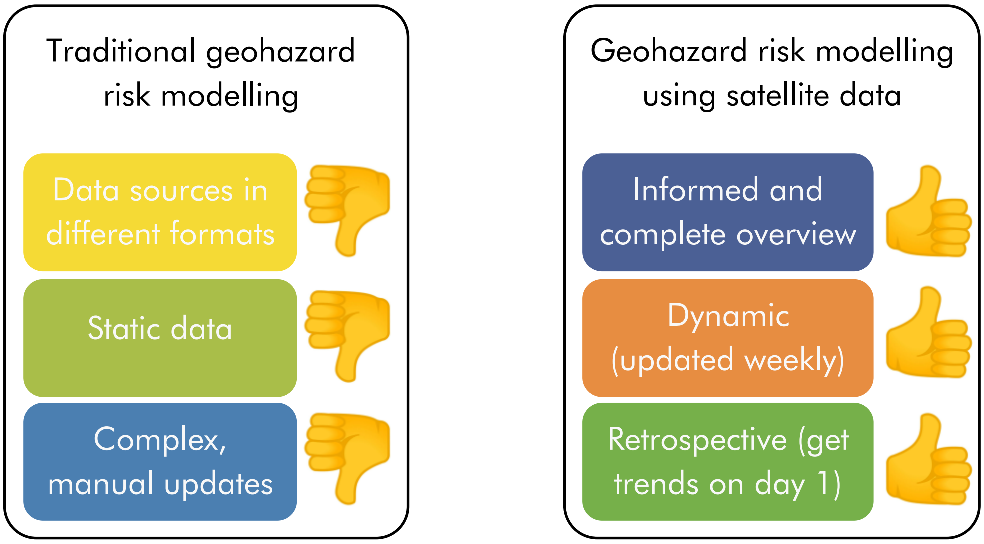


Figure 10. Key characteristics of the geohazard risk data sources

Claims handling

When a claim is made, and to minimize, within reason, their exposure to financial loss, insurers will send their loss adjuster or assessor, or appoint an engineer, to inspect the property and advise them on the extent and cause of damage. Damage involving structural failure or environmental impact needs immediate evaluation and resolution.

Following an event, expert knowledge and a professional interpretation is required to validate a claim. Often, engineers or surveyors are sent on site to gather evidence to help determine possible causes of damage. An initial visual inspection is first carried out while sensors may be installed where ongoing monitoring is required. All this happens, of course, *after* the event. Often there will be little or no information concerning the condition and behaviour of the property or asset leading up to and during the event. Important evidence may be damaged or destroyed by the event itself. Measurements of ongoing post-event movements and other factors may reveal trends that do not truly reflect the trends prior to and leading up to the event.

Satellite data, including SAR data, is the *only* data source that allows retrospective analysis due to the availability of archived satellite data going back at regular intervals for at least 5 years for most locations across the globe. This complements visual inspections by providing continuous data sources leading up to and following the event. Combined with the appropriate engineering insight, it is possible to identify causes of events and whether the problem was developing over a prolonged period of time or occurred suddenly due to some natural or man-made action.

Informed by this valuable additional information, disputes can be settled more quickly and reliably. This saves time and costs and increases customer satisfaction.

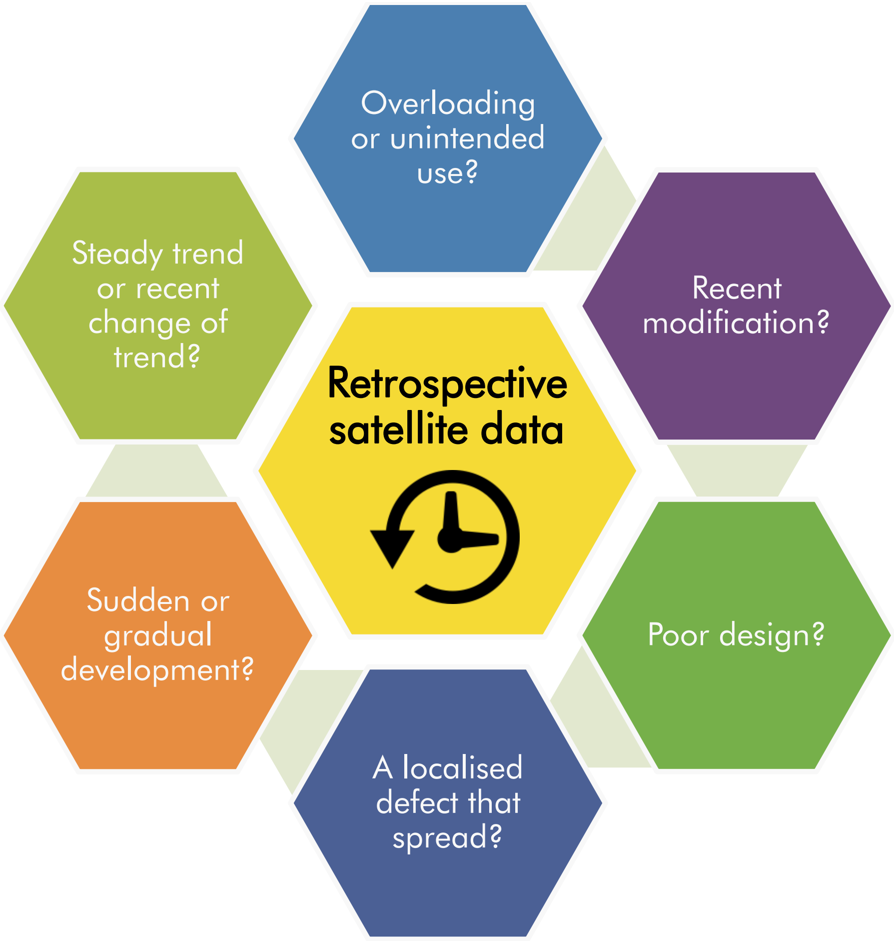


Figure 11. Identifying causes with retrospective satellite data

EXPERT OPINION

Dr Burt Look, OAM, DIC, FIAust, DGE
Principal, FSG Geotechnics & Foundations, QLD, Australia

Dr Burt Look is a technical advisor and expert witness in forensic investigations in the areas of earthworks, expansive clays, landslides, ground improvement, risk assessment and site characterisation.

Dr Look, please define the term *Forensic Engineering*

When unexpected defects or failures of infrastructure assets or structures occur, there is a need to determine their cause so that we learn lessons to help prevent them happening again and to assist insurers to settle any claims in an informed manner. Engineering experts in relevant fields gather information regarding the design, construction, monitoring and maintenance of the asset prior to the incident as well as the state of the asset following the incident. Analyses are used to recreate possible scenarios that led to the incident. However, site specific data guides the analytical models.

"There is a need to determine the cause so that we learn lessons to help prevent them happening again"

What information is important to have but often difficult to obtain in forensic investigations?

Black box voice and data recorders in aircraft accident investigation provide vital information on the circumstances leading up to an accident. Similarly, in civil engineering projects, it is important to have instrumentation and monitoring data leading up to an incident to help identify causal factors, or simply to monitor performance to adjust and avoid failures. Unlike aircraft, monitoring data is not compulsory on all projects. Even when implemented on civil projects, not all possibilities or areas are covered due to the multiple modes in which failure can occur.

