# THE ROAD FROM RUIN

## ANALYSIS OF SATELLITE DATA CAN HELP TO MONITOR TRANSPORT NETWORKS FOR SIGNS THAT THEY NEED REPAIR. PHILIP BRISCOE EXPLAINS HOW

The most significant environmental causes of infrastructure system failures are terrain motion and flooding. Instances of extreme weather are increasing and this trend is predicted to continue. Transport networks, prone to degradation from sustained and increasing usage, as well as terrain motion and flooding, are an important key to improving resilience across the integrated infrastructure system. They often act as the conduit for energy and urban systems with related pipes and cables often placed below roads and alongside railways. This integrated system and all sub-systems can also be affected simultaneously by environmental events that affect landscape around transport assets.

Transport network maintenance generally considers typical network usage and infrastructure asset managers already use multiple technologies to monitor an asset's condition and rate of change to drive maintenance scheduling. These technologies include LiDAR, aerial imagery, tilt meters, traditional in-situ ground instruments, weather forecasting and distributed acoustic sensing. But serious consideration needs to be made for landscape hazards, to accurately direct the placement of ground sensors and mitigate maintenance activity.

A resilient infrastructure system, working well in our drive towards the Smart Cities of the future, is one that integrates asset monitoring tools with the monitoring of landscape hazards, which can affect all infrastructure systems. Satellite data analytics and the business decision-support tools that are derived from it, are therefore powerful commercial, social and environmental tools that will prove essential elements in the quest for reduced disruption, improved resilience and wide-spread benefit to organisations and public alike.

To generate valuable and usable decision-support tools for the infrastructure sector, complex datasets from multiple sources – including open-access and acquired satellite data, UAV data and ground-based sensor data – must be aggregated using a single platform that can operate at the scale and speed required to process such vast information. The processing of the imagery and data from a time-series (multiple points in the past and present) involves algorithmic recognition of patterns that can be attributed to geographical events or situations, such as changes in the landscape related to subsidence or changes in the colour of soil or vegetation related to moisture levels. The next challenge is to give the data context by georeferencing and presenting it using visual tools such as a map-based representation of the data separated into distinct data layers that can be analysed independently or as part of a map that shows merged data layers simultaneously.

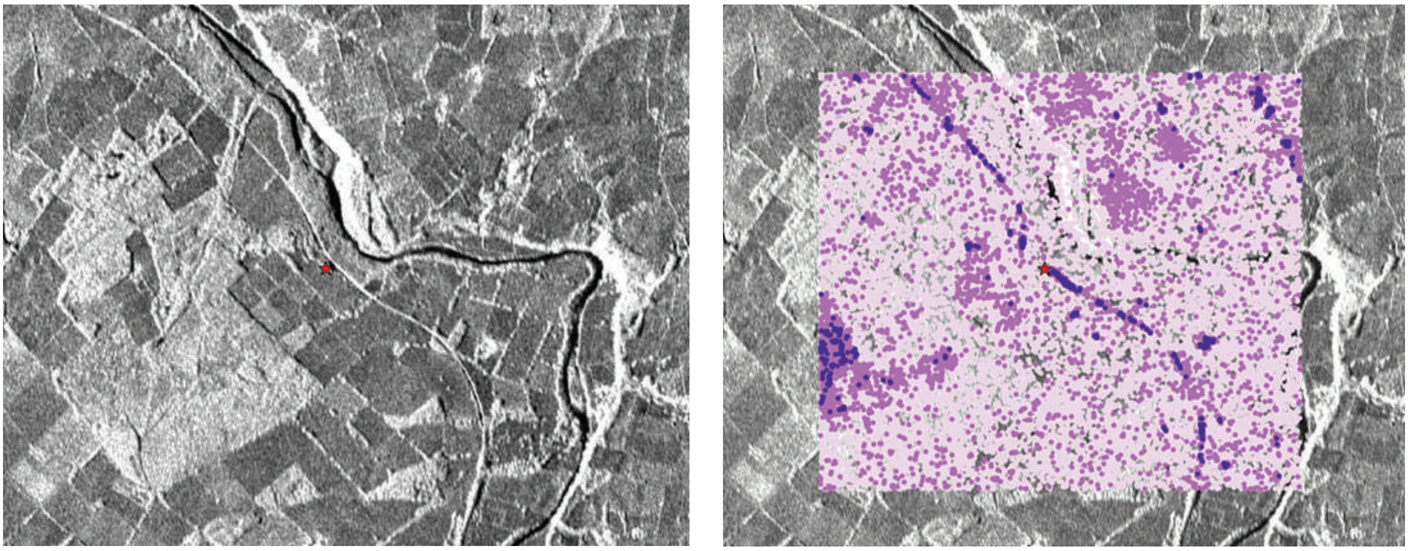
This processed information can be used to identity and monitor geographical areas of high risk where disruption to urban living might occur based on recognised data patterns of soil moisture and terrain motion that indicate risk of flooding or subsidence.

