Sentinel EO Data - SAR and Multispectral Monitoring

Sentinel-1

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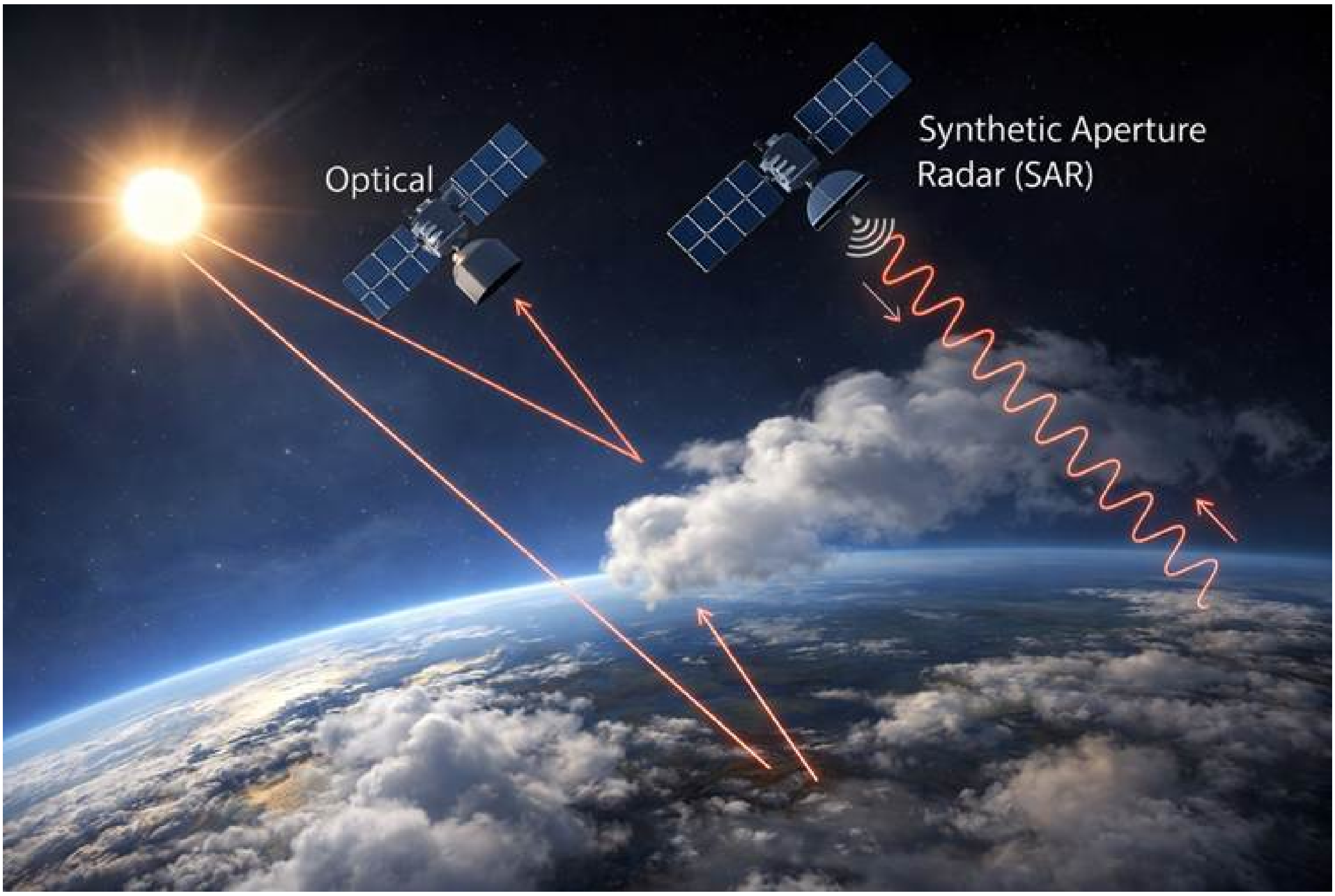
SAR Introduction and Sentinel 1 Fundamentals

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.

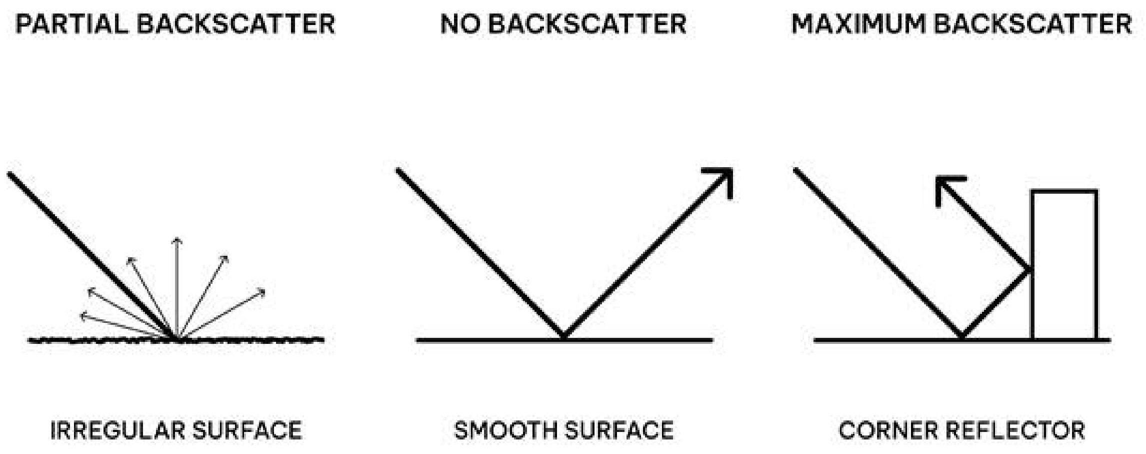
Sentinel 1 is a radar imaging mission developed by the European Space Agency and consists of two satellites, Sentinel 1A and Sentinel 1B. These satellites operate in the same orbit but are phased to ensure frequent and consistent observations of the Earth’s surface. Each satellite is equipped with a 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.

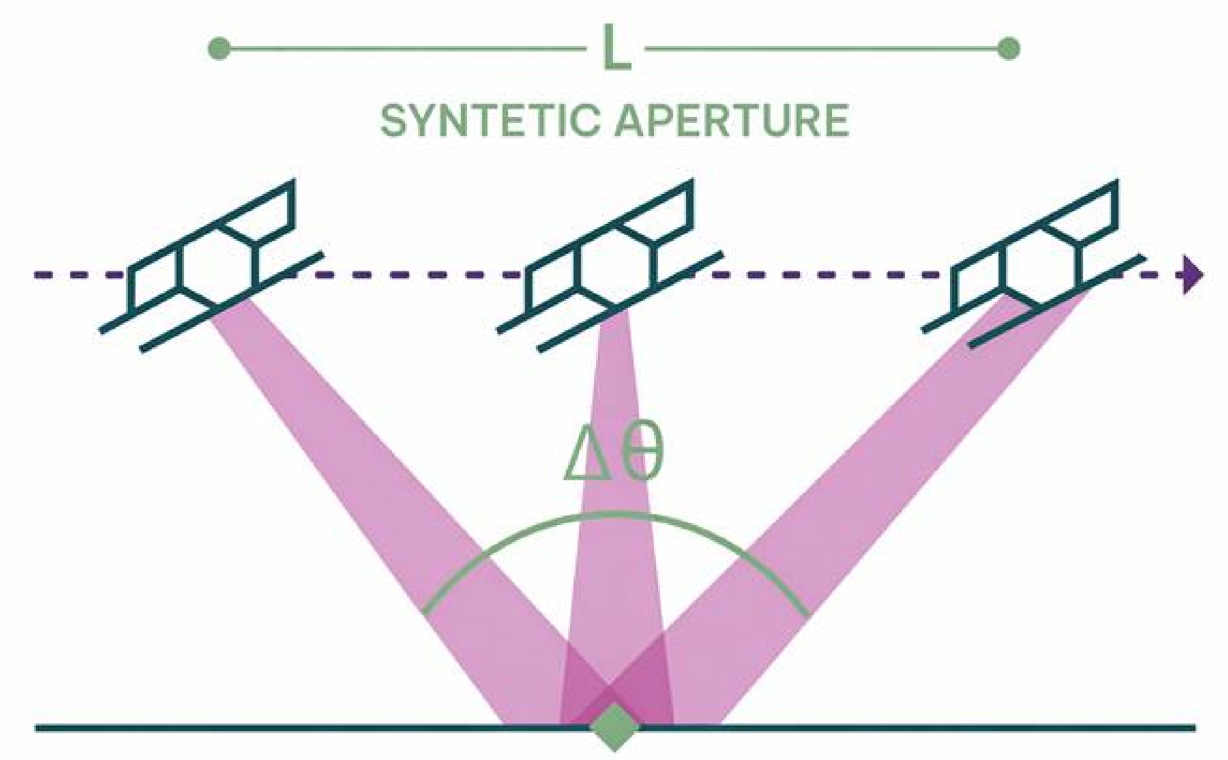
The amplitude indicates how strongly a surface reflects the radar signal, providing information about the physical properties of the target. The phase, on the other hand, contains information about the distance between the satellite and the observed surface. These two components form the basis for extracting 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.