"It is useful on all [construction] projects to know trends of asset condition during and post construction"

The stress-strain response is used to assess the stability of engineering structures. Applied stress is compared with acceptable stress and strain in analysis. During construction, the performance is usually assessed in terms of its strain or displacement. Rigorous monitoring occurs on mainly critical projects; however, it is useful on all projects to know trends of asset condition during and post construction. This assists in a maintenance strategy to determine whether change is occurring that may cause an incident, or post failure, whether it was a gradual, inexorable deterioration.

How can InSAR help Forensic Engineering cases?

Where incidents occur unexpectedly, it is rare to have regular monitoring of parameters such as asset displacement leading up to an incident. Satellite InSAR analysis allows retrospective measurement of displacement because images are being acquired and stored of the entire Earth's land surface all the time and at regular intervals. Such historical data with wide area coverage prior to an incident can be obtained to detect both long-term trends and conditions leading to the incident. The data is highly consistent since it is acquired by the same techniques at regular intervals.

"Satellite InSAR data allows retrospective measurement of displacement… to detect conditions leading to the incident"

How important is engineering know-how in the interpretation of satellite InSAR data?

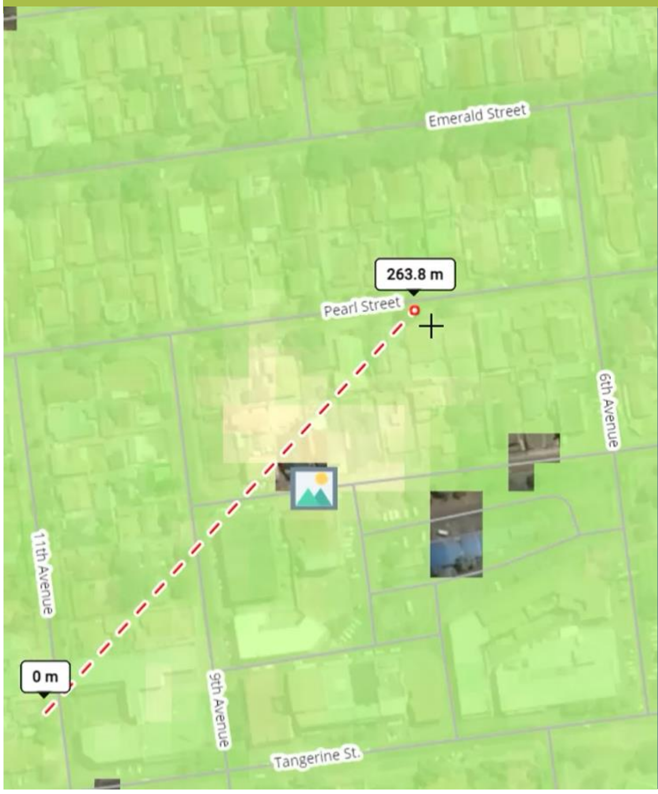
Geohazards often cause unusual, non-linear patterns of movement due to the complexity of soil and rock mechanics. The selection of appropriate data analysis techniques and parameters requires a thorough understanding of these engineering processes. In forensic engineering, experience and judgement must be supported by relevant analytical and site-specific data. Erroneous data has serious consequences. Incidents often occur during construction activities and these activities can disrupt satellite data with data noise. A forensic engineering expert builds an opinion based on evidence that can withstand the scrutiny of other experts. Thus, satellite data analysis expertise is also essential in the application of this data to forensic engineering.

"The selection of appropriate data analysis techniques and parameters requires a thorough understanding of engineering processes"

CASE STUDY 1

Gauteng, South Africa

The densely populated Gauteng province includes the cities of Johannesburg and Pretoria but 25% of it sits on dolomite rock making it highly susceptible to sinkholes. While sinkholes tend to occur with little or no warning, precursors such as ground settlement that may be imperceptible to the naked eye can often provide an early warning.



THE CHALLENGE

- Local changes in ground or building movement can provide early warning of sinkholes but surveying regularly the 5,000km² of dolomite in Gauteng would be too expensive and impractical.

THE SOLUTION

- Regular measurement of ground and building displacement by InSAR analysis of satellite images.
- In a pilot study including known historical sinkhole events in Gauteng, precursors to sinkhole development were identified.

THE BENEFITS

- A proven, cost-effective method to provide an early warning of more sinkhole events.
- Proactive maintenance reduces the danger, cost and disruption of sinkhole events.

MEET YOUR FRIEND SAR

Let's learn some more about how satellite SAR data is used in infrastructure asset management, see some common applications and address the frequently asked questions.

Displacement measurement

The movement of objects and the ground surface between successive satellite passes is measured by calculating the phase difference between successive images as illustrated in Figure 10. Rather than direct displacement, the output is fractions of the phase. If all displacements are less than half a wavelength (a few centimetres) then they are easy to determine but if they are greater than half a wavelength this leads to ambiguity. The phase difference between two SAR images is shown in an interferogram, such as the one in Figure 11 obtained from two SAR images, one taken before and one after the magnitude 6.7 earthquake in Bam, Iran. The coloured fringes indicate that ground surface displacements caused by the earthquake increased to several times the wavelength (2.8cm in this case) used to produce the images.

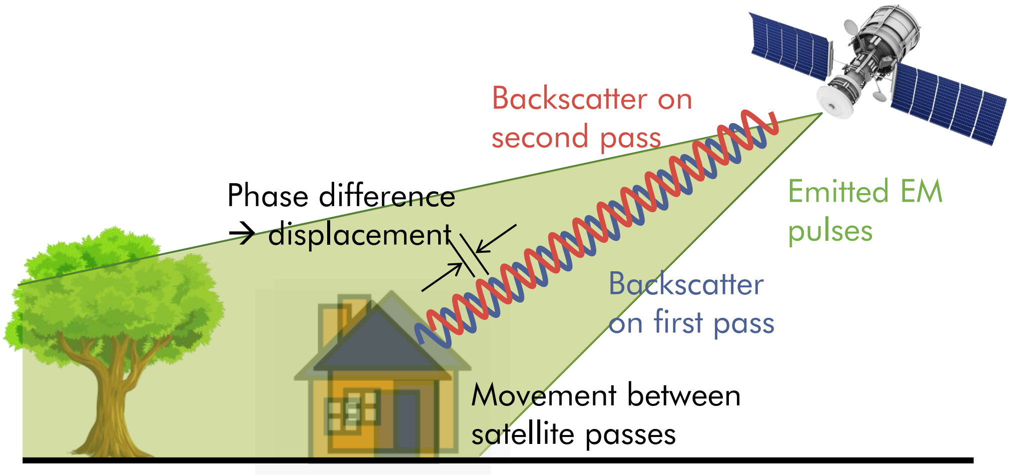


Figure 10. Displacement measurement by satellite SAR

Displacement output is obtained by correcting for topography using a digital elevation model (DEM) in a process called differential interferometric SAR (DInSAR). Further processing to remove residual topographical errors, orbital errors, atmospheric effects and data noise produces a displacement map with centimetric precision. The displacements are in the line-of-sight (LOS) direction between the object and the satellite sensor which will be at some inclination to the vertical.

