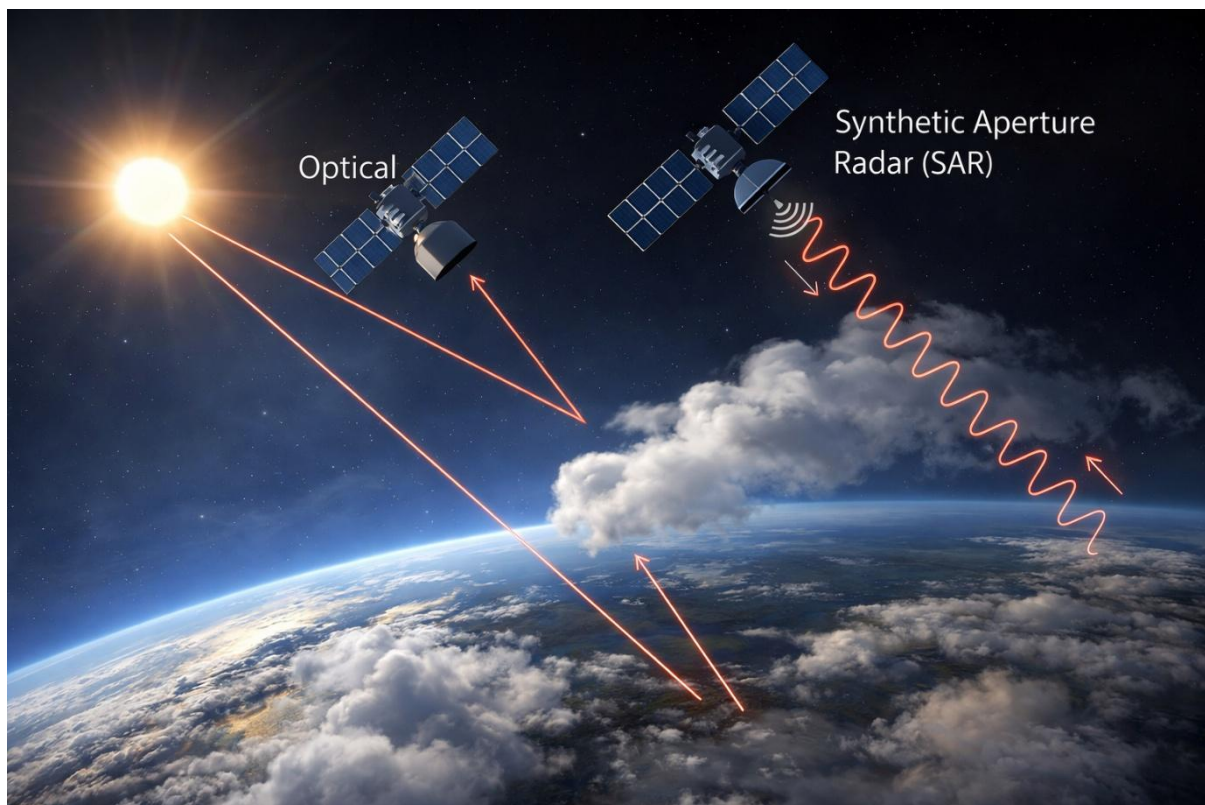


SAR Introduction and Sentinel 1 Fundamentals

Welcome. In this video, we explore one of the most powerful technologies used in Earth observation today: Synthetic Aperture Radar, commonly referred to as SAR. We focus on the Sentinel 1 mission, which represents the radar component of the European Union's Copernicus Earth observation programme, and use it as a reference to understand how radar systems observe the Earth's surface under conditions where optical sensors are limited. From this starting point, we will examine how SAR works from a physical and technical perspective, including how radar signals interact with the surface, how images are formed and how geophysical measurements can be extracted from the data.

Sentinel 1 is a radar imaging mission developed by the European Space Agency and consists of two satellites, Sentinel 1A and Sentinel 1B. These satellites operate in the same orbit but are phased to ensure frequent and consistent observations of the Earth's surface. Each satellite is equipped with a C-band Synthetic Aperture Radar instrument, operating at microwave frequencies with a wavelength of approximately 5.6 centimeters.