Infrastructure operators can use these tools to remotely and accurately monitor and assess the landscape factors that affect the condition, long-term stability and resilience of their assets. And with additional monitoring and alerting systems to identify potential and actual 'failure' events, asset managers can take proactive action to mitigate a potential event, or to react quickly and precisely to detected failures therefore making the infrastructure assets more resilient and minimising costly future interventions.

For example, a time series of synthetic aperture radar imagery can be analysed to identify terrain motion which can be used as an early warning system for potential earthworks movements that might affect rail or road transportation networks.

### Technology and processes

Through the application of satellite data teamed with cutting-edge software and highly-skilled workforce, the geo-analytics now available can highlight areas of change across large territories, allowing



Sentinel 1 radar data backscatter analysis to identify subsidence over time. Left: raw backscatter; Right: analysed backscatter

asset managers to direct more detailed investigation.

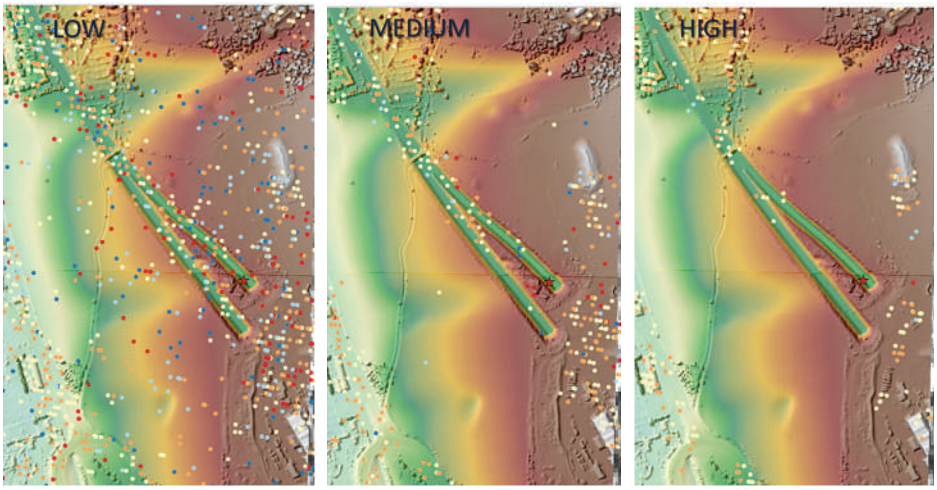
The European Space Agency (ESA)'s Sentinel 1 satellites are synthetic aperture radars developed to monitor environmental change, specifically terrain motion and soil moisture. The Sentinel 1 radar mission is composed of a pair of C-band synthetic aperture radars (Sentinels 1a and 1b) that operate at 5.4GHz and can collect dual polarisation data at a range of spatial scales to suit various applications. These radar sensors will revisit the same location on the Earth every six days throughout Europe and every 12 days across much of the rest of the world.

The Sentinel 1 orbits have been carefully designed to have a narrow, highly precise orbital tube, which is highly beneficial to applications involving differential interferometry. The Sentinel 1 radars are more sensitive to increasing levels of backscattered microwaves than their precursors, which, it is hoped, will improve the estimation of important landscape processes, such as biomass accumulation and soil moisture. A significant advantage of radar data is that it can typically be acquired both day and night

Sentinel 1 datasets can be interrogated using automated, interferometric processing workflows to monitor terrain motion and to assess soil moisture levels. Differential interferometry works with the phase component of a radar dataset. Specifically, it measures the phase difference between radar waves returned from the same ground target at different periods of time. A portion of this difference can be ascribed to terrain motion through long-established interferometric techniques, such as persistent scatterers and small baseline subsets. Under ideal conditions, these methods can readily identify sub-centimetre changes, particularly in urban environments.