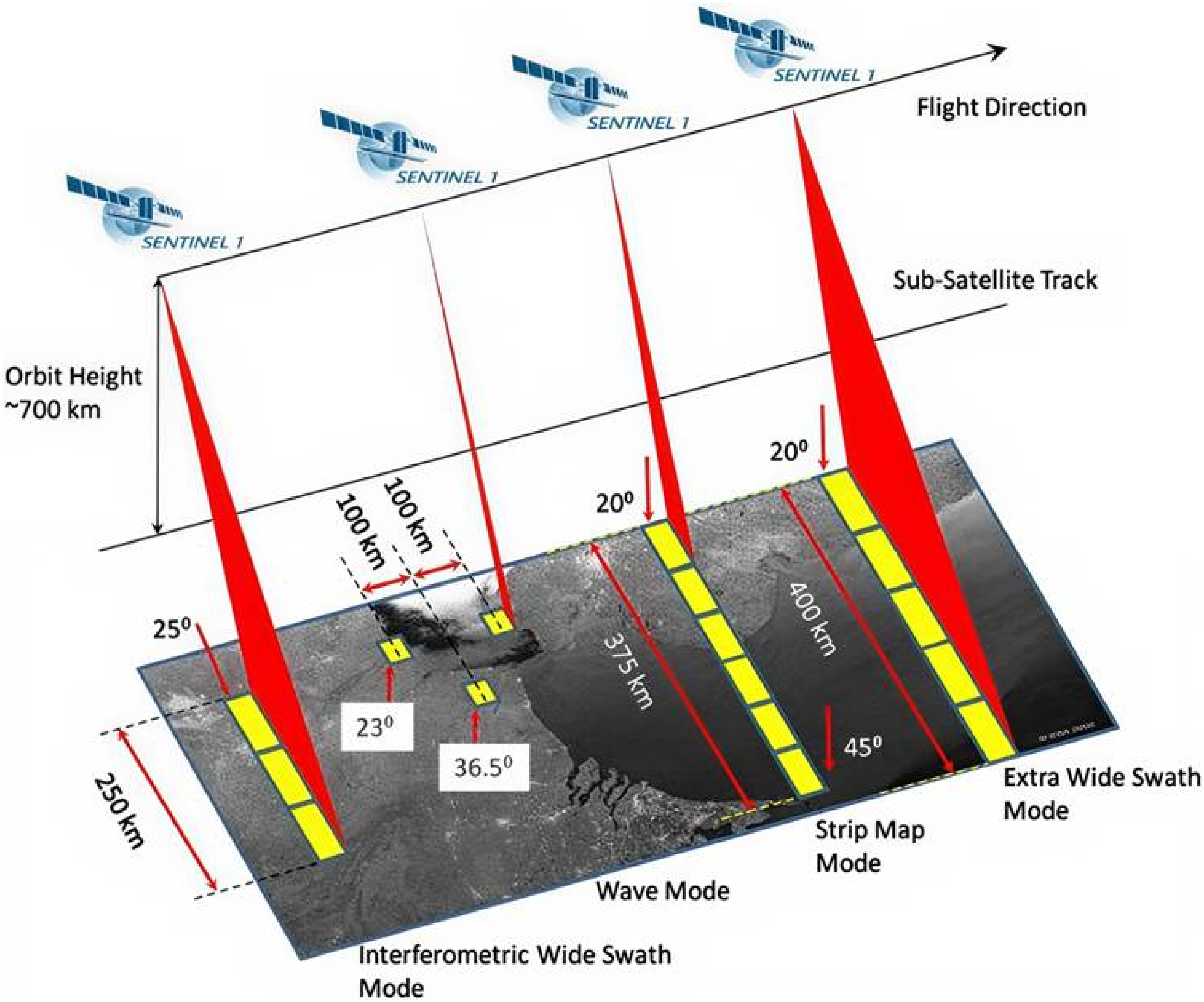
When a radar wave reaches the Earth's surface, the way it is reflected depends on several physical characteristics, the most important of which is surface roughness. If the surface is smooth relative to the radar wavelength, the signal is reflected away from the sensor in a specular manner, similar to 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

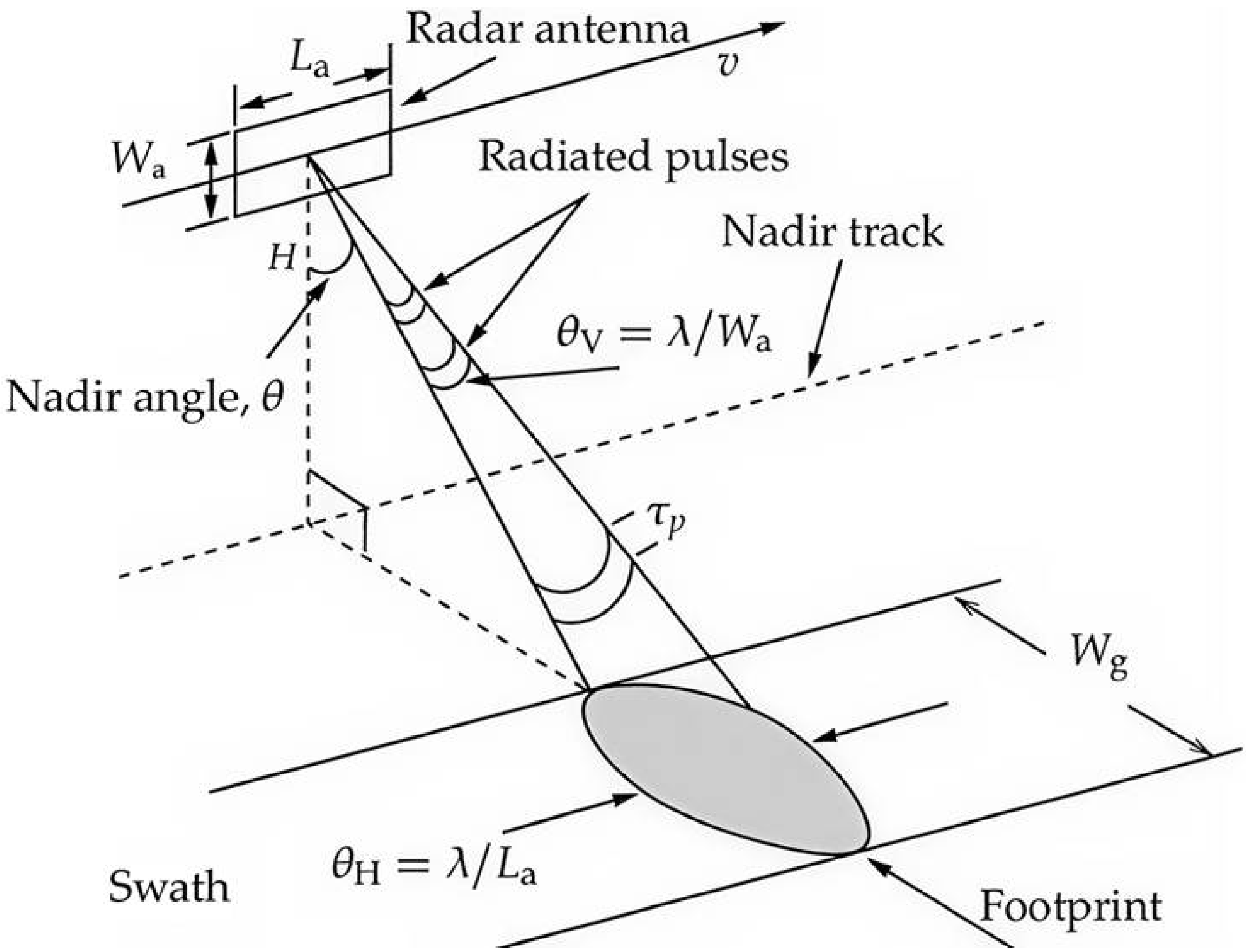


The term Synthetic Aperture Radar refers to a specific imaging technique that allows radar systems to achieve high spatial resolution without requiring physically large antennas. In traditional radar systems, image resolution depends directly on the size of the antenna. A larger antenna provides better 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.