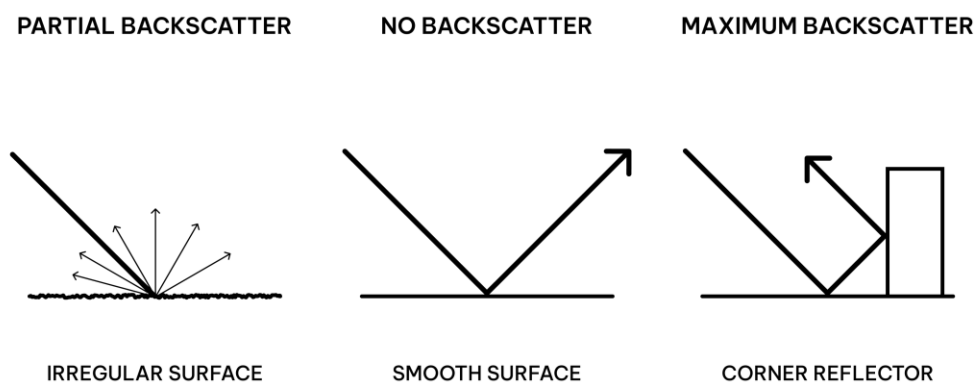


Unlike optical sensors, which rely on sunlight reflected from the Earth, Sentinel 1 is an active sensor. It emits its own microwave signal toward the surface and measures the portion of that signal that is reflected back. This capability allows Sentinel 1 to observe the Earth independently of daylight conditions and largely independently of atmospheric effects such as cloud cover. For this reason, radar data plays a critical role in operational monitoring systems, where continuous and reliable observations are required. The mission provides systematic and

high-resolution radar imagery that supports a wide range of applications, including land deformation monitoring, flood mapping, maritime surveillance, agricultural observation and infrastructure stability assessment.

To understand how this information is generated, it is necessary to briefly review the physical principles behind radar sensing. Radar systems operate by transmitting electromagnetic waves and measuring how these waves interact with the Earth's surface. The transmitted signal travels at the speed of light and, when it encounters an object, part of the energy is scattered in different directions. A portion of this scattered energy returns to the radar sensor and is recorded. From this returned signal, two key quantities are measured: amplitude and phase.

The amplitude indicates how strongly a surface reflects the radar signal, providing information about the physical properties of the target. The phase, on the other hand, contains information about the distance between the satellite and the observed surface. These two components form the basis for extracting meaningful information from SAR data. Radar systems typically operate in the microwave region of the electromagnetic spectrum. These wavelengths are particularly useful because they interact with the physical structure of the surface in distinctive ways. For example, microwave signals can penetrate vegetation canopies and, in some conditions, even dry soil. This makes radar particularly effective for observing features that are not directly visible with optical sensors.

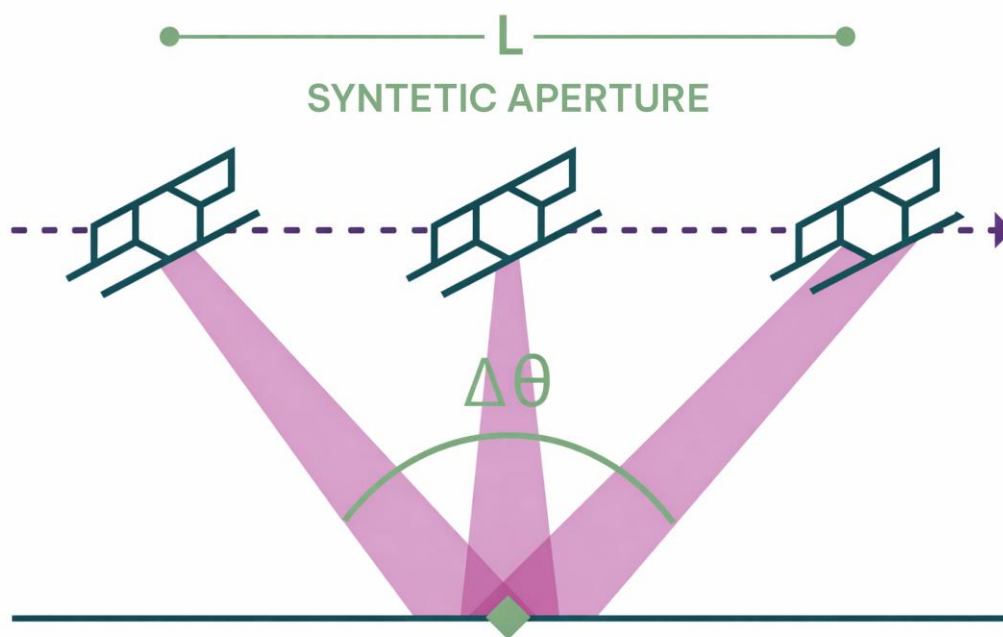


When a radar wave reaches the Earth's surface, the way it is reflected depends on several physical characteristics, the most important of which is surface roughness. If the surface is smooth relative to the radar wavelength, the signal is reflected away from the sensor in a specular manner, similar to a mirror. This is why calm water surfaces often appear very dark in radar images. If the surface is rough, the signal is scattered in multiple directions and a portion of that energy returns to the sensor. Urban environments are a typical example of this behavior,