Radar imagery can also be used to estimate surface soil moisture based on the appropriate selection of environmental setting and radar frequency. X-band radars are typically scattered by small structural elements, such as leaves and twigs in the vegetation canopy, and so its sensitivity to soil moisture is relatively low, even in locations with modest vegetation cover, since most scattering at this frequency occurs above the soil. C-band radars are backscattered by larger vegetation structures, such as tree branches, so penetrating the upper vegetation strata and producing a stronger relationship with soil moisture content. Therefore, Sentinel 1 can be effectively used in agricultural and grassland environments to estimate soil moisture.

The Sentinel 1 sensors are well suited to monitoring transport networks given their large 'footprint', revisit frequency, spatial resolution and ESA's open data policy. Optical imagery from Sentinel 2 enhances the estimation of soil moisture levels. Wherever further data is required for a more granular view of the landscape and/or an asset, low-cost sensors can be deployed in an extremely targeted manner to supplement the satellite data where a known risk has been identified. These sensors can record soil temperature, water pressure and water content.




Degrees of analysis of Sentinel 1 radar data to measure terrain motion

## Adding value

Satellite geospatial analytics are an additional tool in the asset manager's existing toolkit. As with any new technology, the value is only really recognised and ultimately acted on if the information produced is easy to use and intuitive. To ensure this, analytical outputs can be hosted in an online environment and presented as interactive visualisations, such as colour-coded risk maps for easy interpretation. The asset manager is really interested in change, and only change that falls outside of pre-set thresholds, so 'alerts' can be triggered as pertinent changes occur as the satellite data analytics are updated with the availability of every new source data input. This means that even the most minor change such as sub-centimetre terrain movement of a rail or road embankment, can be highlighted, which enables engineers to investigate change before any significant disruption or damage occurs.

One of the main benefits of using satellites is that vast areas of road or rail infrastructure can be continually monitored with zero intrusion to the working asset or the requirement for expensive manual resource. In the first instance, geospatial satellite data analytics provide a coarse-scale assessment that flags up potential issues that need to be



either further analysed using higher resolution but costlier commercial satellite data or inspected on the ground. Importantly, satellite data can enhance traditional techniques of monitoring infrastructure through its ability to cover vast areas of land, its frequency of data collection and the fact that the analysis can be done remotely at low cost.

With any technology that uses machine learning, there can be a higher level of false positives in its early days of deployment, caused for example by measurements of ground motion resulting from planned infrastructure maintenance, but as such data is fed back into the system, accuracy increases and therefore false positives are reduced.

## Integrating workflows

The key to adoption of satellite data by asset managers is to enable results to be combined from multiple systems to optimise its effect. Geospatial satellite data analytics can be presented in an interactive portal and other georeferenced datasets can be imported into the system and added as additional data layers. Importantly, the data can be further analysed with the satellite data outputs to further calibrate it and increase accuracies. The underlying data can also be parsed into other systems as an automated process, such as a web map service, or users can simply download the data in a simple format such as a CSV file for manual input into other systems.

As resilience becomes a key word for urban environments and supporting infrastructure, this integrated approach supports a new way for organisations to collaborate, from highways managers to rail operators to energy providers. In place of multiple systems being run by individual companies or local government entities, either a shared geospatial environmental monitoring platform or the automated integration of data between systems allows asset managers to share critical information often relating to the same locations and, importantly, the same threats.

The fusion of satellite imagery and ground-sensor network data enables landscape hazards to be located with precision. Enhanced monitoring with additional sensors and deployment of ground personnel can then be focused by asset owners to efficiently allocate scarce resources to provide an efficient and resilient transport network as part of a fully integrated infrastructure system.

It is with these advances in data capture, processing and intelligent application of derived analytics that infrastructure asset management can become an even more forward-thinking, proactive process to reduce disruption and improve resilience.

**THE FUSION OF SATELLITE IMAGERY AND GROUND-SENSOR NETWORK DATA ENABLES LANDSCAPE HAZARDS TO BE LOCATED WITH PRECISION**

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