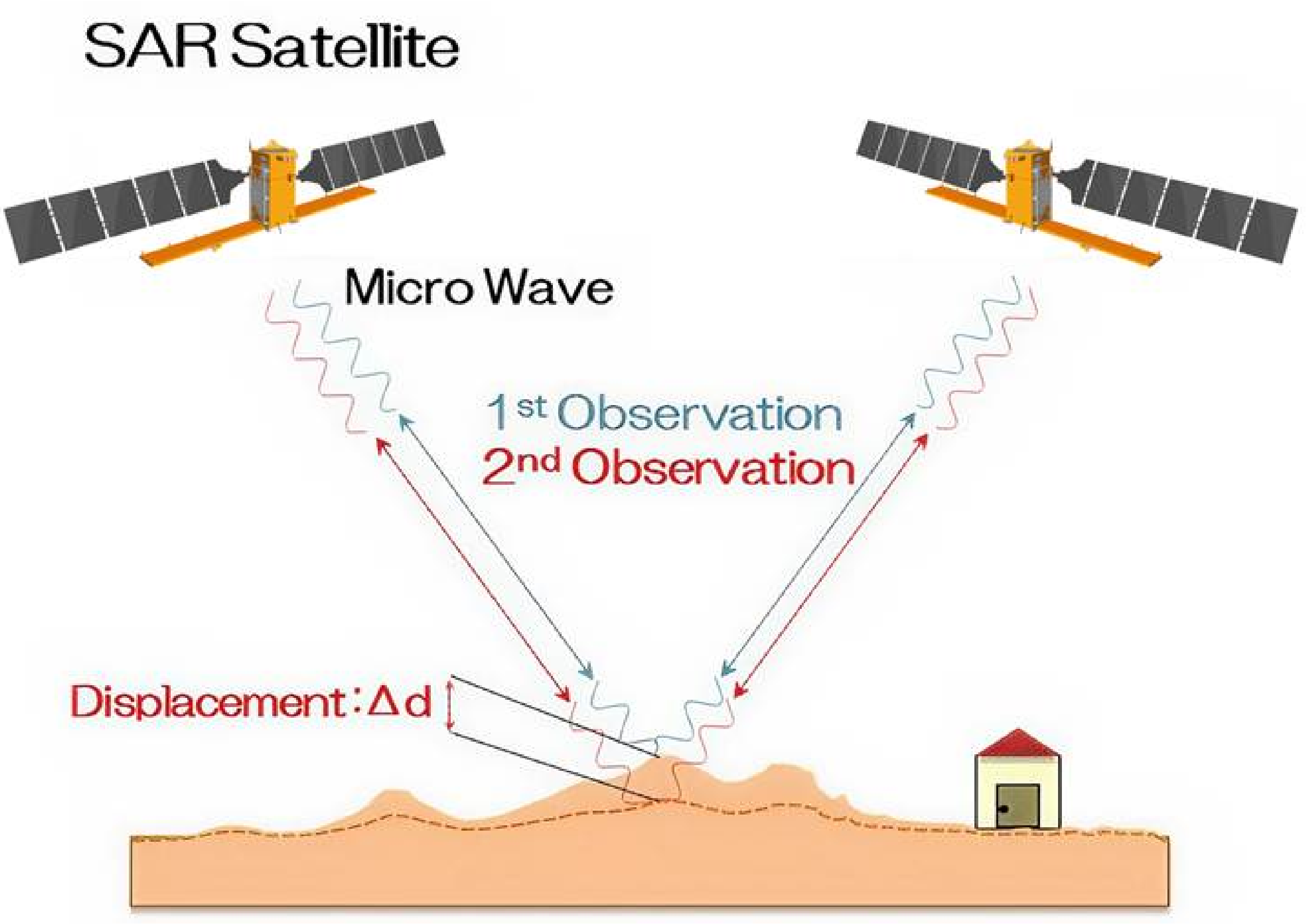
The azimuth dimension corresponds to the direction of the satellite’s motion. Azimuth resolution is achieved through the synthetic aperture process, which combines multiple observations collected over time. By coherently integrating radar echoes acquired along the orbit, the system can distinguish objects 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.

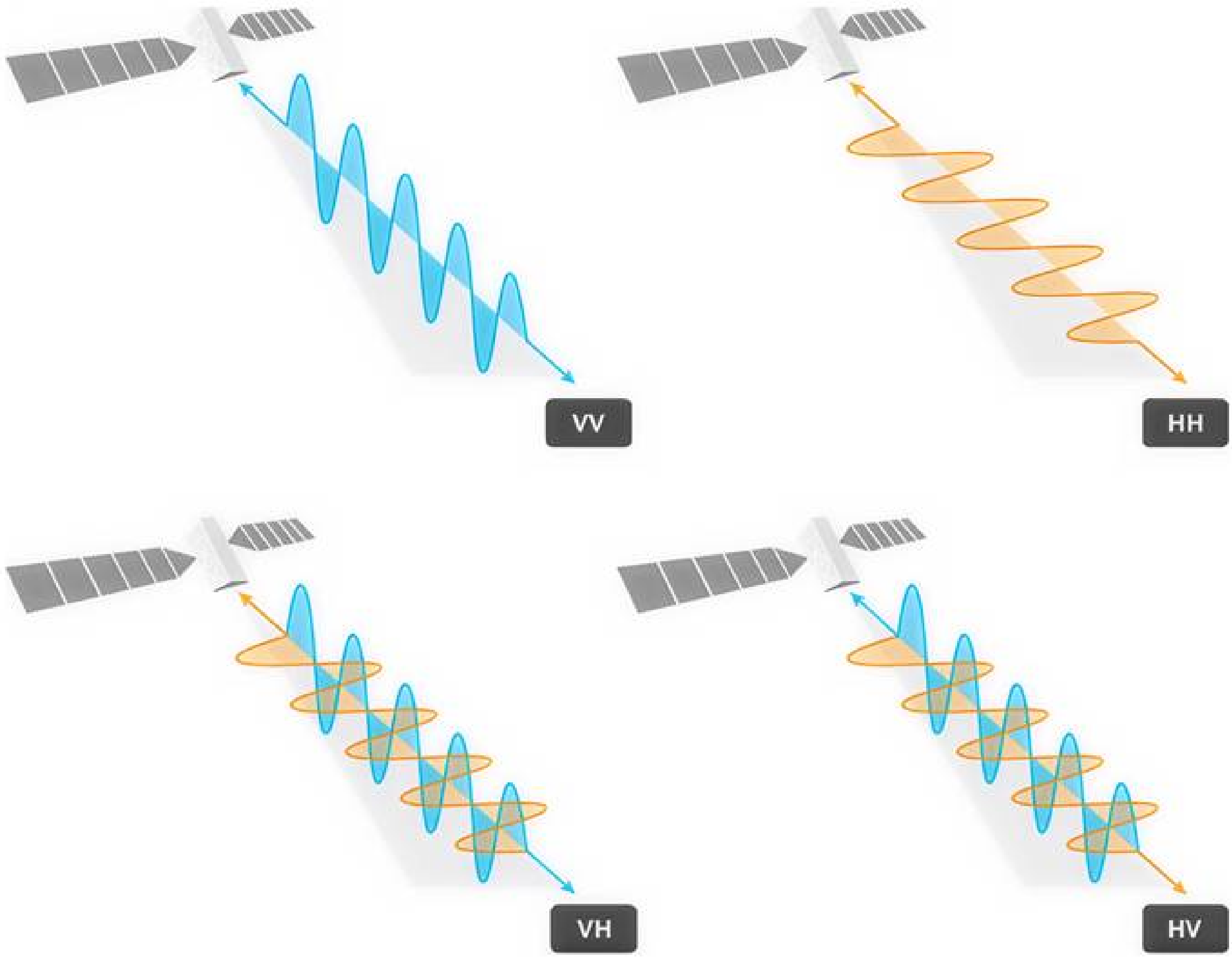
Azimuth compression combines multiple radar echoes acquired during the satellite motion, enabling the synthetic aperture effect. Motion compensation ensures that any deviations in the satellite trajectory are correctly accounted for, preserving geometric accuracy. Radiometric calibration converts the 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.

Sentinel-2

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SAR Introduction and Sentinel 2 Fundamentals

Welcome. In this video, we will explore Sentinel-2, one of the most important satellite missions for land observation and part of the European Union's Copernicus Earth observation programme. The objective is to understand not only what Sentinel-2 is, but how it works from a technological perspective, how it measures the Earth's surface through multispectral observations and how its data can be interpreted in real-world applications. Rather than treating satellite imagery as simple visual content, we will approach Sentinel-2 as a physical measurement system that records the interaction between electromagnetic radiation, the atmosphere and the Earth's surface.

Its output is therefore not just an image, but quantitative information that supports analysis and inference. This distinction is methodological as well as conceptual. In Earth observation, it is not enough to know what is observed; it is also essential to understand how reliably the sensor measures it over time. This introduces concepts such as radiometric stability and calibration consistency, which are fundamental for multi-temporal analysis.

Sentinel-2 measurements become meaningful through analytical processes such as index computation, feature extraction, classification and time-series analysis. In this sense, Sentinel-2 is not only an imaging system, but a measurement platform that supports higher-level interpretation. We will begin by introducing the mission and its architecture, then move to the design of its multispectral sensor and finally explore how this data supports environmental monitoring, agriculture and geospatial analysis within structured workflows such as those implemented in EagleArca.

Sentinel 2 Mission Overview

Sentinel-2 is part of the European Union's Copernicus Earth observation programme and is designed to provide systematic, high-resolution optical observations of the Earth's land surface. More precisely, it delivers spatially detailed and spectrally rich measurements that support continuous environmental monitoring rather than occasional image acquisition. As an optical mission, Sentinel-2 is a passive sensing system. It does not emit its own signal, but records solar radiation reflected by the Earth’s surface and atmosphere. What it acquires is therefore not a direct image, but a multispectral measurement influenced by both surface properties and atmospheric conditions.

The mission is based on a two-satellite constellation composed of Sentinel-2A and Sentinel-2B. These satellites operate in the same orbital plane and are phased to ensure frequent and consistent observations of the same areas over time. This configuration improves revisit time, increases the temporal density of observations and supports the monitoring of dynamic processes such as vegetation growth, land use change and environmental variability. This temporal dimension is fundamental because the value of Sentinel-2 often lies not in individual images, but in consistent time series acquired under stable geometric and radiometric conditions. This enables the analysis of trends, seasonal cycles and anomalies, while also increasing the probability of obtaining usable cloud-free observations, which remains one of the main limitations of optical remote sensing.

From an orbital perspective, Sentinel-2 operates in a sun-synchronous orbit, meaning that it passes over the same location at approximately the same local solar time during each revisit. This stabilizes illumination geometry, reduces variability caused by changing sun angles and improves the physical consistency of temporal comparisons. The mission operates at an altitude of approximately 786 kilometers, representing a balance between spatial resolution, swath width and coverage efficiency. This allows Sentinel-2 to observe large areas while maintaining sufficient spatial detail for operational analysis at field and landscape scale.

Overall, Sentinel-2 is designed for continuous and repeatable monitoring of land surfaces, with particular focus on vegetation, soil conditions, inland waters and coastal areas, making it especially suitable for time-series analysis and change detection.

Sensor Architecture: MultiSpectral Instrument and Pushbroom Design

At the core of Sentinel 2 is its primary payload, known as the MultiSpectral Instrument, or MSI. This instrument is responsible for acquiring multispectral data, meaning that it measures reflected solar radiation across multiple wavelengths of the electromagnetic spectrum. These measurements capture how different surfaces interact with radiation, allowing the analysis of physical and biophysical properties rather than simply producing visual imagery.