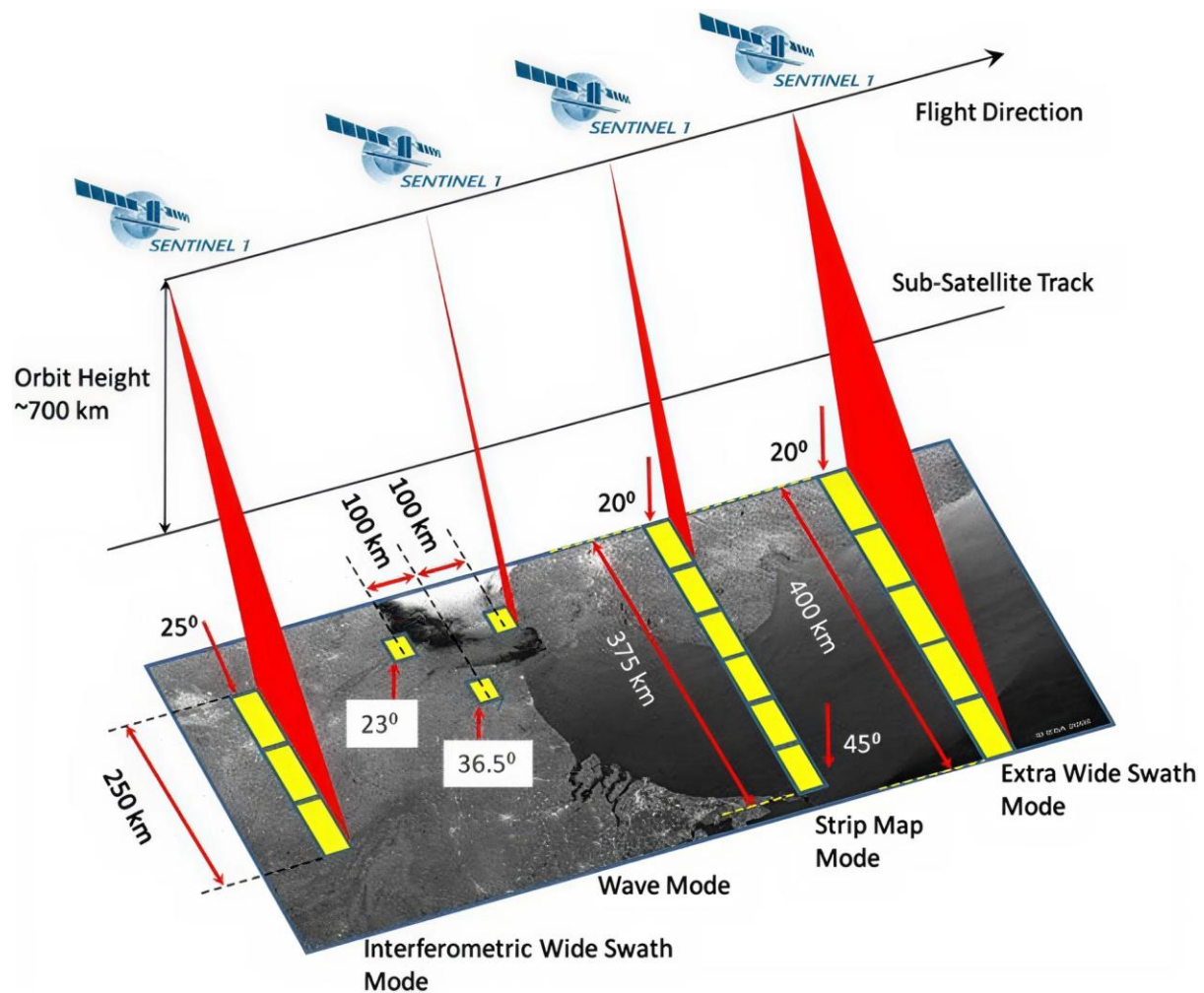
where buildings and infrastructure generate strong radar reflections due to multiple scattering between vertical and horizontal surfaces, a phenomenon often referred to as the corner reflector effect. This results in a strong backscatter signal, making urban areas clearly distinguishable in radar imagery.

Another important factor is the dielectric property of the material. Surfaces with higher dielectric constants, such as wet soils, tend to reflect more radar energy than dry surfaces. This allows radar data to be used for detecting variations in soil moisture and surface water conditions. Vegetation also plays a significant role in radar scattering. Leaves, branches and trunks create complex interactions with the radar signal, generating patterns that can be used to infer vegetation structure and density. Understanding these interaction mechanisms is essential for correctly interpreting SAR imagery, as the observed signal is always the result of a combination of surface geometry, material properties and environmental conditions.