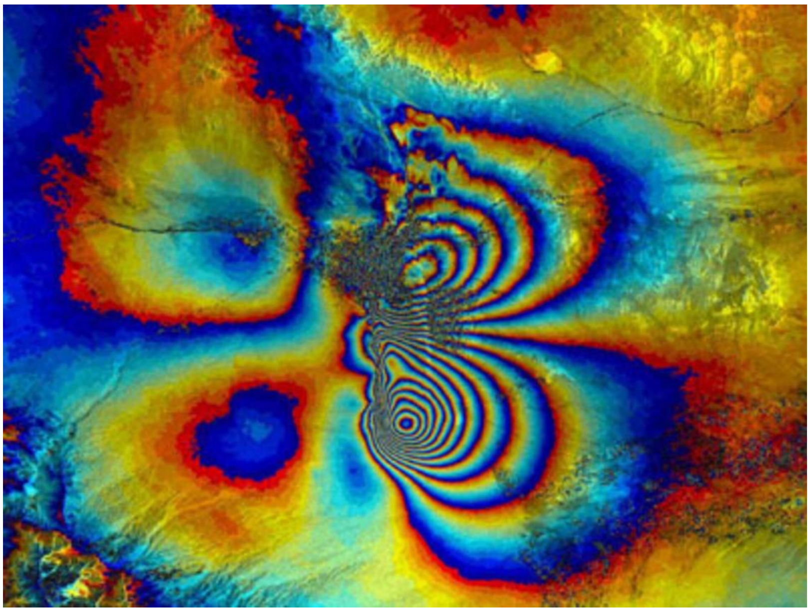


Figure 11. Interferogram of ground motion associated with the Dec 2003 earthquake at Bam, Iran ©ESA.

Displacement: getting millimetric precision

Analysing a time series stack of images – usually a minimum of 20 – enhances displacement precision by improving corrections for errors such as atmospheric effects and residual topographical errors. There are several algorithms to do this which are suited to different conditions, but they all enable the spatiotemporal analysis of the radar phase across multiple images to produce displacement data with millimetric precision and about 2-4mm accuracy depending on the frequency band.

Either average velocity or displacement over different time periods can be calculated and the data presented as coloured dots or pixels overlaid on maps or optical satellite images to indicate their location, such as that shown in Figure 12.

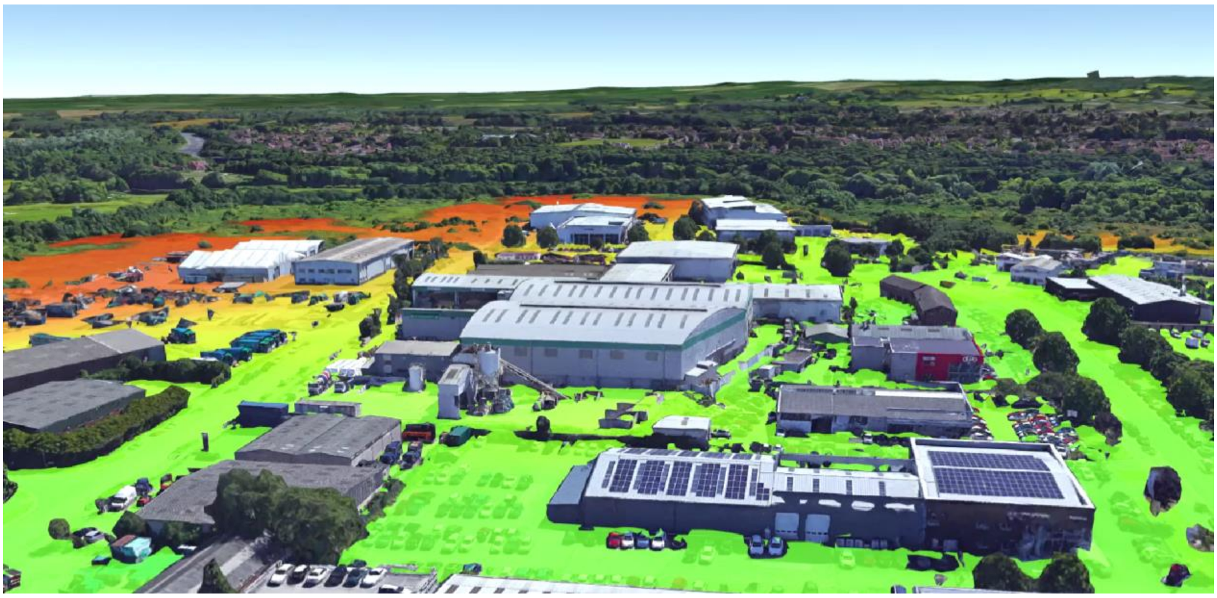


Figure 12. Ground surface vertical velocity (mm/year) presented as coloured pixels on a 3D surface model

Vertical and horizontal displacement

The displacements obtained from InSAR, whether from one pair of images or a time series, are in the line-of-sight (LOS) direction, i.e. along a straight line from the satellite antenna to the object on the Earth's surface. The ascending and descending orbits have different LOS directions on opposite sides of the vertical axis at known incidence angles as illustrated in Figure 13. Displacement data is derived independently from ascending or descending images. Positive values denote movement towards the satellite and negative values movement away from the satellite.

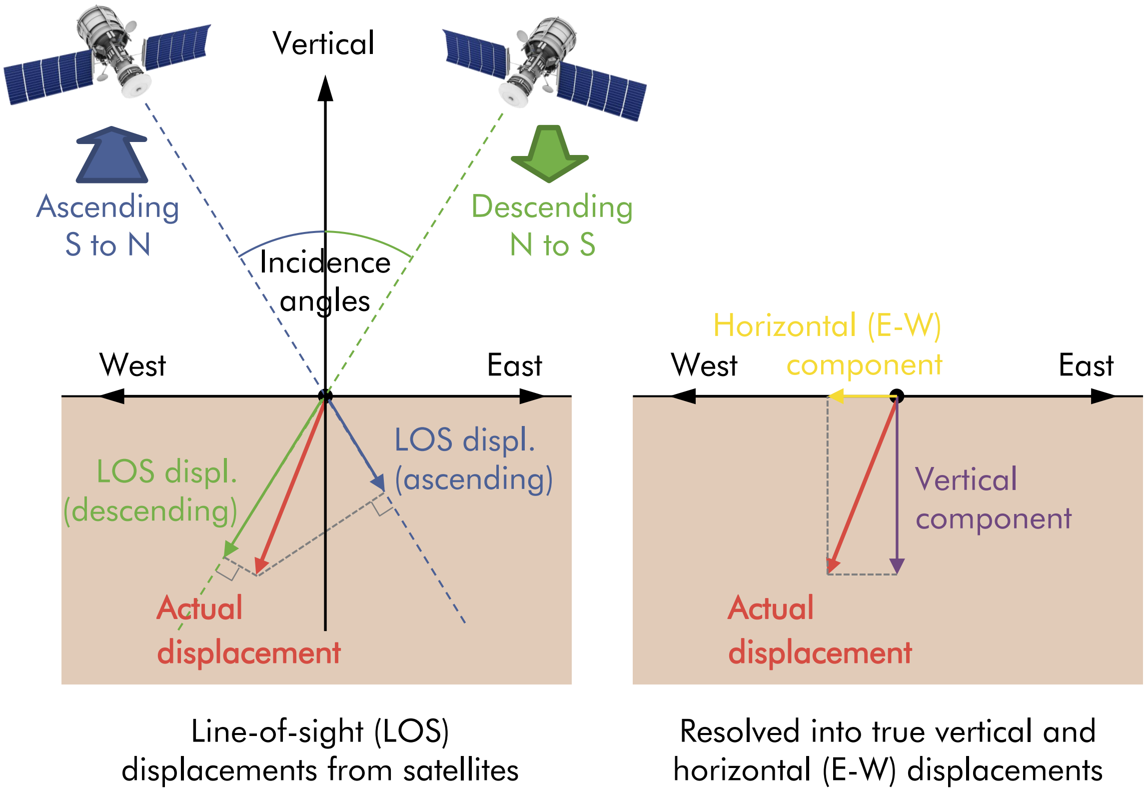


Figure 13. Converting displacement data from LOS to true vertical and horizontal (E-W)