One of the key characteristics of MSI is that it is based on a pushbroom acquisition system. In a pushbroom sensor, data is collected line by line as the satellite moves along its orbit. Instead of scanning the ground using moving mirrors, the instrument uses a linear array of detectors that continuously captures an entire line across the swath. As the satellite advances, these lines are sequentially recorded and combined into a two-dimensional image. This design offers several important advantages. One important technical aspect of this configuration is the improvement in signal-to-noise ratio.

Because each detector continuously observes the same ground track as the satellite moves forward, the integration time per pixel is higher compared to scanning systems. This leads to a stronger and more stable signal, which is particularly important for detecting subtle variations in surface reflectance. It reduces mechanical complexity, improves radiometric stability and allows for consistent multispectral acquisition across a wide swath of approximately 290 kilometers.

Radiometric consistency is essential for temporal analysis. If the sensor calibration were to drift over time, it would become difficult to distinguish between actual surface changes and variations introduced by the instrument itself. For this reason, Sentinel 2 is designed with strict calibration protocols to ensure long-term measurement consistency. Because of these characteristics, pushbroom systems are particularly well suited for large-scale and systematic Earth observation missions such as Sentinel 2, where continuous, repeatable and quantitatively consistent measurements are required.

The MSI instrument is specifically designed to support detailed analysis of land surfaces, enabling the observation of vegetation, soil properties and environmental conditions through its multispectral measurements, which can be further interpreted through spectral analysis, indices and time-series approaches.

Spectral Design: Understanding the Multispectral Bands

One of the defining features of Sentinel-2 is its spectral design. The MultiSpectral Instrument acquires data across 13 spectral bands distributed over the visible, near-infrared, red-edge and short-wave infrared regions of the electromagnetic spectrum. These bands are the result of a deliberate scientific and engineering design, where each wavelength range is selected to capture specific surface and biophysical properties, enabling physically meaningful analysis of vegetation, soil, water and environmental processes. These bands are not acquired at the same spatial resolution. Some are provided at 10 meters, others at 20 meters and others at 60 meters.

This multi-resolution structure reflects a trade-off between spectral sensitivity, spatial detail, swath width and acquisition efficiency. More generally, Sentinel-2 is a strong example of balanced satellite design, since spatial resolution, spectral richness, revisit time and coverage cannot all be maximized at once. Let us begin with the visible region. The visible bands include blue, green and red wavelengths, corresponding to the portion of the spectrum perceived by the human eye and allowing the reconstruction of natural-color images. Their role, however, goes beyond visualization. The blue band is useful for atmospheric correction and water-related analysis, the green band contributes to vegetation and surface characterization and the red band is essential for vegetation analysis because chlorophyll strongly absorbs radiation in this region.

Moving beyond the visible region, we enter the near-infrared, or NIR. Healthy vegetation strongly reflects near-infrared light due to the internal structure of plant leaves. The contrast between red absorption and near-infrared reflection is fundamental for distinguishing vegetation from other surface types and forms the basis for many spectral indices used in remote sensing. Sentinel-2 also includes red-edge bands, located in the transition zone between red and near-infrared wavelengths. This region is highly sensitive to chlorophyll content and plant condition, making it valuable for detecting subtle changes in vegetation status. This is one of Sentinel-2's key innovations compared to earlier multispectral missions and supports applications such as precision agriculture and ecosystem monitoring.

Finally, Sentinel-2 includes short-wave infrared, or SWIR, bands. These wavelengths are especially important for analyzing moisture and surface composition. Since water absorbs strongly in the SWIR region, wet surfaces appear darker than dry ones. This makes SWIR bands useful for detecting soil moisture variations, assessing vegetation water content, identifying burned areas and analyzing changes in surface conditions. By combining information from visible, near-infrared, red-edge and short-wave infrared bands, Sentinel-2 provides a spectrally rich representation of the Earth's surface. Each pixel contains a spectral signature that encodes the interaction between radiation, atmosphere and surface and can be transformed into meaningful indicators for classification, index computation and environmental monitoring.

Spatial Resolution and Swath Design

In addition to its spectral capabilities, Sentinel 2 is characterized by a multi-resolution acquisition system. Not all spectral bands are captured at the same spatial resolution. Instead, the data is provided at three different levels: 10 meters, 20 meters and 60 meters. This structure is not arbitrary, but reflects a deliberate design choice aimed at balancing spectral sensitivity, spatial detail and acquisition efficiency within the constraints of spaceborne observation.

The 10-meter resolution bands include the most operationally relevant channels for land observation, particularly in the visible and near-infrared regions. These bands provide the spatial detail required for mapping vegetation patterns, agricultural fields, urban structures and land cover features at a scale that is directly usable for operational analysis. The 20-meter bands include the red-edge and short-wave infrared channels. These bands are extremely valuable from a spectral perspective, as they capture key biophysical properties such as chlorophyll variation and moisture content, but they are more demanding in terms of sensor design and signal quality. The 20-meter resolution therefore represents a compromise that preserves spectral information while maintaining acceptable spatial detail.

The 60-meter bands are mainly used for atmospheric correction and support functions. In this case, spatial detail is less critical because the objective is to characterize atmospheric effects rather than resolve fine surface structures, allowing these bands to be optimized for calibration and correction purposes. This multi-resolution structure reflects a broader engineering trade-off. More generally, Earth observation missions are constrained by a fundamental trade-off between spatial resolution, spectral richness, temporal revisit and swath width. Improving one of these dimensions typically comes at the expense of the others.

Sentinel 2 is designed as a balanced system, providing sufficient performance across all four dimensions to support both detailed analysis and large-scale, operational monitoring. In practice, it is not possible to simultaneously maximize all these dimensions without significant constraints. Sentinel 2 achieves an effective balance between these factors, delivering data that is both information-rich and operationally scalable across large areas. Another important aspect is the swath width, which is approximately 290 kilometers. This wide coverage allows Sentinel 2 to observe large portions of the Earth's surface during each acquisition, contributing to frequent revisit times and enabling systematic, repeatable monitoring rather than isolated observations.

It also ensures that the data can be efficiently integrated into large-scale analysis workflows, where regional or continental coverage is required. As a result, Sentinel 2 supports both local and regional applications, making it suitable for a wide range of monitoring activities, from precision agriculture to large-scale environmental assessment and enabling seamless integration with other geospatial datasets within GIS environments. This effectively places Sentinel 2 at an intermediate or meso-scale, level of observation. Its spatial resolution is fine enough to capture field-level and urban patterns, while its wide coverage enables regional and large-scale analysis. This makes it particularly effective for applications that require both spatial detail and broad geographic context.

What Sentinel 2 Actually Measures

To properly interpret Sentinel 2 data, it is important to understand what the sensor actually measures. Sentinel 2 is an optical passive sensor. This means that it does not emit its own signal, but instead records solar radiation that is reflected by the Earth's surface and modified by the atmosphere. The sensor does not directly measure objects. Instead, it measures radiance. This radiance can be transformed into reflectance, which is more directly related to surface properties. This distinction is fundamental because most quantitative analyses rely on surface reflectance rather than raw sensor measurements. Reflectance describes how incoming radiation interacts with materials according to their physical and chemical properties.

The measurement process involves a sequence of physical interactions. Sunlight first travels through the atmosphere, where part of the radiation is scattered and absorbed. The remaining radiation reaches the Earth's surface, where it interacts with vegetation, soil, water or artificial structures. Each of these surfaces reflects radiation differently, producing distinct spectral responses. The reflected signal then travels back through the atmosphere, undergoing further modifications before being detected by the satellite sensor. As a result, what Sentinel 2 records is not a simple photograph, but a multispectral measurement that integrates the combined effects of surface properties and atmospheric conditions.

This is why the signal cannot be interpreted directly as a visual image, but must be understood as a physical measurement influenced by multiple factors. Because of this, the measured signal is affected not only by the surface itself, but also by atmospheric variability, which can introduce distortions and reduce comparability between acquisitions. For this reason, atmospheric correction plays a central role in data processing, especially when quantitative analysis or time-series comparison is required.

To support different types of analysis, Sentinel 2 data is typically distributed in multiple processing levels. One level represents top-of-atmosphere reflectance, which corresponds to the signal as measured by the sensor, including atmospheric effects. Another level represents surface reflectance, where atmospheric contributions have been reduced to better approximate the intrinsic properties of the observed surface. This distinction is essential when comparing data over time or extracting quantitative indicators, because variations in the signal may originate either from real surface changes or from differences in atmospheric conditions. Understanding this measurement process is fundamental, because it clarifies that each pixel represents a physically derived spectral response over an area, and that Sentinel 2 data must always be interpreted in terms of radiative interaction and not simply as a visual representation of the Earth’s surface.

Data Interpretation Fundamentals

Once we understand how Sentinel-2 measures the Earth’s surface, the next step is to understand how to interpret its data. Each pixel does not represent an object directly, but contains a set of reflectance values measured across the spectral bands and integrated over a finite ground area. Together, these values form a spectral signature, which describes how a surface interacts with radiation across different wavelengths.

Different materials, such as vegetation, soil, water or artificial surfaces, exhibit distinct spectral behaviors and this allows us to distinguish them. However, spectral signatures are not uniquely interpretable on their own. Similar responses can correspond to different surface conditions, so interpretation requires spectral, spatial and temporal context. For this reason, Sentinel-2 data should not be treated only as visual imagery, but as quantitative measurements. A true-color image can support orientation and general understanding, but the real analytical value emerges when we examine the relationships between spectral bands.