Synthetic Aperture and SAR Image Formation

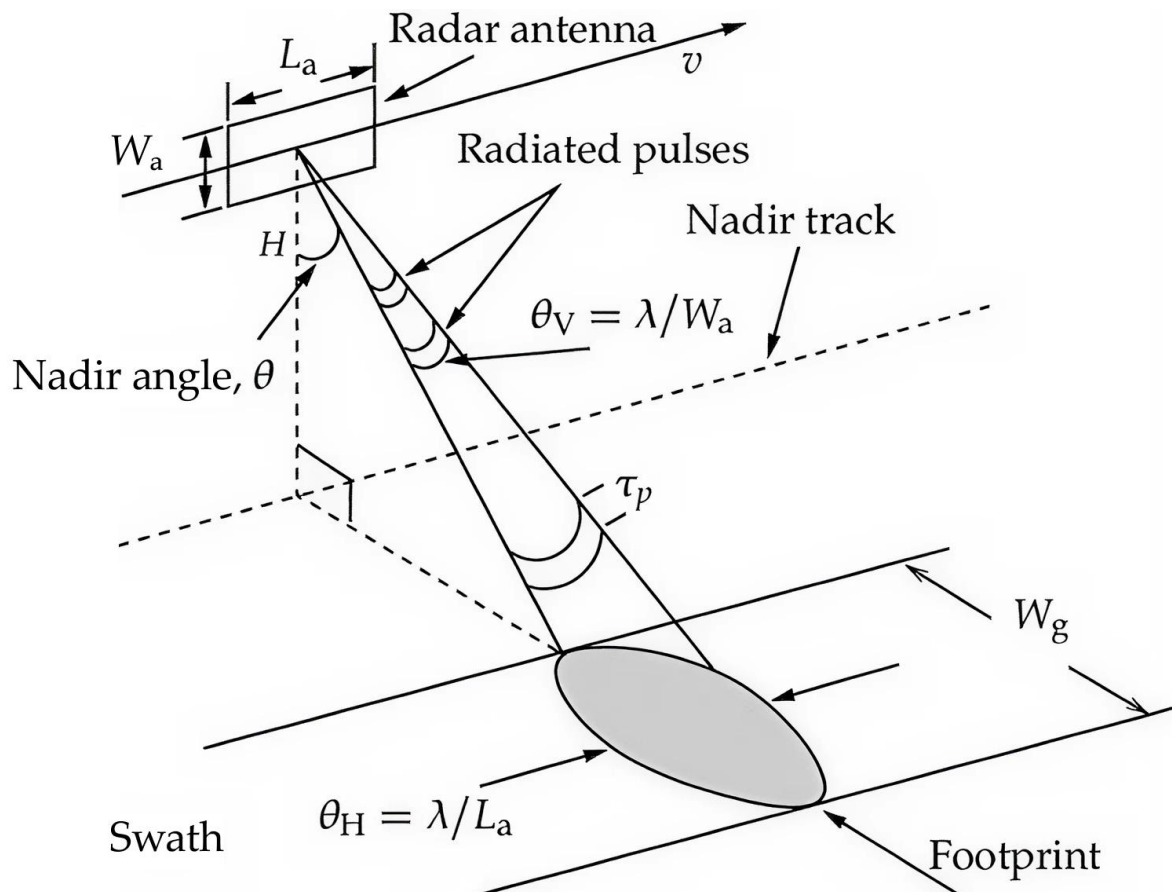


The term Synthetic Aperture Radar refers to a specific imaging technique that allows radar systems to achieve high spatial resolution without requiring physically large antennas. In traditional radar systems, image resolution depends directly on the size of the antenna. A larger antenna provides better angular resolution, but in satellite applications, building very large antennas is not practical. SAR overcomes this limitation by exploiting the motion of the satellite along its orbit. As the satellite moves, the radar instrument repeatedly transmits pulses toward the same ground area. Each of these pulses is recorded together with the amplitude and phase of the returned signal.



Because the satellite changes position over time, each measurement is effectively acquired from a slightly different location along the orbit. By combining all these observations through advanced signal processing, it is possible to simulate the effect of a much larger antenna. This process creates what is known as a synthetic aperture, which is significantly larger than the physical antenna mounted on the satellite. The result is a radar image with much higher spatial resolution than would otherwise be achievable.

SAR images are constructed using two spatial dimensions: range and azimuth. The range dimension corresponds to the distance between the radar sensor and the target. Range resolution depends on the duration of the transmitted radar pulse, with shorter pulses providing finer resolution.