On its own, LOS displacement data provides an indication of patterns of movement. If it is known that movements are predominately vertical (e.g. heave and subsidence of a horizontal ground surface), then vertical displacements can be deduced straightforwardly. If the prevailing direction of displacement is unknown (e.g. on sloping ground), then one set of LOS displacements may be insufficient to deduce the true pattern of movement.

When both ascending and descending orbit LOS displacement data at known incidence angles have been obtained, then displacements can be resolved into true vertical and horizontal (east-to-west) directions, or in other directions such as in the direction of east-west sloping ground. Some temporal interpolation is required because the ascending and descending images are not acquired at the same time and some spatial interpolation is required because the measurement points may be distributed differently between the ascending and descending images.

Horizontal displacements can be determined currently only in the east-west direction due to the near-polar orbit of the satellites and the east-west inclination of the satellite views. Data analysis techniques to decompose displacements into the horizontal north-south direction are under development and will be available soon. Also, new satellites with mid-inclination orbits, such as at 45° to the polar orbit, offer the possibility of detecting north-south horizontal displacements more easily in the near future.

Soil moisture

The amplitude of reflected SAR signals depends on a number of factors, in particular surface roughness, slope angle and the dielectric constant of the ground. Soil moisture influences the dielectric constant so, with all other factors constant, changes in the amplitude of received signals between successive images indicate changes in soil moisture. With some in situ measurements to determine absolute values of moisture content and to calibrate their variation with SAR amplitude, useful maps of soil moisture, such as that shown in Figure 14, can be produced. This a very useful application of SAR data in geotechnical engineering because geohazards such as landslides and swelling clays are heavily influenced by changes in soil moisture.

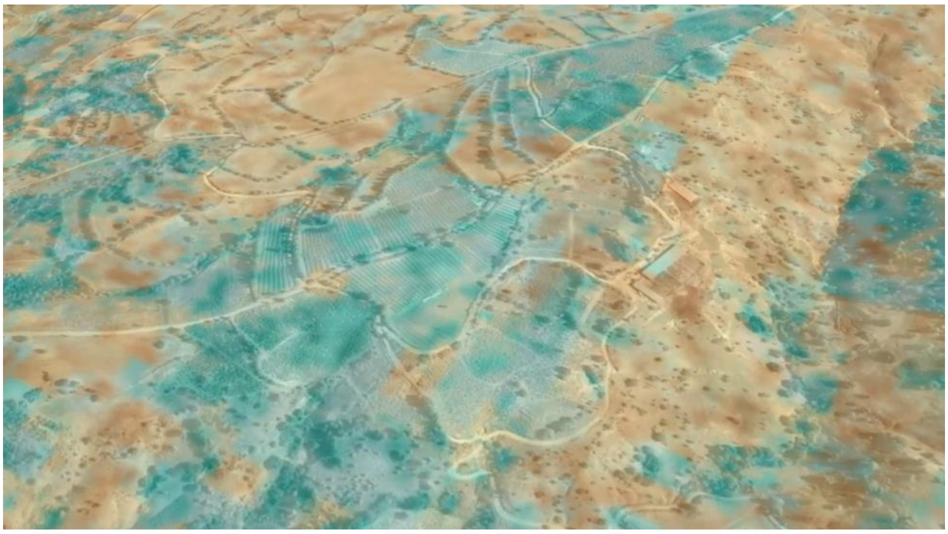


Figure 14: Calibrated satellite SAR soil moisture output

GIS

Large data files of displacement, soil moisture and other data associated with their geolocation are created. These are best uploaded to a web-based geographical information system (GIS) for viewing the data overlaid on maps, optical satellite images or 3D surface models. GIS also allows the plotting of temporal graphs and profiles, setting warning trigger levels and downloading specific data sets of interest.

FAQs

What's the spatial resolution of data?	This depends on the satellite. Freely available Sentinel-1 data has a resolution of about 5m in the range (E-W) direction and about 20m in the azimuth (N-S) direction. Some commercial satellites have much better spatial resolution and planned missions have sub-metre values.
How accurate is the displacement data?	The displacement accuracy is about 2-4mm on accumulated displacement and 1mm/year on velocities. But note that displacements may be the average of various reflecting objects within a pixel (20m x 5m in the case of Sentinel-1 images) or from one particularly strong reflecting object, so the uncertainty is greater on the spatial distribution of displacement within each pixel than the averaged displacement value itself.
How often is data recorded?	Freely available Sentinel-1 data alternates between ascending and descending image captures every 3 or 6 days for most land-based locations. Commercial data may be available more frequently and some satellites can even be tasked to capture data from a location as often as daily. Note that time-series InSAR analysis for millimetric displacement precision must be repeated each time a new image is acquired.
Have these techniques been validated?	The ESA-funded Terrafirma project in 2009 validated SAR data from rural and urban sites in The Netherlands. They found standard deviations of differences between time-series InSAR and ground truth of only 1.0 to 1.8mm/year (search "Terrafirma validation" on internet). There are also countless other examples of InSAR data complemented by and co-validated with in situ surveys.
How accurate is the location of each data point?	While displacements are measured with millimetric accuracy, the location of a data point associated with a displacement value can be up to about 10m out in the horizontal and vertical direction. Higher spatial resolution tends to mean higher geolocation accuracy, so the error may drop to about 1-3m for high resolution commercial satellites.

Do the techniques still work in vegetated areas?	While the built environment reflects SAR signals very well, the natural landscape and vegetation reflect SAR signals in a more irregular and unpredictable way. Vegetation also changes and grows with time. These all mean that fewer or no measurement points may be obtained as vegetation density increases. There are InSAR analysis techniques to help overcome this in many cases. Alternatively, using longer wavelength SAR increases the penetration through vegetation at the expense of spatial resolution.
Can you guarantee that data for a particular object will be obtained?	It is possible to estimate the density of measurement points that will be obtained and the higher the density the higher the probability of obtaining data near a particular point of interest. Note that geolocation uncertainty also means that you can never be sure that a specific point in space to, say, the nearest 50cm is being measured. The only way to do this is to install a corner reflector (see below).
How far back can historical data go?	Freely available Sentinel-1 SAR data exists for most of the Earth's land surface from 2014 onwards. Earlier SAR satellite data exists from 1991 to 2012 with less complete coverage. Other commercial satellite data is likely to exist for major cities and some other areas of interest and archives can be searched.
Do the techniques work in cloud cover?	Yes, SAR operates in microwave and radio wave parts of the electromagnetic spectrum which means they go straight through clouds and operate in any weather conditions, day and night.