A key example is the Normalized Difference Vegetation Index, or NDVI. NDVI is based on the contrast between red and near-infrared reflectance: vegetation absorbs strongly in the red band and reflects strongly in the near-infrared. By combining these bands, NDVI provides an indicator of vegetation vigor. High values generally correspond to dense and active vegetation, while lower values may indicate sparse vegetation, stressed crops, bare soil or non-vegetated surfaces. However, NDVI is not a direct measurement of vegetation health, but a proxy derived from spectral behavior. A stressed crop field may show lower NDVI values than healthy vegetation even before this is clearly visible in standard imagery, but similar NDVI values can still correspond to different conditions depending on season, crop type and environmental context.

In addition to NDVI, Sentinel-2 red-edge bands allow more sensitive analysis of vegetation condition. They capture subtle variations in chlorophyll content and canopy structure, making it possible to detect stress earlier than with standard vegetation indices. Beyond indices, spectral signatures can also support classification and modeling processes, where pixels are assigned to thematic categories such as vegetation, water, soil or built-up areas. In this sense, Sentinel-2 acts as a source of data for higher-level inference, rather than as a direct provider of semantic information.

Spatial context is essential. A single pixel value has limited meaning on its own, while clusters, gradients and boundaries can reveal processes that are not visible at the level of an individual measurement. Temporal context is equally important. By building time series of observations acquired under consistent conditions, it becomes possible to analyze how spectral signatures evolve, identify trends, recognize seasonal cycles and distinguish normal variability from significant change. Understanding these principles is essential, because interpretation always depends on the combination of spectral information, spatial patterns, temporal evolution and contextual knowledge, transforming raw measurements into meaningful insight.

Practical Applications

The principles discussed so far support a wide range of practical applications. These are not generic uses of satellite imagery, but applications derived from the spectral, spatial and temporal properties of Sentinel-2 data, which allow surface processes to be observed in a consistent and quantitative way.

In agriculture, Sentinel-2 supports crop monitoring over time. Vegetation indices, spectral patterns and red-edge information make it possible to identify spatial variability in crop development, detect early anomalies and distinguish normal seasonal dynamics from stress conditions related to soil properties, irrigation efficiency, nutrient availability or plant health. Time-series analysis also supports phenological monitoring, helping track growth stages, delays and crop behavior at both field and regional scale. Another key application is land cover classification. By analyzing spectral signatures, each pixel can be associated with categories such as vegetation, water, soil or built-up surface. This can be done through rule-based approaches or machine learning techniques, producing thematic maps that transform raw measurements into structured geographic information for planning, monitoring and reporting.

In environmental monitoring, Sentinel-2 enables the observation of ecosystems and natural processes. Forest dynamics, vegetation change, degradation, recovery and disturbance events can be analyzed by comparing spectral responses across multiple acquisitions. Burned areas, for example, show characteristic changes, especially in the short-wave infrared region. Hydrological applications rely on the distinct spectral behavior of water, particularly in the near-infrared and short-wave infrared regions. This makes it possible to delineate rivers, lakes and reservoirs and monitor changes in water extent linked to seasonal dynamics, floods or droughts. Visible reflectance can also provide qualitative indications of sediment presence or biological activity, although these signals require careful interpretation.

In urban and land use analysis, Sentinel-2 allows major land cover categories such as built-up areas, vegetation and bare soil to be distinguished. This supports the monitoring of urban expansion, land consumption and green space distribution, providing useful information for urban planning, environmental assessment and infrastructure management. A particularly powerful capability is change detection. By comparing observations acquired at different times under consistent conditions, Sentinel-2 supports the analysis of vegetation changes, land use transformation, water extent variation and post-disaster impacts. This shifts the focus from static mapping to dynamic analysis, where processes are interpreted through their evolution over time.

Finally, Sentinel-2 interpretation becomes stronger when integrated with other data sources. Its geometric accuracy allows reliable alignment with other geospatial datasets, which is essential for multi-source analysis. When combined with Sentinel-1 radar observations, elevation models, meteorological data and in-situ measurements, Sentinel-2 provides a more complete picture of surface conditions, reduces interpretative ambiguity and supports more robust decision-making across different spatial and temporal scales.

Sentinel 2 Data Visualization in EagleArca

We now move to how Sentinel-2 data can be visualized and interpreted within the EagleArca platform. In EagleArca, geospatial information is organized into layers that can be visualized, combined and explored in a unified environment. Sentinel-2 data is available within this system, allowing multispectral observations to be consulted alongside other geospatial datasets.

A first level of interaction is the visual representation of the observed area. By combining spectral bands, the platform reconstructs an optical view of the territory, supporting the recognition of vegetation, water bodies, soil and built-up areas. This view helps with orientation and initial interpretation. However, Sentinel-2 does not directly provide semantic information such as land cover classes. It provides multispectral measurements, which must be interpreted according to their spectral behavior. Within EagleArca, users can explore these measurements and distinguish land cover types such as vegetation, bare soil, water surfaces and built environments.

The platform provides a super-resolved reconstruction at approximately 1 meter to enhance visual interpretation. The classification layer is available both at approximately 10 meters and at an enhanced resolution close to 1 meter. These representations improve the readability of spatial patterns and help relate spectral information to real-world features. Sentinel-2 also contributes to higher-level thematic layers such as Agriculture and Urbanization, supporting domain-specific analysis. These layers should be interpreted as thematic representations that support analysis, rather than direct outputs of the satellite.

A key aspect of EagleArca is the integration of Sentinel-2 data with other geospatial layers. Since all data is georeferenced, Sentinel-2 observations can be overlaid with terrain models, infrastructure data or environmental variables. For example, vegetation patterns can be analyzed together with elevation, land use or environmental conditions to better understand the territory. From an operational perspective, EagleArca allows users to activate and deactivate layers, focus on specific areas and explore relationships between datasets. This interactive approach is essential when working with multispectral data, where interpretation depends on comparing multiple sources. In this way, Sentinel-2 within EagleArca is not just imagery, but part of an integrated geospatial environment that supports exploration, interpretation and decision-making.

Interpretation within a GIS Workflow

To fully exploit the potential of Sentinel 2 data, it is essential to consider how it is used within a broader geospatial workflow. Sentinel 2 provides quantitative multispectral measurements of surface reflectance and these measurements gain their full value when they are integrated with other sources of information and interpreted within a GIS-based environment. In this context, it does not operate in isolation, but becomes part of a layered analytical system where different datasets contribute complementary information.

By combining these observations with additional geospatial layers, such as elevation models, infrastructure data, meteorological information or radar measurements, it becomes possible to analyze relationships between environmental and spatial variables rather than observing them separately. Variations in vegetation patterns, for example, can be interpreted in relation to terrain characteristics, soil conditions or water availability, while land cover information can be compared with infrastructure or administrative boundaries to support planning and monitoring activities. This type of integration enables a transition from simple observation to structured interpretation. Meaning does not emerge from a single dataset alone, but from the relationships established between multiple sources of information, which together provide a more complete representation of the territory.

From an operational perspective, this workflow can be implemented within platforms such as EagleArca, where geospatial layers can be visualized, combined and explored interactively. At the same time, the same data can be exported in standard formats, such as GeoTIFF and used in external GIS tools like QGIS for more advanced processing, modeling and analysis. This flexibility allows users to adapt their workflow depending on the level of complexity required, moving from exploratory visualization to more advanced analytical approaches. Ultimately, integrating Sentinel 2 within a GIS workflow enables the transformation of raw multispectral measurements into structured, actionable information, supporting decision-making processes across a wide range of applications.

Sentinel-3

https://www.youtube.com/embed/-3_9G92ZIqQ?si=GJFoD97VtnJUYFvH

Welcome. In this video, we explore one of the most technically sophisticated missions within the Copernicus Earth Observation Programme: Sentinel-3.

https://www.youtube.com/embed/-3_9G92ZIqQ?si=GJFoD97VtnJUYFvH

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Sentinel-3 in the Copernicus Ecosystem

Welcome. In this video, we explore one of the most technically sophisticated missions within the Copernicus Earth Observation Programme: Sentinel-3. To understand what makes it distinctive, it helps to briefly place it within the broader context of the programme. Sentinel-1 is a radar mission that provides structural and surface deformation information regardless of cloud cover or lighting conditions. Sentinel-2 delivers high-resolution multispectral optical imagery, optimised for detailed land surface analysis at field and landscape scale. Sentinel-5P monitors the composition of the atmosphere, tracking pollutants and greenhouse gases at global scale. Sentinel-3 was designed with a different philosophy altogether.

Its mission is centred around the systematic observation of large-scale environmental dynamics: temperature, ocean conditions, vegetation status at regional scale, atmospheric composition, and climate-related processes. While Sentinel-2 can resolve individual fields and urban blocks at ten meters, Sentinel-3 operates at coarser spatial resolution but compensates with broader geographic coverage, stronger temporal consistency, and a fundamentally different measurement capability: the ability to measure the physical temperature of the Earth's surface. This makes Sentinel-3 not simply an imaging system, but an environmental monitoring platform in the full scientific sense. Its role is to observe how environmental variables evolve over time, contributing to our understanding of climate, ecosystems, agriculture, and urban thermal dynamics.

Mission Architecture and Instruments

The Sentinel-3 constellation consists of multiple satellites operating in a coordinated manner to ensure continuous global coverage and a high temporal revisit capability. Like other

Copernicus missions, Sentinel-3 operates in a sun-synchronous orbit, meaning it passes over the same locations at approximately the same local solar time during each revisit. This stabilizes illumination geometry and ensures that observations acquired at different times remain comparable. What makes Sentinel-3 architecturally unique within the Copernicus family is its payload. Unlike Sentinel-2, which is built around a single multispectral instrument, Sentinel-3 incorporates multiple complementary instruments, each designed to observe a different component of the Earth system.