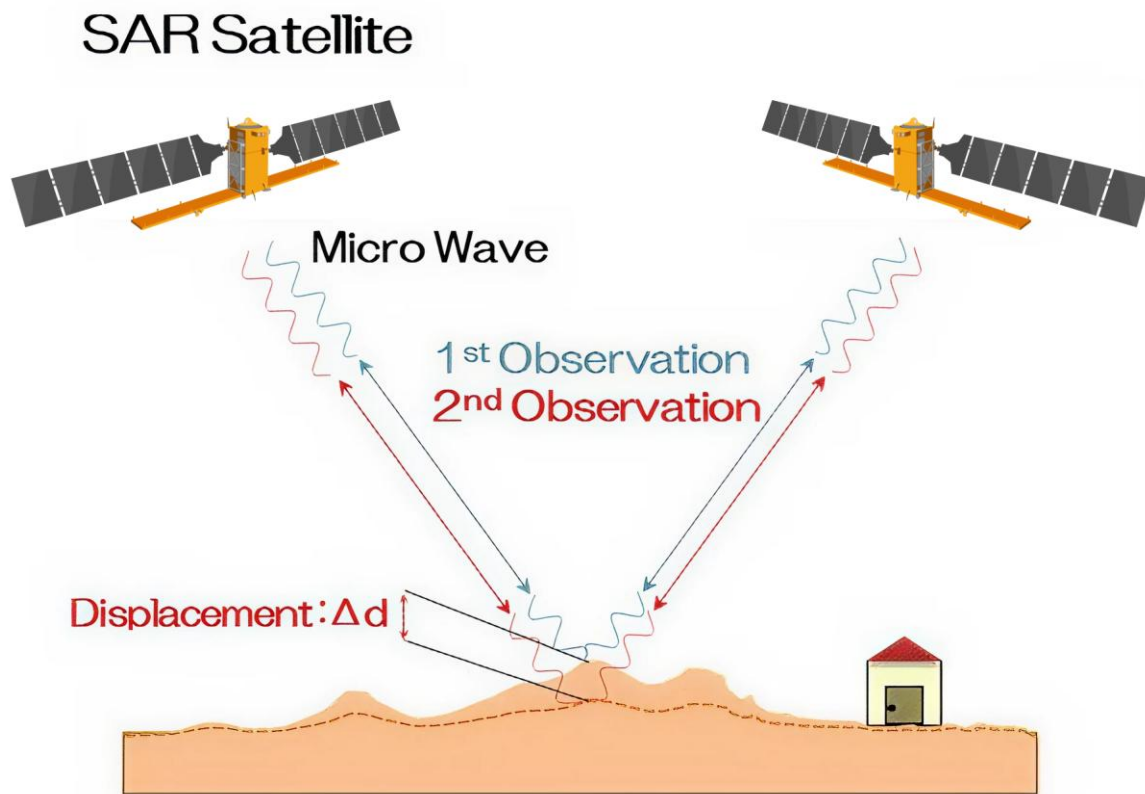
The azimuth dimension corresponds to the direction of the satellite's motion. Azimuth resolution is achieved through the synthetic aperture process, which combines multiple observations collected over time. By coherently integrating radar echoes acquired along the orbit, the system can distinguish objects that are very close to each other along the flight path. This process requires precise control and analysis of the phase information contained in the radar signal.

The generation of a SAR image involves several processing steps. Initially, the radar system records raw echoes as complex signals containing both amplitude and phase. These signals must then be processed to reconstruct a coherent and geometrically accurate image. Key steps in this process include range compression, azimuth compression, motion compensation and radiometric calibration. Range compression improves resolution in the distance direction by correlating the received signal with the transmitted pulse.

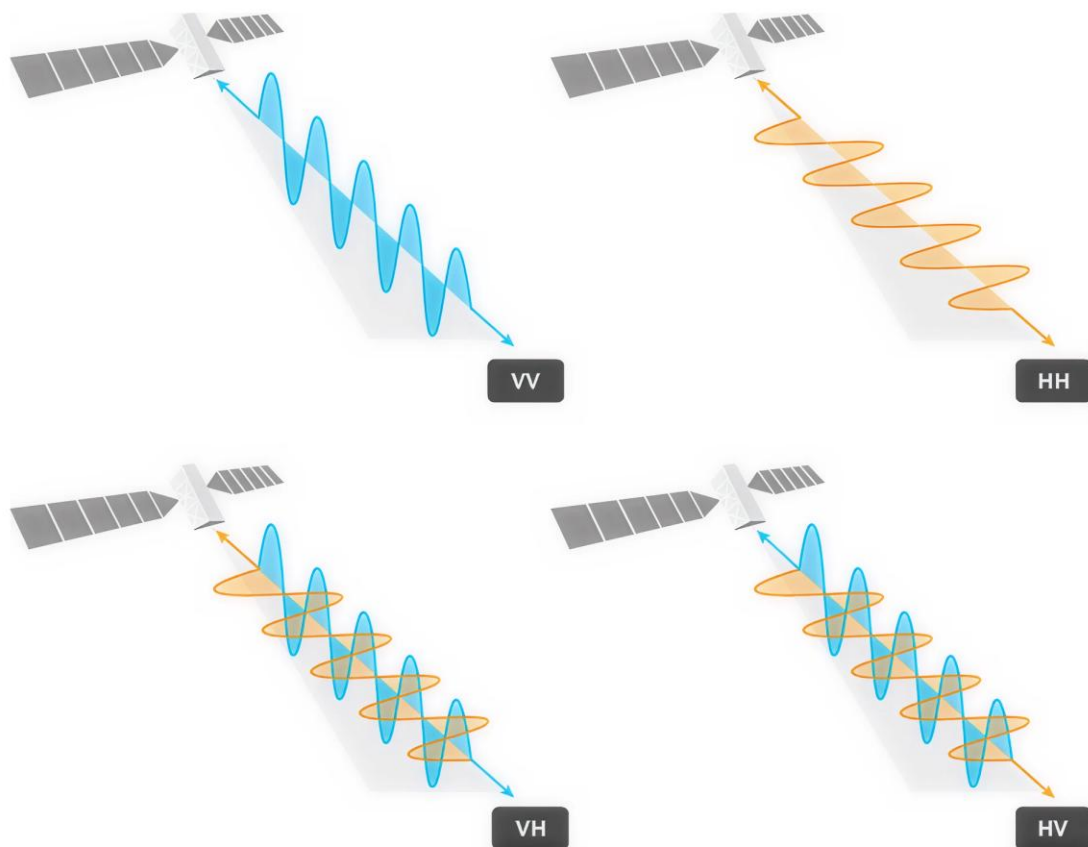
Azimuth compression combines multiple radar echoes acquired during the satellite motion, enabling the synthetic aperture effect. Motion compensation ensures that any deviations in the satellite trajectory are correctly accounted for, preserving geometric accuracy. Radiometric calibration converts the raw signal into standardized backscatter values, allowing meaningful comparison across different acquisitions. The final result is a radar image in which each pixel represents the backscatter intensity associated with a specific ground location.