CORNER REFLECTOR

Where insufficient measurement points are obtained or to guarantee displacement data at a specific location, a metallic trihedral corner reflector can be installed. It needs to be designed to be the correct size (typically about 1m across) and to point in the right direction towards the ascending or descending orbit of the chosen satellite. It will not provide historical data prior to its installation.

THE BUSINESS CASE

Here we look at the key advantages of using SAR satellite data for estimating the risk to geohazards and establishing a potential cause of the damage related to ground movement claims. The advantages highlighted below form a compelling business case for adopting this technology for property and infrastructure asset insurance.

Fast, objective process.

It is increasingly recognised that data and technology offer the insurance industry the tools to quantify the risks to different hazards and validate claims in an efficient and reliable manner. A lot of modelling and *insurtech* companies focus on these two aspects to improve the underwriting and claims processes. For example, modelling companies are increasingly using satellite data to develop the hazard estimation while others are incorporating climate change scenarios in their modelling.

Subsidence cost to insurance industry: $12 billion per year.

Climate change

Geohazard models are becoming outdated and inaccurate, while the number of properties and infrastructure assets exposed to these geohazards is increasing rapidly due to climate change. With access to historical and current measurements by satellite SAR data, insurers can undertake more reliable risk estimation and more informed underwriting.

"Companies that offer consistently best-in-class customer experiences tend to grow faster and more profitably."
McKinsey, 2015

Customer experience

SAR data helps insurers determine the cause of subsidence and thus damage at a much faster pace and in a more objective way, targeting the two most important factors contributing to a positive customer experience: the speed of settlement and the transparency of the claims process.

"Speedy turnaround time helps insurers reduce adjuster costs by deploying them only when absolutely needed while also increasing customer satisfaction by proactively reaching out to the customer after a disaster before they file their claim."
Corelogic, 2021

Claims validation

With satellite SAR data, fewer site visits are required. The experts dealing with the cause of damage from ground deformation and geohazards are based in the office, meaning that no expertise may be required on-site, no samples taken to a lab and no permission needed to access the property. For large infrastructure claims related to ground movement, the claim can be validated using historical analysis of the displacement in the area derived from satellite SAR data to attribute the movement to a relevant cause.

Labour shortage

No workforce is required on site to obtain the satellite SAR data used in risk estimation and claims handling. It is all performed by office-based specialists. This provides the insurer the ability to respond to claims faster. It also limits the need for someone to visit, install and update monitoring devices on property and infrastructure. Overall, the labour demand is significantly less than with traditional approaches.

With so much real-time data being generated, digital technology is pushing insurers toward new types of business that help consumers mitigate risk rather than simply protect against it."
McKinsey, 2021

The case for satellite SAR data

The benefits of satellite SAR data to the insurance industry are many, as summarised in Figure 15. Some of the benefits are unique to this format and cannot even be obtained with other recent technological approaches.

Satellite-based monitoring is a non-invasive, remote, and cost-effective method for measuring displacements and evaluating geohazards. This technique offers frequent and timely identification of ground instability as well as observations of the ground terrain geometry (e.g., elevation, slope). Satellites have been in operation for decades; however, their spatial resolution has improved significantly in recent years (sub-metre spatial resolution), enabling the monitoring of smaller scale geological phenomena and conditions including the occurrence of geohazards (e.g., sinkholes) in finer detail.

In recent years, the use of satellite data has been more attractive due to the global coverage and high temporal frequency of some satellite constellations, enabling the assessment of almost anywhere in the world. What is more, the processing methods used in extracting information from satellite imagery have also improved, thanks to IT advancements, enabling the application of faster and more efficient algorithms for handling large volumes of satellite data. In this regard, the introduction of SAR satellites, capable of detecting ground

“Data is fast becoming one of the most—if not the most—valuable asset for any organization.”
McKinsey, 2021

displacements accurately (up to millimetric scale) has also contributed to the advancement of spaceborne solutions for monitoring geohazards. Such developments facilitate a new era for remote sensing and collection of information making it possible to develop geohazard assessment tools. Such tools can significantly improve the time and cost efficiency of the current procedures followed for monitoring geohazards at a large scale, both remotely and accurately.

Another major benefit of SAR data is that it is the only method that offers retrospective analysis due to the availability of historical satellite data since 2015. This can therefore be an invaluable technique for claims validation. Was there subsidence at the property before the policy? Was there movement in the ground before the construction project started? SAR data is the only method that allows you to answer such questions immediately, using archived data.

Moreover, when used as a monitoring and risk estimation tool it can cover large areas at very low costs, making it one of the most value-for-money techniques. No other data collection method comes close in terms of the total area or linear km’s and rate of measurement that can be achieved over a whole year. For example, a single, annual visual inspection of a property may cost around $2,000. Satellite SAR data can be used to monitor whole areas containing hundreds of properties for less than $30k and at a fraction of the cost of visual inspections per property. Furthermore, the satellite SAR survey can be repeated 60 times in one year! Alerts can be triggered in areas of concern, where risk for specific geohazards has increased above pre-defined thresholds. This way insurers can deal with the issue before it becomes a bigger problem and thus minimise the pay-out.