SLSTR: Sea and Land Surface Temperature Radiometer

The most important instrument for our discussion is the Sea and Land Surface Temperature Radiometer, known as SLSTR. This instrument is specifically designed to measure land and sea surface temperatures with high radiometric precision. It operates across multiple spectral channels, including visible, near-infrared, and thermal infrared wavelengths. The thermal infrared region is particularly important because all objects above absolute zero emit thermal radiation. By measuring this emitted radiation, Sentinel-3 can estimate the physical temperature of the Earth's surface. This is fundamentally different from Sentinel-2, which measures reflected solar radiation. SLSTR measures radiation that the surface itself emits.

OLCI: Ocean and Land Colour Instrument

The second major instrument is the Ocean and Land Colour Instrument, or OLCI. This is a multispectral optical instrument designed to measure reflected radiation across a large number of spectral bands. OLCI is particularly important for monitoring vegetation, water quality, chlorophyll concentration, and environmental conditions over both land and ocean surfaces. Although Sentinel-2 provides higher spatial resolution for detailed land observation, Sentinel-3 OLCI offers broader regional coverage and strong spectral sensitivity, making it useful for large-scale environmental assessments, vegetation monitoring at continental scale, and atmospheric correction support.

SRAL and Atmospheric Capabilities

The third instrument is the Synthetic Aperture Radar Altimeter, or SRAL. This instrument is more strongly associated with oceanography and water surface measurements, but it contributes to hydrological and environmental studies by enabling precise measurement of surface elevation, particularly for oceans, rivers, lakes, and ice surfaces. Its contribution is especially relevant for sea level monitoring, inland water dynamics, and hydrological analysis related to climate.

Finally, Sentinel-3 incorporates atmospheric observation capabilities that support the characterization of atmospheric particles, aerosols, and gases. This atmospheric dimension becomes particularly important when Sentinel-3 data is integrated with other missions such as Sentinel-5P, which focuses specifically on atmospheric composition, or with weather forecasting services. Together, these systems contribute to a more complete understanding of how surface observations connect to atmospheric dynamics.

What Sentinel-3 Measures

Environmental Variables

To properly understand the analytical value of Sentinel-3, it is necessary to move beyond the idea of satellite imagery as a visual product and think instead in terms of geophysical variables. Sentinel-3 generates multidimensional datasets that describe the physical state of the Earth system numerically. Each pixel is not simply a visual element, but a container of physical information describing environmental conditions at a specific location and a specific time.

Land Surface Temperature and Heat Fluxes

The most central variable produced by Sentinel-3 is Land Surface Temperature, commonly abbreviated as LST. This parameter represents the physical temperature of the Earth's surface itself. It is not the same as air temperature measured by a weather station. Instead, it describes the thermal state of the ground, vegetation, urban surfaces, or water bodies as observed from space through thermal infrared measurements. LST is an extremely important environmental variable because surface temperature controls many physical processes: energy balance, water stress in vegetation, urban heat accumulation, and climatic dynamics. In practice, LST is always provided alongside an uncertainty value, which quantifies the expected error margin and helps analysts understand the reliability of the retrieved temperature.

Alongside LST, Sentinel-3 provides two closely related variables that describe how energy is exchanged between the Earth's surface and the atmosphere: latent heat flux and sensible heat flux. Latent heat flux is associated with phase changes of water, particularly evaporation and transpiration. When water evaporates from a surface or is released by vegetation through transpiration, energy is absorbed from the surface and transferred into the atmosphere. In agricultural environments, latent heat is strongly connected to evapotranspiration and vegetation activity.

Sensible heat flux, by contrast, represents direct heat transfer between the surface and the air without phase change. Urban surfaces dominated by asphalt and concrete tend to exhibit strong sensible heat flux because these materials absorb solar radiation and release heat directly into the atmosphere. The balance between these two fluxes is extremely diagnostic. In vegetated and well-watered areas, latent heat tends to dominate because energy is consumed by evapotranspiration. In dry or highly urbanized areas, sensible heat dominates, leading to stronger surface warming. This balance is one of the most informative indicators in the entire dataset.

Soil, Atmosphere and Additional Variables

Sentinel-3 also provides soil wetness information, which estimates the amount of moisture present in the soil. This variable is critical for agriculture because soil moisture directly influences crop growth, irrigation efficiency, runoff generation, and drought risk.

Among the atmospheric variables, the dataset includes cloud fraction, which describes how much of the observed area is covered by clouds and therefore affects the reliability of surface measurements. Dew point temperature indicates the atmospheric moisture content and is related to condensation, fog formation, and moisture-related environmental conditions. Solar radiation describes the incoming solar energy reaching the surface, which drives photosynthesis, evaporation, thermal dynamics, and ecosystem productivity. Thermal radiation describes the energy emitted by the Earth's surface back into the atmosphere and space. Together, incoming solar radiation and outgoing thermal radiation define the Earth's radiative balance.

Total column water vapor and total column ozone provide integrated measurements of atmospheric moisture and ozone abundance. Ozone plays a critical role in absorbing harmful ultraviolet radiation, while water vapor is one of the most important greenhouse gases and strongly influences cloud formation and energy transfer. Specific humidity measures the mass of water vapor in the air relative to the total air mass; unlike relative humidity, it is independent of temperature, which makes it particularly useful for weather forecasting and atmospheric modeling.

Surface pressure influences weather systems and wind patterns. Wind speed and direction are reconstructed through two orthogonal components: the u-wind, oriented east-west, and the v-wind, oriented north-south. Together they describe atmospheric circulation dynamics that influence pollution dispersion, evapotranspiration, and thermal comfort. Additional variables include skin temperature at the surface-atmosphere interface, snow albedo and snow depth for hydrological and climate analysis, and temperature profiles through different atmospheric layers.

The key point is that these variables should never be interpreted in isolation. Their true value emerges through integration. A region with elevated land surface temperature, low soil wetness, high sensible heat flux, and low vegetation activity may indicate drought stress or degraded environmental conditions. An urban area with high thermal radiation and low latent heat may correspond to strong heat island effects. Environmental systems are interconnected, and it is precisely this interconnection that makes Sentinel-3 so powerful when used within a multi-layer analytical environment.

Applications in Urban Environments

The Heat Island Effect

One of the most important applications of Sentinel-3 data is the analysis of the Urban Heat Island effect. Urban areas tend to accumulate and retain more heat than surrounding rural areas. This happens primarily because urban materials such as asphalt, concrete, and dense infrastructure absorb solar radiation during the day and release it slowly during the night, accentuating the thermal differential with surrounding rural areas. Urban areas also tend to have less vegetation, which would otherwise contribute to natural cooling through evapotranspiration. As a result, cities retain heat for longer periods, reaching significantly higher temperatures compared to neighboring undeveloped areas.

This effect has several practical consequences. It increases energy consumption for cooling systems, raising economic costs. It creates health risks, particularly for vulnerable populations, through increased exposure to heat. It also contributes to air quality deterioration, since higher temperatures can promote the formation of air pollutants such as ozone. In agricultural areas adjacent to urban centers, elevated temperatures can affect growing conditions and crop performance. Using Sentinel-3 thermal data, it becomes possible to spatially identify areas with elevated surface temperatures across urban environments. Zones with poor vegetation coverage and high building density often exhibit significantly higher thermal signatures compared to parks or peri-urban green areas.

Identifying heat accumulation zones allows urban planners to implement targeted cooling strategies: the creation or expansion of green spaces, the introduction of cool roofs, or the use of reflective materials in construction to reduce heat absorption. Monitoring these zones over time then makes it possible to evaluate whether such interventions are actually reducing thermal stress. This type of analysis is particularly critical in urban planning, helping to assess the effectiveness of climate resilience measures and to guide decisions about future urban development.

Applications in Agriculture

Thermal Stress and Water Management

In agricultural contexts, the role of Sentinel-3 is equally important, though the interpretation shifts toward a different set of processes. Crops are strongly sensitive to temperature conditions. Elevated surface temperature can indicate water stress, drought conditions, reduced evapotranspiration efficiency, or declining vegetation health. Because these thermal signals often appear before visible symptoms of stress become evident, Sentinel-3 can act as an early indicator for agricultural risk.

A field that exhibits unusually high surface temperature compared to surrounding areas may indicate insufficient irrigation, a soil moisture deficit, or crop stress. This becomes especially powerful when thermal information is combined with vegetation indices derived from Sentinel-2. If Sentinel-2 indicates reduced vegetation vigour through lower NDVI values, and Sentinel-3 simultaneously shows elevated surface temperatures in the same region, the combined interpretation strongly suggests active stress conditions affecting the crops. This type of multi-source integration allows agricultural monitoring to move from simple observation toward more robust diagnostic analysis.

Drought monitoring represents a particularly important application. At regional scale, OLCI contributes by monitoring crop cycles and biomass trends, providing the broader vegetation context within which thermal anomalies can be interpreted. Surface temperature anomalies often precede the visible degradation of vegetation condition. This means thermal monitoring can act as an early indicator of drought impact. When integrated with meteorological forecast services and soil moisture estimations, Sentinel-3 becomes part of a larger environmental intelligence framework supporting agricultural risk management. By monitoring temperature and moisture levels over time, agricultural managers can anticipate periods of water scarcity and adjust farming practices to reduce the impact.

The latent and sensible heat information is also directly applicable in agricultural management. By comparing these two fluxes across different fields, analysts can assess the efficiency of water use in crops. If a field is producing a large amount of sensible heat and a low amount of latent heat, it could indicate that the crops are under water stress and that transpiration is suppressed. Combined with soil wetness data, these variables allow a nuanced and physically grounded interpretation of crop status.