Interferometric SAR, Polarization and Applications

One of the most powerful capabilities of SAR technology is interferometry, commonly referred to as InSAR. InSAR is based on the comparison of multiple radar images acquired either from slightly different positions or at different times. By analyzing the phase differences between these acquisitions, it becomes possible to detect very small variations in the distance between the satellite and the ground.



These variations can correspond to ground displacement on the order of millimeters, making InSAR a highly effective tool for monitoring surface deformation. Because Sentinel 1 provides frequent and geometrically consistent observations of the same areas, it is particularly well suited for interferometric analysis over time. Through this approach, it is possible to monitor a wide range of geophysical processes, including land subsidence, tectonic deformation, volcanic activity, landslides and infrastructure stability. In addition to interferometry, another important concept in radar remote sensing is polarization.



Radar signals can be transmitted and received with different polarization states, typically horizontal or vertical. Different surface types interact with these polarization configurations in different ways, producing distinct scattering responses. By analyzing multiple polarization channels, it is possible to extract additional information about surface structure and scattering mechanisms. This is particularly useful in applications such as vegetation analysis, forest monitoring and agricultural assessment.

The combination of SAR imaging, interferometric techniques and polarization analysis makes Sentinel 1 a highly versatile system for Earth observation. For example, in flood monitoring, water surfaces tend to appear dark in radar imagery due to specular reflection, allowing flooded areas to be identified even under cloud cover. In deformation monitoring, interferometric analysis enables the detection of slow ground movements that are not visible through conventional observation methods. In agriculture, the sensitivity of radar signals to soil moisture and vegetation structure provides valuable insights into crop conditions.

In maritime applications, SAR can detect ships and monitor sea ice regardless of weather conditions. In infrastructure monitoring, radar-based deformation measurements can help identify structural instability in buildings, bridges and other assets. Overall, SAR represents a fundamental component of modern Earth observation. By combining microwave sensing, satellite motion and advanced signal processing, it enables continuous monitoring of the Earth's surface under conditions where optical systems are limited.

The Sentinel 1 mission has made this technology widely accessible through the Copernicus programme, providing a reliable source of data for scientific, operational and decision-making applications. When integrated with optical and atmospheric observations from other Sentinel missions, SAR contributes to a more comprehensive and multi-dimensional understanding of environmental processes.

Advanced Applications of Sentinel 1: Landslides, Subsidence and Phase Displacement

We now move from the theoretical principles of SAR and interferometry to a set of advanced applications based on Sentinel 1 data. In particular, we will focus on three key phenomena: landslides, subsidence and phase displacement monitoring. All these applications rely on interferometric analysis, which allows us to measure ground deformation with millimetric precision and to observe how it evolves over time. The objective is to understand how these techniques can be applied in real-world scenarios to monitor terrain stability, assess risks and support decision-making processes.

Sentinel 1 is particularly well suited for this type of analysis thanks to its acquisition characteristics. It provides consistent observations over time, frequent revisit intervals and stable imaging geometry, all of which are essential for reliable time-series analysis. By applying interferometric techniques such as Differential InSAR, Persistent Scatterer Interferometry and Small Baseline Subset approaches, it becomes possible to detect very small surface displacements and to track their evolution across multiple acquisitions. These approaches differ in how they select stable targets and reconstruct deformation over time, enabling reliable analysis even in complex environments.

Let us begin with landslide monitoring. Landslides are often associated with factors such as intense rainfall, soil saturation, seismic activity or slope instability. However, in many cases, they are preceded by gradual ground deformation that may not be detectable through traditional observation methods. Sentinel 1 allows the identification of these pre-failure signals by analyzing phase variations over time. By comparing repeated acquisitions of the same slope, it is possible to detect slow displacement patterns and identify areas that are progressively becoming unstable. Through time-series analysis, operators can recognize active slopes, areas with increasing deformation rates and zones that may be at risk of failure.