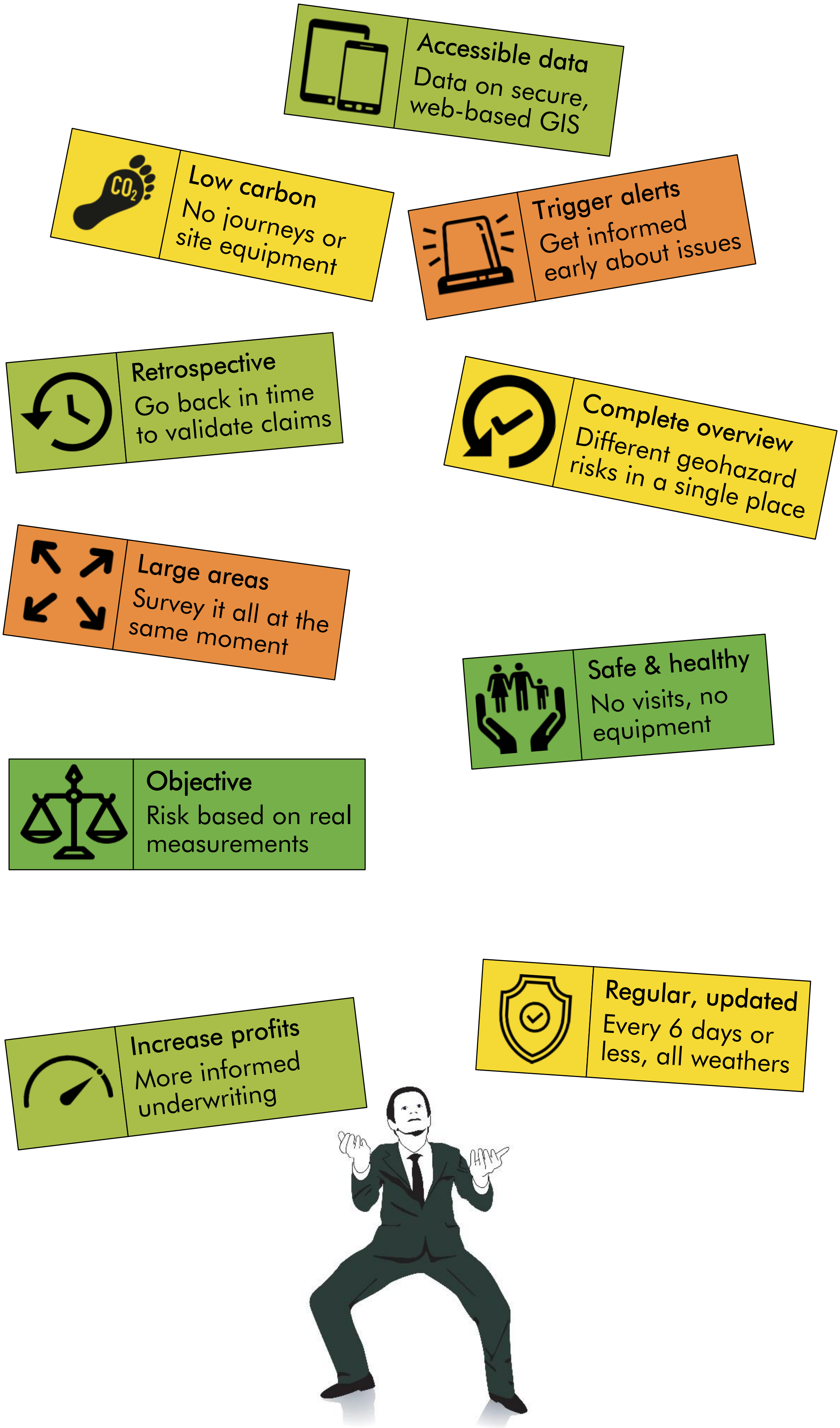
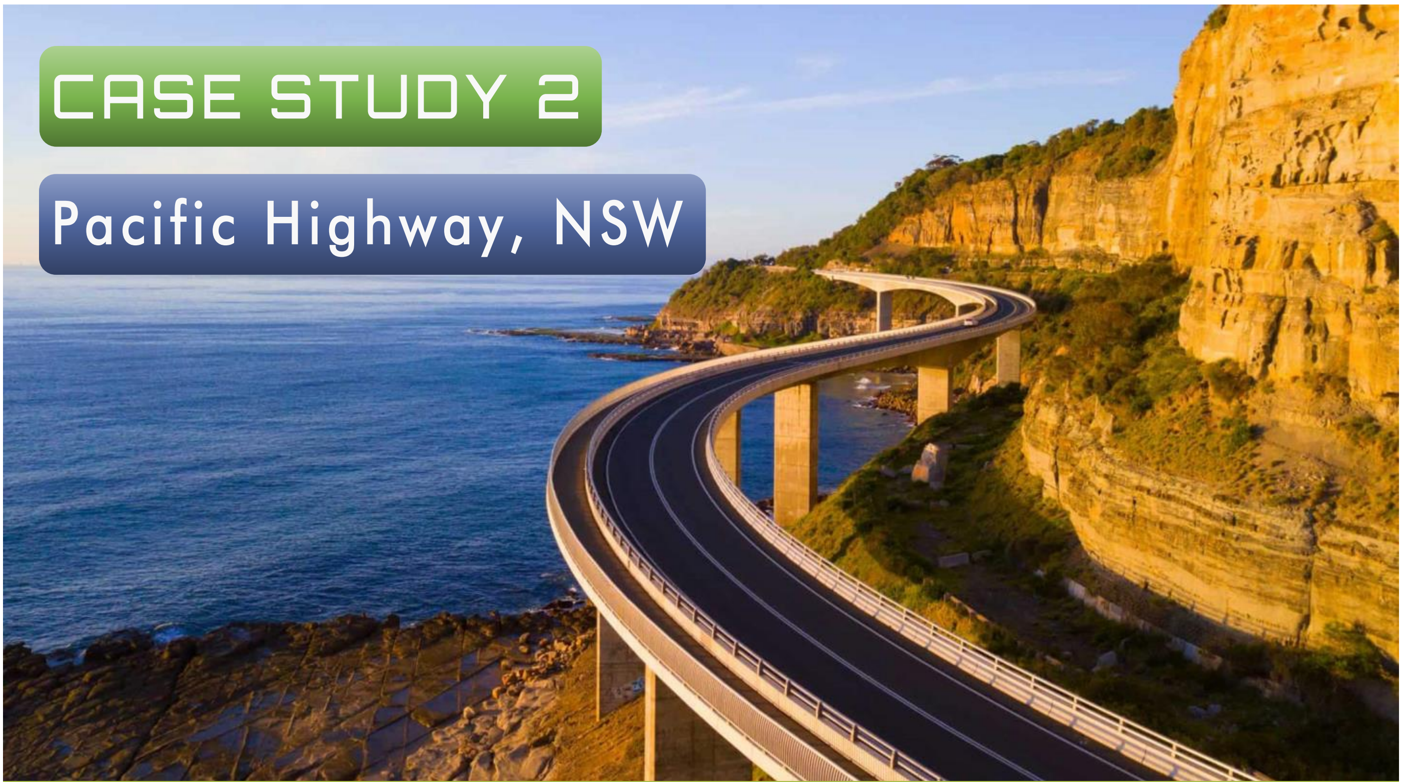


Figure 15. The many benefits of satellite SAR data to the insurance sector

CASE STUDY 2

Pacific Highway, NSW



During construction of a new river bridge for the Pacific Highway in New South Wales, a dispute arose over displacements noticed in an existing adjacent bridge. One key advantage of satellite data is the ability to obtain information retrospectively. Combined with engineering expertise it becomes a powerful forensic tool.

THE CHALLENGE

- No displacement data for the existing bridge prior to or during construction of the new bridge was recorded, making it virtually impossible to establish the cause of the displacements.

THE SOLUTION

- InSAR displacement analysis of the existing bridge, abutments and river banks both during construction and for a two-year period prior to construction.
- Earthworks and other construction activities made obtaining coherent data particularly challenging, requiring a combination of analysis methods. Civil engineering expertise was needed to interpret the effect of construction activities on the displacement data and dismiss unreliable data.

THE BENEFITS

- Reliable, independently-determined displacement data – which was critical to the dispute – was available for the first time.
- A cause of the existing bridge displacements was established with a high degree of certainty.
- The dispute was settled in a more informed manner.

IMPLEMENTATION

When satellite SAR data is being considered as a risk assessment and monitoring tool, providers of these services should be approached to discuss suitable solutions. At this initial stage and through all the subsequent stages possibly all the way to purchase and application, it is good to know the right questions to ask so that the service meets everybody's expectations. The purpose of this chapter is to provide outline guidance on some of the issues that need to be raised and agreed upon when procuring satellite SAR data.

Procurement

Ideally at an early stage in the procurement process but certainly prior to signing, it is vitally important that all insurance stakeholders as well as the provider of the satellite SAR data understand the purpose of the data collection. All need to be clear on what output will be produced following processing and presentation of the data and agree that it is appropriate for the intended purpose. The output should also be obtainable accurately by a well-defined process. All these are important because satellite SAR data involves advanced and continuously developing technology that may be unfamiliar to some stakeholders. A thorough engagement process with potential providers is recommended so that the right data sources and processing techniques are proposed to meet the needs of a project and to help ensure that stakeholders fully appreciate the service being offered.