Broader Environmental Monitoring

Beyond urban and agricultural applications, Sentinel-3 supports a wide range of environmental monitoring activities. Through OLCI, it contributes to the observation of vegetation dynamics over large territories, supporting the monitoring of crop cycles, biomass trends, and ecosystem behavior at scales that Sentinel-2 alone cannot efficiently cover. For urbanization studies, OLCI can contribute to broader land cover interpretation and environmental quality assessment, especially when integrated with higher-resolution datasets.

In coastal and marine environments, sea surface temperature data from SLSTR plays a critical role. Rising sea temperatures can indicate stress on marine ecosystems, including coral bleaching and changes in fish migration patterns. Monitoring the temperature of water bodies also supports the analysis of pollution dynamics and sediment transport in rivers, lakes, and estuaries.

For wildfire monitoring, the ability of Sentinel-3 to detect thermal anomalies allows early identification of active fire events in forests and grasslands, supporting early warning systems and rapid response efforts. Surface temperature and thermal radiation data also contribute to climate research, enabling the assessment of long-term warming trends and regional climate variability. Combined with historical climate records, these datasets support the modeling of future climate scenarios and inform environmental policy. In all these cases, Sentinel-3 is not simply providing images, but structured measurements of the physical state of the environment.

Visualization in EagleArca

Within the EagleArca platform, Sentinel-3 data is available through two distinct layer types, each serving a different analytical purpose.

The Heat Island Layer

The first is the Heat Island layer. This layer aggregates Sentinel-3 data over an extended period, typically at least one year, and calculates average land surface temperatures across different seasons. This temporal aggregation allows users to identify persistent heat accumulation zones, analyze seasonal temperature patterns, and evaluate long-term trends in urban thermal behavior. Users can compare summer and winter thermal patterns, identify hotspot areas, and examine how these relate to land cover, vegetation density, or infrastructure distribution.

When combined with Sentinel-2 classification data, the Heat Island layer provides a powerful tool for understanding how urban morphology and the distribution of green spaces influence thermal dynamics. The layer also enables the monitoring of long-term trends in urban heat island development, identifying areas that may be getting progressively warmer over the years. Since elevated temperatures promote the formation of pollutants such as ozone, this information is directly relevant for air quality assessment alongside thermal risk evaluation.

The Sentinel-3 Daily Data Layer

The second layer is the Sentinel-3 Daily Data layer. Unlike the aggregated Heat Island product, this layer is updated every time new data from Sentinel-3 becomes available, which is typically every 24 hours, providing near-real-time access to environmental variables. These include land surface temperature, latent heat, sensible heat, soil wetness, and wind components, as well as atmospheric parameters such as specific humidity, solar radiation, ozone, and water vapor. For coastal areas, sea surface temperature is also included, which is important for understanding oceanic processes and climate-related phenomena.

This daily update capability makes the layer particularly valuable for dynamic decision-making. Farmers can monitor evolving thermal and moisture conditions. Urban managers can track heat accumulation during heat waves. Environmental analysts can follow atmospheric dynamics in near real time. The key value of both layers within EagleArca is not simply visualization, but integration. Because all layers within the platform are georeferenced within the same coordinate system, Sentinel-3 products can be seamlessly combined with Sentinel-2 classification, Digital Elevation Models, infrastructure layers, or meteorological datasets. This spatial consistency transforms what might otherwise be disconnected measurements into a coherent and interpretable view of the environment.

Integration with Other Sentinel Missions

One of the most important conceptual points about Sentinel-3 is how it fits within the broader Copernicus ecosystem. Sentinel-3 is not a replacement for Sentinel-1 or Sentinel-2. Rather, it contributes a different and complementary dimension to the overall observational framework.

Sentinel-2 provides spatially detailed multispectral observations at ten-meter resolution, enabling field-level analysis of vegetation, soil, water, and urban surfaces. Sentinel-3 provides the thermal and environmental context that helps explain many of the patterns visible in Sentinel-2 data. When crops show anomalous spectral behavior in Sentinel-2, Sentinel-3 thermal and moisture data can help diagnose whether the cause is heat stress, water deficit, or some other environmental factor.

When urban areas show dense built-up patterns in Sentinel-2 classification, Sentinel-3 can reveal the thermal consequences of that urbanization. Sentinel-1, meanwhile, contributes structural and deformation information through radar observation, working independently of cloud cover. Together, the three missions create a much richer understanding of the territory than any single system could provide.

A critical aspect of interpretation is also understanding the scale at which Sentinel-3 operates. Its spatial resolution is coarser than that of Sentinel-2, but this is compensated by broader coverage and strong temporal consistency. Sentinel-3 is not the right tool for identifying individual buildings or narrow agricultural rows. However, it is extremely effective for understanding large-scale environmental processes: heat distribution across metropolitan areas, drought evolution across agricultural regions, vegetation dynamics over large ecosystems, and temperature anomalies at continental scale.

The Role of Sentinel-3 in Modern Earth Observation

Sentinel-3 is a mission designed not simply to observe the Earth visually, but to measure the physical state of the environment. Through its instruments, particularly SLSTR and OLCI, it provides critical information about surface temperature, vegetation dynamics at regional scale, atmospheric composition, environmental stress, and climatic behavior.

Its applications in urbanization include heat island analysis, environmental quality assessment, urban climate resilience studies, and the long-term monitoring of thermal patterns. In agriculture, Sentinel-3 supports drought monitoring, early detection of thermal stress, crop condition assessment, and water management evaluation. In environmental science, it contributes to coastal analysis, wildfire detection, ecosystem monitoring, and climate research.

When integrated with Sentinel-1, Sentinel-2, elevation models, meteorological services, and GIS-based platforms such as EagleArca, Sentinel-3 becomes part of a comprehensive environmental monitoring ecosystem capable of supporting both operational analysis and long-term decision-making. Ultimately, Sentinel-3 demonstrates how modern satellite systems are evolving beyond simple imaging toward continuous, multidimensional observation of the Earth system, enabling us to better understand the complex interactions between climate, environment, human activity, and territorial dynamics.

Sentinel-5P

https://www.youtube.com/embed/plxlSlNN384?si=5UB-_GjF3yLcqKeq

Welcome. In this video, we explore Sentinel-5P, the atmospheric monitoring mission of the Copernicus Earth Observation Programme.

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Sentinel-5P in the Copernicus Ecosystem

Welcome. In this video, we explore Sentinel-5P, the atmospheric monitoring mission of the Copernicus Earth Observation Programme. The Copernicus programme includes a family of satellite missions, each focused on a different aspect of Earth observation. Sentinel-1 focuses on radar observations of the surface. Sentinel-2 provides high-resolution multispectral optical imagery of land cover. Sentinel-3 observes large-scale environmental dynamics, including surface temperature and ocean conditions. Sentinel-5P addresses a fundamentally different domain: the composition of the atmosphere itself.

Operational since 2017, Sentinel-5P is dedicated to delivering high-precision, global measurements of key atmospheric constituents, including both pollutants and greenhouse gases. Its data supports applications in air quality management, climate research, urban planning, and agriculture. While the other Sentinel missions primarily observe what is on or near the surface, Sentinel-5P observes what is above it, providing the atmospheric dimension of environmental intelligence within the Copernicus programme.

The TROPOMI Instrument

At the core of Sentinel-5P is the TROPOMI instrument, which stands for Tropospheric Monitoring Instrument. TROPOMI is an advanced spectrometer capable of measuring the concentration of a wide range of atmospheric components across the entire globe. Its spatial resolution of approximately seven by seven kilometers makes it one of the most detailed atmospheric sensors currently in orbit. Unlike earlier instruments that focused on specific gases or geographic regions, TROPOMI provides continuous global coverage and delivers a comprehensive view of atmospheric composition on a daily basis.

The components measured by TROPOMI include ozone, nitrogen dioxide, methane, carbon monoxide, sulphur dioxide, formaldehyde, aerosols, particulate matter, and water vapor. Each of these plays a specific role in atmospheric chemistry, air quality, and climate dynamics. Together, they form a complete picture of atmospheric state that no single previous instrument could provide with this level of spatial detail and global consistency. This breadth of measurement is what makes Sentinel-5P uniquely valuable within the Copernicus architecture.

Atmospheric Components Monitored by Sentinel-5P

Nitrogen Dioxide, Sulphur Dioxide, and Formaldehyde

Nitrogen dioxide, or NO2, is one of the primary pollutants tracked by Sentinel-5P. It is produced mainly by combustion processes, including vehicle emissions, industrial activity, and fossil fuel combustion. Elevated NO2 concentrations are most commonly found in urban environments, where transportation and energy consumption are concentrated. Beyond its direct health effects, which include respiratory and cardiovascular problems, NO2 plays a key role in the formation of ground-level ozone through chemical reactions with other atmospheric compounds in the presence of sunlight.

Sulphur dioxide, or SO2, is emitted by volcanoes, power plants, and various industrial processes. It is harmful to respiratory health and also reacts in the atmosphere to form acid rain, which can damage ecosystems and infrastructure. Monitoring SO2 concentrations is therefore particularly valuable in regions with active volcanic activity or significant industrial emissions. Formaldehyde, or HCHO, is another pollutant measured by TROPOMI. It is a significant precursor of ground-level ozone and a contributor to atmospheric pollution in industrial areas. Monitoring formaldehyde is essential for understanding the chemical dynamics of atmospheric pollution and the processes that drive ozone formation.