In operational scenarios, this information can be used to support early warning systems. Monitoring a slope over time makes it possible to detect acceleration in displacement, which is often a critical precursor of slope failure. This allows authorities to take preventive actions, such as restricting access, reinforcing the terrain or deploying additional monitoring systems.

We now move to subsidence monitoring. Subsidence refers to the gradual sinking of the ground surface and can affect large areas over long periods. It is commonly associated with groundwater extraction, mining activities, soil compaction or urban development. Using Sentinel 1 data, subsidence can be measured through time-series interferometric analysis. This process typically involves identifying stable reference points, tracking phase changes across

multiple acquisitions and converting these phase variations into displacement values. By tracking phase changes across multiple acquisitions, it is possible to estimate displacement velocities and generate maps that represent ground movement over time. In these maps, negative values typically indicate downward motion, while positive values correspond to uplift.

These maps allow the identification of spatial patterns, such as uniform subsidence across an area or localized deformation linked to specific activities. In urban environments, this type of analysis is particularly valuable. It enables the detection of differential subsidence that may affect buildings, roads or infrastructure networks. By identifying areas with higher deformation rates, planners and engineers can prioritize interventions, monitor critical zones and reduce the risk of structural damage.

The third aspect is phase displacement monitoring, which represents a more general approach to deformation analysis. Phase displacement refers to changes in the radar signal phase over time, which correspond to variations in the distance between the satellite and the ground along the radar line of sight. This measurement includes both vertical motion and horizontal motion toward or away from the satellite, meaning it does not represent purely vertical displacement. By analyzing multiple acquisitions, it is possible to reconstruct deformation time series for individual locations. This allows the identification of gradual trends, seasonal variations and sudden changes in ground movement.

Phase displacement monitoring is widely used in infrastructure analysis. For example, bridges, buildings or other structures can be monitored over time by identifying stable radar targets and tracking their displacement. If the observed time series shows consistent movement, acceleration or irregular behavior, this may indicate potential structural issues. One of the key advantages of this approach is that it is non-invasive, as it does not require the installation of physical sensors on the structure. In real-world applications, landslide monitoring, subsidence analysis and phase displacement are often used together.

Each approach provides a different perspective on ground dynamics. Landslide analysis focuses on slope instability, subsidence highlights vertical ground movement over large areas and phase displacement provides a detailed temporal description of deformation. By integrating these analyses, it becomes possible to obtain a more comprehensive understanding of terrain behavior. To further improve interpretation, Sentinel 1 data can be combined with additional sources of information, such as Digital Elevation Models, rainfall data, geological maps or in-situ measurements. This multi-source approach increases the reliability of the analysis and supports more informed decision-making.

At the same time, it is important to consider some limitations of radar-based measurements. Displacement is measured along the radar line of sight, which means it does not directly correspond to purely vertical or horizontal motion. Vegetation can reduce signal coherence, atmospheric conditions may introduce noise and complex terrain can lead to phase interpretation challenges. Understanding these limitations is essential for correctly interpreting the results and avoiding misinterpretation.

Data Visualization in EagleArca

We are now going to explore how Sentinel 1 radar data can be visualized and used within the EagleArca platform and how its analytical value increases when it is combined with other geospatial information. The objective is not simply to access satellite data, but to understand how this data is transformed into an interactive analytical layer that allows users to observe and interpret ground deformation processes such as subsidence and displacement over time. Within EagleArca, Sentinel 1 data is available as a dedicated geospatial layer derived from interferometric analysis. This layer provides information about ground displacement along the radar line of sight, enabling the monitoring of terrain dynamics over time.

By interacting with the map, it is possible to select specific areas of interest and access the associated data. Among the available information is the average deformation velocity, typically calculated over a temporal baseline of approximately two years. This value represents the rate of ground movement and allows users to quickly identify areas affected by subsidence or uplift. In addition to this aggregated value, the platform also provides access to the temporal evolution of deformation. For each selected location, a time series is available, showing how displacement changes over time.

This temporal representation makes it possible to recognize different patterns. A linear trend may indicate a steady and continuous deformation process, while non-linear trends, seasonal oscillations or sudden variations may reveal more complex dynamics related to environmental conditions or structural factors. In this way, the Sentinel 1 layer is not just a static map, but an analytical tool that allows users to understand not only where deformation occurs, but also how it evolves over time. A key feature of the EagleArca platform is that all layers are georeferenced within the same coordinate system. This allows Sentinel 1 data to be seamlessly combined with other geospatial datasets, enabling integrated analysis.