"A thorough engagement process with potential providers is recommended"

For example, it may not be possible to obtain satellite SAR data for specific assets or property due to some parts being hidden from the view of the satellite by dense vegetation. It is better to discuss these issues openly and alternative data collection methods arranged beforehand, such as small areas of visual inspections or modelling, rather than stakeholders learning later that there are gaps in site coverage.

The starting point for internal discussions is to set the goals and objectives of the investigation or monitoring and to decide what information is required. To plan the full regime of monitoring that may include other techniques as well as satellite SAR data. Will an initial pilot study be undertaken if the techniques are being applied for the first time? Is the area of interest visible to satellites at all locations?

The duration of the monitoring is important as is the frequency of output generation and these need to be considered within the lifecycle of the assets being insured. Will the results be reported at set intervals in a formal manner, or the data uploaded to a GIS platform and stakeholders notified of an update? Is the monitoring intended to facilitate risk estimations for underwriting, to provide early warning of possible failures or to inform claims validation techniques?

Once the goals and objectives of the monitoring have been agreed internally, detailed discussions with potential providers of satellite SAR data should be held to reach a common set of expectations for the information that can be obtained. Providers can confirm which parameters can be obtained for the area of interest, the likelihood of obtaining sufficient measurement points, the accuracy and precision of data, spatial resolution, geolocation accuracy and frequency of measurements. They can propose strategies and options for increasing the amount and quality of information obtained.

An important consideration is for the internal resources and protocols within the relevant stakeholder organisations to be planned and ready for the arrival of the first satellite SAR data. Who will be responsible for viewing and interpreting the data, monitoring trends and acting on alarms? Will the client or data provider be responsible for interpretation and recommendations? Do either the client or provider have sufficient in-house expertise and resources to view and interpret the data? Engineers are needed for interpretation and decision making, in particular to avoid false alarms. Specialist skills are needed for data analysis, communication and storage.

"Who will be responsible for viewing and interpreting data?"

"Engineers are needed for interpretation and decision-making"

All the new information needs to feed into forward work planning and the decision-making process on the timing and nature of mitigation measures.

Standards

The processing of satellite SAR data into high-precision outputs of displacement and soil moisture, for example, uses relatively recent technology that continues to evolve. Consequently, there is not much formal standardisation of the techniques although the techniques are scientifically rigorous, validated and peer reviewed. The growing use of these techniques in infrastructure asset monitoring means that there is a need for a degree of standardisation and standards development is in its early stages (see *Future* chapter).

Nonetheless, there are standards in related fields that should be adopted by providers and specified by clients. These include standards for data formatting (ISO/TR 19121:2000 Geographic information — Imagery and gridded data) and metadata formats (ISO 19115 Geographic information — Metadata in three parts) to facilitate the transfer of data more easily between databases and platforms.

Specification

As in all procurement, specifications can range from the very detailed to the quite open. With the processing of satellite SAR data into outputs such as displacement and soil moisture being relatively new technology under continuous development by various providers, open specifications based on performance and outputs are more suitable. Independent advice on specification should be sought at an early stage from potential providers of satellite SAR data.

Satellite SAR monitoring of property and infrastructure assets creates large volumes of data that need to be accessible but managed securely to protect intellectual property rights and commercial interests and to keep sensitive information from getting into the wrong hands. So, data security is an area where organisations may choose to specify work in a more detailed way. Some of the standards described in the previous section provide specifications for data security.

Data back-up is essential to protect them from corruption, hardware failure and other risks. Greater data protection is gained by using different types of secure storage in different locations, such as locally and on cloud-based servers, while still having sufficiently fast access to the data.

Data visualisation is another area where specification may need to be more detailed, particularly if data needs to be displayed on existing client GIS platforms. Some of the standards described in the previous section provide standard data formats for portability that may be adopted. Overlaying the data on maps or optical satellite images helps in the visualisation of the data and should be a standard requirement. Also, dashboard tools such as the plotting of temporal graphs or isochronous horizontal profiles and the possibility to download data in a transferable format to other data analysis software, e.g. spreadsheets, should come as standard. Warnings when pre-defined trigger levels are reached can also be specified to be managed by the GIS platform. Specific requirements on the security of GIS platforms are also summarised in the box below.

Web-based GIS SaaS minimum requirements

The web-based software-as-a-service (SaaS) is accessed using any of the latest versions of a modern web browser. No installation is required on the user's PC or device.

It should follow industry standard security protocols for web apps. The web app, database and geoserver should be hosted on a cloud server with disk encryption, SSL encryption and web application firewall (WAF). Data should be replicated for backup purposes to a remote location on a cloud server and again encrypted.

A closed registration policy should be adopted, meaning that a user can only gain access by invitation from the system administrator and authentication is needed before accessing any data. A strong password policy should be employed with password expiration and two-factor authentication to increase user login security. Each user is then connected to a specific set of data with no access to other data.

Pricing

The cost of providing processed satellite SAR data for risk estimation and claims handling depends on a multitude of factors, as summarised in Figure 16. Note that there is not necessarily a linear relationship between certain factors and price. For example, if the study area were doubled in size, the cost of providing the data would not double because some of the tasks are automated and would simply involve some slightly longer computer processing times. So, economies of scale do have a significant effect.

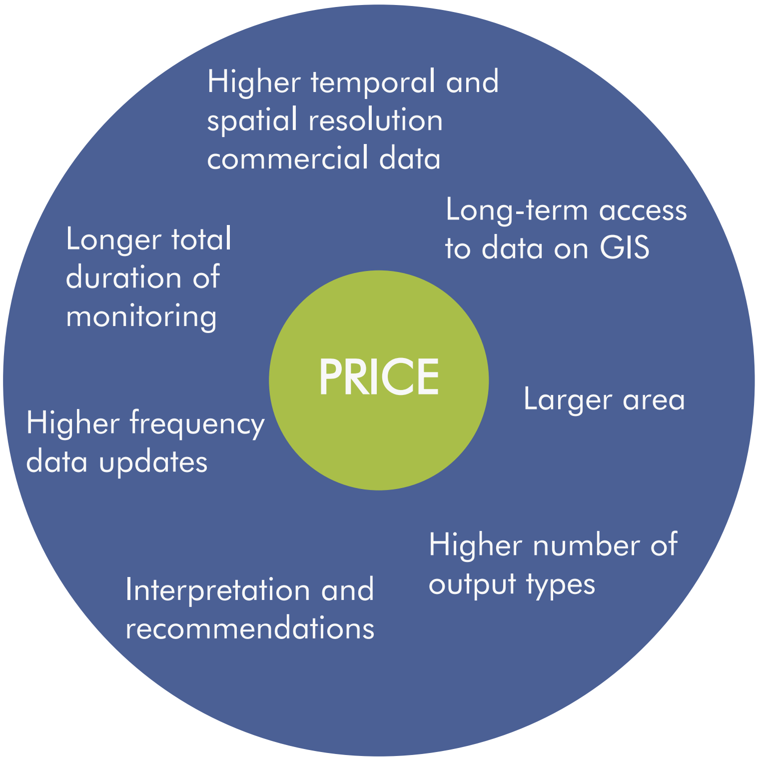


Figure 16. Factors that increase the cost of satellite SAR data

The frequency of satellite data acquisition and frequency of processing and updating output are not quite the same thing. Although data may be acquired every few days, costs can be reduced by processing data and updating output at longer intervals, say on a monthly basis, while still retaining the same temporal resolution of data. This is because time-series InSAR analysis needs to be repeated for the entire sequence each time new data is added, so the workload is much higher if the analysis is repeated every time new satellite data is acquired.

The volume of data and the length of time it needs to be accessible on a web-based GIS platform both have an impact on data storage costs on cloud-based servers.

The satellite data can make the greatest difference to the cost. It can range from cost-free to a significant proportion of project costs for commercial data with higher spatial and temporal resolution where that is required. Satellites can even be tasked to acquire data more regularly from areas of interest at even higher cost. This has a big impact on costs due to the high number of images (at least 20) usually required for analysis. Note that some analysis providers have agreements with certain commercial satellite data companies. While this may reduce the cost of acquiring the data, it means that providers can favour data from certain satellite data companies.

Satellite SAR data Procurement checklist

AGREED BY ALL STAKEHOLDERS

- ☐ Purpose of data collection
- ☐ Information needed
- ☐ Output that will be produced

TECHNICAL REQUIREMENTS

- ☐ Measurement precision & accuracy
- ☐ Site areas to be included
- ☐ Spatial resolution
- ☐ Geolocation accuracy
- ☐ Time interval between data updates
- ☐ Total duration of monitoring

PRACTICAL REQUIREMENTS

- ☐ Formal reporting
- ☐ Platform to access and view data
- ☐ Data update notifications
- ☐ Trigger levels for any warnings
- ☐ Protocols for issuing warnings
- ☐ Strategies for spatial gaps in data
- ☐ Combining other monitoring approaches
- ☐ Pilot study needed?

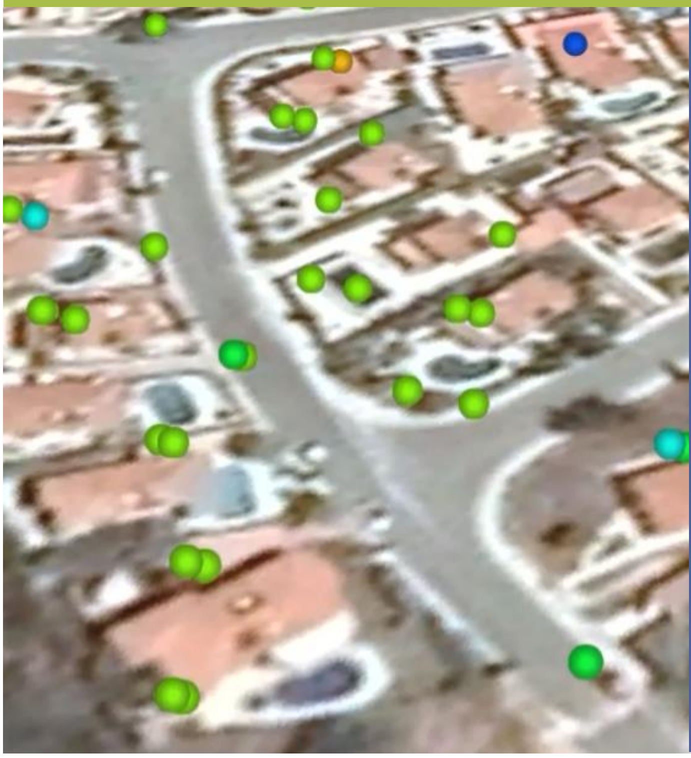
INTEGRATION

- ☐ Who is responsible to view the output?
- ☐ Who is responsible for interpretation?
- ☐ How will someone respond to alarms?
- ☐ Decision-making on interventions
- ☐ Who has the expertise to interpret data?
- ☐ Integration with claims handling process

CASE STUDY 3

Pissouri, Cyprus

Pissouri Bay is a popular tourist resort and the village inland has seen a rapid growth in the number of holiday properties. However, the geology and topography in some parts of the village make it susceptible to landslides. Unfortunately, some properties have been severely damaged by mass movements, so new property investors rightly want to ensure that their purchases are not susceptible to landslides.



THE CHALLENGE

- Prospective property buyers were informed that a site in a village notorious for mass movement was stable but needed to verify that for both themselves and their insurance company.
- In situ surveys would have been expensive and taken months to accumulate sufficient data.

THE SOLUTION

- A retrospective InSAR analysis using archived satellite data was used to show that no significant mass movement had occurred at the site or its vicinity in recent years.

THE BENEFIT

- Both the buyer and insurer had reliable, impartial technical information concerning the stability of the site.
- The information was provided quickly and cost-effectively.

THE FUTURE

The increasing pressure to improve efficiency and reliability in pricing and underwriting as well as claims processing in insurance, point to a growth in the use and value of satellite data.

With extreme weather events becoming more common there is a need to stay up to date with risk evaluations to ensure that the frequency and severity of geohazards is represented the right way. As more data is collected and as analysis methods are improved by utilising technologies such as artificial intelligence, predicting trends will become more accurate and it will be possible to make informed decisions with greater confidence.

The need to avoid manual, subjective risk assessments, to decrease time and cost and improve customer experience, all mean that the adoption of remote sensing techniques of asset monitoring and claims validation – satellite SAR data in particular – will continue to grow.

The new surveying, monitoring and risk assessment techniques will not replace the old (e.g. manual surveys) but interfacing between them needs to improve so that they are used in a balanced and effective way to maximise available resources.

The number of satellites, particularly commercial microsatellites, will continue to grow rapidly. This will bring more affordable high-resolution optical and SAR data and higher frequency revisits. There will be greater choice of wavelengths suited to different applications and inclined orbits will permit easier horizontal north-south displacement measurement.

Increased adoption of satellite SAR data for construction monitoring will bring some broad level standardisation while still allowing ample scope for further technological developments. The Geoscience and Remote Sensing Society (GRSS) of the Institute of Electrical and Electronics Engineers (IEEE) has already prepared proposals for standards development including in the field of satellite SAR data. Meanwhile, the *Monitoring in Geotechnical Engineering* working group of the ISO technical committee on Geotechnics, whose remit includes geohazards, is working on a draft document including annexes for new technologies such as satellite SAR data.

"Artificial intelligence (AI) could be one of the biggest game changers for the insurance industry in the next 10 years."
Deloitte, 2019

"AI and its related technologies will have a seismic impact on all aspects of the insurance industry, from distribution to underwriting and pricing to claims."
McKinsey, 2021.

CONCLUSION

The insurance industry is facing a daunting combination of both old and new challenges. Climate change is increasing the frequency and severity of geohazards exacerbating the damage and cost to insurers. Claims handling and validation are becoming more complex, expensive and time-consuming, while expectations of customers are becoming more demanding. Labour shortages further limit the ability of the industry to assess and respond to risk.

It has been shown that, when combined with other investigation and monitoring approaches, satellite SAR data provides a cost-effective, reliable and objective means of assessing site geohazards and measuring ground movements and moisture changes. This allows more informed and earlier decision making for risk estimation. Retrospective analysis using historical data allows for the effective validation of claims.

The continuing development of artificial intelligence technologies and launches of satellite constellations combined with the increasing need for improved pricing, underwriting and claims handling in the insurance sector mean that the use of satellite SAR data is likely to increase exponentially in the coming years.

Find out more about Geofem services for the insurance sector