For example, when deformation data is combined with a Digital Elevation Model, it becomes possible to analyze how ground movement relates to terrain morphology. Subsidence in flat areas may indicate potential water accumulation issues, while deformation along slopes may suggest instability or landslide risk. Similarly, integrating Sentinel 1 data with land use or land cover information helps distinguish between deformation occurring in urban areas, agricultural fields or natural environments, providing essential context for interpretation.

In urban scenarios, combining deformation data with infrastructure layers such as buildings, roads or pipelines allows the identification of critical assets that may be affected by ground movement, supporting risk assessment and maintenance planning. In agricultural contexts, Sentinel 1 data can be combined with information derived from Sentinel 2 or other environmental indicators, making it possible to analyze the relationship between soil conditions, irrigation practices and seasonal dynamics. Another important integration is with meteorological data, such as rainfall and temperature. By correlating deformation patterns with environmental variables, it becomes possible to investigate how external factors influence ground movement.

The key point is that, while the Sentinel 1 layer provides valuable information on its own, its full analytical potential emerges when it is integrated with other datasets, such as terrain models,

land use information, environmental indicators and meteorological data, allowing multiple variables to be analyzed together. From an operational perspective, EagleArca enables users to dynamically activate and deactivate layers, adjust visualization parameters and interact with specific locations to access detailed information. This interactive approach is particularly important when working with complex datasets such as SAR-derived deformation, which always require contextual interpretation. Moreover, the ability to observe both spatial distribution and temporal evolution within the same environment provides a comprehensive understanding of the monitored area.

In conclusion, the visualization of Sentinel 1 data in EagleArca demonstrates how advanced satellite analytics can be transformed into accessible and actionable information. By combining spatial analysis, temporal monitoring and multi-layer integration, the platform enables users to better understand and manage ground deformation phenomena.

Interpreting Geospatial Layers and Practical Applications

Once geospatial data has been visualized, the next step is to understand how to interpret it correctly and how to translate that information into practical applications. Geospatial analysis is based on the concept of layers, where each layer represents a specific type of information associated with a geographic location. These layers can include satellite-derived data, terrain models, land use classifications, infrastructure maps or environmental indicators. Each layer contains values that describe a particular physical or modeled variable. In the case of raster data, these values are organized in pixels, while vector data is represented through geometries such as points, lines and polygons.

Interpreting these layers requires understanding both what the data represents and how it has been generated. When analyzing a layer for the first time, it is important to avoid interpreting values in isolation. A single value may provide limited information, while its meaning becomes clearer when considered within its spatial context. For this reason, one of the most important aspects of geospatial interpretation is the ability to recognize spatial patterns. For example, clusters of high values may indicate localized anomalies, while linear patterns can follow infrastructure or geological features. The distribution of values across an area often reveals underlying processes that are not immediately visible at a single point. For example, clusters of similar values may indicate consistent environmental conditions, while gradients or abrupt changes can suggest transitions between different states or the presence of anomalies.

In addition to spatial patterns, temporal analysis also plays a crucial role. When time-series data is available, it becomes possible to observe how a variable evolves over time, identifying trends, seasonal variations or sudden changes. This temporal dimension is particularly important in applications such as environmental monitoring, infrastructure assessment and agricultural analysis, where processes are dynamic rather than static. Another key principle is the integration of multiple layers. Individual datasets provide partial information, but when combined, they allow a more comprehensive understanding of the system being observed.

For instance, in agriculture, combining vegetation indices, soil moisture information and temperature data can help explain variations in crop performance. In urban environments, integrating deformation data with infrastructure layers can support risk assessment and maintenance planning. In environmental analysis, combining terrain data with meteorological information can help identify areas exposed to flooding or erosion. In practical scenarios, geospatial layers are used to support decision-making across different domains. In agriculture, they contribute to monitoring crop conditions and optimizing resource use. In urban contexts, they support infrastructure management and planning. In environmental monitoring, they help identify risks and understand natural processes.

It is also important to consider that geospatial data is not limited to a single platform. One of the strengths of modern geospatial systems is their interoperability. Data can be exported and used in external GIS environments, enabling more advanced or customized analysis. Common formats include raster files such as GeoTIFF and vector formats such as Shapefiles, which can be imported into tools like QGIS. These environments allow users to perform more detailed spatial analysis, apply custom processing workflows and integrate additional datasets. The ability to move between different tools ensures flexibility in the analytical process. Initial exploration and visualization can be performed within platforms like EagleArca, while more advanced processing and modeling can be carried out in dedicated GIS software.

Ultimately, interpreting geospatial layers is both a technical and analytical task. It requires understanding the nature of the data, recognizing spatial and temporal patterns and integrating multiple sources of information into a coherent framework. As the availability of geospatial data continues to grow, the ability to interpret and use these layers effectively becomes increasingly important across a wide range of applications. In conclusion, geospatial layers are not simply visual elements on a map, but structured representations of complex spatial processes. When correctly interpreted and combined, they provide valuable insights that support informed decision-making in agriculture, urban planning and environmental monitoring.