Methane and Carbon Monoxide

Methane, or CH4, is one of the most important greenhouse gases tracked by Sentinel-5P. Despite being present in the atmosphere in smaller quantities than carbon dioxide, methane has a significantly higher warming potential. Emissions originate from a variety of sources, including livestock farming, rice paddies, landfills, and oil and gas production. By detecting methane hotspots at global scale, Sentinel-5P provides critical data for climate modeling and emissions monitoring, enabling policymakers to identify emission sources and target mitigation efforts more effectively.

Carbon monoxide, or CO, is a colorless, odorless gas produced mainly by combustion processes, including wildfires, biomass burning, and fossil fuel use. Measuring CO concentrations across large areas provides insights into both urban pollution levels and large-scale combustion events. Historical CO data, for instance, allows researchers to track changes in the intensity of wildfires and the impact of biomass burning events over time, making it a valuable variable for both air quality assessment and climate research.

Ozone: Stratospheric and Tropospheric

Ozone, or O3, plays a dual role in the atmosphere and must therefore be interpreted carefully depending on where it is found. In the stratosphere, the ozone layer absorbs harmful ultraviolet radiation, protecting life on Earth. This protective function makes stratospheric ozone monitoring important for assessing the long-term health of the ozone layer. At ground level, however, ozone is a harmful secondary pollutant. It is formed when nitrogen dioxide and volatile organic compounds react in the presence of sunlight, contributing to smog and causing adverse effects on both human health and vegetation. Sentinel-5P monitors both stratospheric and tropospheric ozone, providing data to track ozone layer conditions while also identifying areas where surface ozone poses a risk to health and ecosystems.

Aerosols, Particulate Matter, and Secondary Aerosols

Aerosols are fine particles suspended in the atmosphere, originating from dust storms, wildfires, volcanic eruptions, and industrial emissions. They have significant effects on both climate and air quality, influencing cloud formation, reflecting solar radiation, and altering the Earth’s energy balance. Sentinel-5P measures aerosol optical thickness, or AOT, in both the near-infrared and shortwave infrared spectral bands. AOT is a dimensionless coefficient that quantifies the amount of aerosol present in the atmosphere: higher values indicate higher concentrations. These measurements are particularly valuable for climate modeling, as they help scientists understand how aerosols interact with incoming solar radiation and affect cloud formation processes, two factors that directly shape the energy exchange between the atmosphere and the surface below.

The size distribution of aerosol particles is also analyzed, since particles of different sizes behave differently in the atmosphere. Fine aerosols can remain suspended and travel longer distances, while larger particles tend to settle more quickly, a distinction that matters both for air quality assessment and for understanding the geographic reach of pollution events. Sentinel-5P also provides data on secondary inorganic aerosols, including sulfates, nitrates, and ammonium. These compounds are formed in the atmosphere through chemical reactions between gases such as sulphur dioxide and nitrogen oxides with water vapor. Monitoring them allows a more complete understanding of how pollution sources contribute to overall atmospheric composition.

Particulate matter, classified by size as PM10 and PM2.5, is another critical variable. Fine particles are of particular concern because they can penetrate deep into the lungs and enter the bloodstream, contributing to respiratory and cardiovascular diseases. Estimated concentrations, expressed in micrograms per cubic meter, help assess pollution levels across urban and rural environments, guide public health responses, and inform the design of air quality regulations aimed at protecting the most vulnerable populations.

Water Vapor

Water vapor is the most abundant greenhouse gas in the atmosphere and plays a fundamental role in weather and climate dynamics. Sentinel-5P measures total column water vapor, or TCWV, which describes the total amount of water vapor integrated vertically through the atmosphere above a given location. This measurement is essential for weather forecasting, as water vapor directly influences cloud formation, precipitation dynamics, and the exchange of energy between the surface and the atmosphere. Beyond its role in climate science, TCWV data also has practical value in agriculture, where understanding atmospheric moisture conditions supports irrigation planning, helps anticipate periods of crop stress caused by water deficit or excess humidity, and improves the management of water resources at the field scale.

Applications in Urban Environments

Urban environments are among the primary areas of application for Sentinel-5P data. Cities concentrate industrial activity, transportation, and energy consumption, making them major contributors to atmospheric pollution. Sentinel-5P provides urban managers and planners with the ability to monitor pollutant concentrations across large areas and identify the zones most affected by poor air quality.

Real-time monitoring of NO2 allows the identification of pollution hotspots, enabling targeted interventions such as traffic restrictions, clean energy transitions, or the expansion of green infrastructure. During high pollution events or wildfire outbreaks, the spatial data from Sentinel-5P allows authorities to rapidly identify affected areas and implement timely mitigation measures to protect public health. During periods of elevated ozone concentration, municipalities can issue health warnings or adjust industrial activity to protect vulnerable populations, particularly children and the elderly. Methane monitoring is also directly relevant in urban contexts, where leaks from natural gas pipelines or storage facilities can be detected and rapidly addressed, improving both safety and environmental performance.

In the longer term, tracking how pollutant levels evolve over months and years in response to regulatory changes or infrastructure investments allows decision-makers to evaluate the effectiveness of their interventions and refine urban environmental policies accordingly.

Applications in Agriculture

In agricultural contexts, Sentinel-5P data provides important insights into how atmospheric conditions affect crop health and farming sustainability. Ground-level ozone is one of the most direct threats: prolonged exposure to elevated ozone concentrations can damage sensitive crops and reduce yields. Monitoring ozone levels spatially and over time allows agricultural managers to identify areas at risk and adjust harvest schedules or farming practices to minimize damage before it becomes economically significant. More broadly, air quality data from Sentinel-5P can support decisions on irrigation scheduling, soil management, and crop stress assessment, helping farmers anticipate how atmospheric conditions might affect their land and plan accordingly.

Elevated levels of NO2 can also signal atmospheric pollution that affects soil health and crop development, and when sustained over time, such air quality trends can become a direct risk factor for vegetation vitality. By combining Sentinel-5P air quality data with vegetation indices derived from Sentinel-2, agronomists can operationally assess whether areas showing reduced vegetation vigor are also experiencing elevated pollutant concentrations, enabling a more targeted and evidence-based approach to crop management decisions.

Methane monitoring is particularly relevant for understanding emissions from livestock farming and rice paddies. By identifying methane hotspots through Sentinel-5P data, farmers and environmental managers can target areas of excessive emissions and implement measures such as biogas capture systems or adjusted feeding practices to reduce their environmental footprint and contribute to climate mitigation goals.

Climate Research and Environmental Monitoring

Beyond urban and agricultural applications, Sentinel-5P plays an essential role in broader climate and environmental research. Long-term monitoring of greenhouse gases such as methane provides scientists with the data needed to assess emission trends, understand how human activities are altering atmospheric composition, and develop projections for future climate conditions. This long-term observational record is one of the most valuable outputs of the mission, as it transforms individual measurements into a continuous archive of atmospheric change.

Aerosol monitoring contributes directly to climate science, since aerosols influence cloud formation and the Earth's energy balance by reflecting and absorbing solar radiation. Understanding the distribution and concentration of aerosols at different atmospheric levels is essential for improving the accuracy of climate models. In regions affected by intense dust storms, wildfires, or volcanic activity, aerosol data from Sentinel-5P provides situational awareness that supports both scientific analysis and operational response.

Visualization in EagleArca: The Air Quality Layer

Within the EagleArca platform, Sentinel-5P data is made available through the Air Quality layer. This layer provides both real-time and historical atmospheric information, displayed as an interactive two-dimensional map that allow users to observe the distribution of pollutants and track changes in atmospheric conditions over time. Each day, the platform updates the layer with the most recent data available from Sentinel-5P, providing near-real-time access to variables such as NO2, methane, CO, ozone, and SO2 concentrations. This daily update capability is particularly valuable for operational monitoring and public health management. In cases of high pollution events or wildfire outbreaks, the data allows rapid identification of affected areas and supports timely mitigation responses.

Equally important is the access to historical data. As Sentinel-5P continuously acquires atmospheric observations, EagleArca archives this information and makes it available for time-series analysis. Users can examine how pollutant concentrations have evolved over periods ranging from days to years, observe the seasonal progression of ozone or methane on a month-by-month or year-over-year basis, monitor long-term trends in greenhouse gas concentrations across specific regions, and verify whether air quality measures or emissions regulations implemented over time have produced measurable, quantifiable improvements. This depth of temporal context transforms the Air Quality layer from a snapshot tool into a genuine decision-support environment, one capable of sustaining ongoing environmental assessments and informing the next cycle of policy and planning decisions.

Integration with Other Sentinel Missions

Sentinel-5P reaches its full analytical potential when its data is combined with the information provided by other Copernicus missions. Within EagleArca, the Air Quality layer can be overlaid with Sentinel-2 optical imagery and vegetation indices to relate atmospheric pollution patterns to land cover and crop or forest health. For instance, combining NO2 or ozone data from Sentinel-5P with NDVI from Sentinel-2 allows analysts to assess whether areas showing reduced vegetation vigour are also experiencing elevated pollutant concentrations.

Integrating Sentinel-5P data with thermal observations from Sentinel-3 supports the study of how urban heat and atmospheric pollution interact. In dense urban environments, high sensible heat flux and elevated pollutant concentrations often co-occur, compounding their effects on air quality and human comfort. Understanding this relationship is particularly relevant for climate resilience planning, where addressing heat accumulation and air quality together produces more effective outcomes than treating them as separate problems.

Sentinel-5P and the Future of Atmospheric Monitoring

Sentinel-5P represents a critical component of modern Earth observation. Its TROPOMI instrument provides a level of atmospheric detail and global consistency that was not previously available from operational satellite systems. By tracking pollutants, greenhouse gases, aerosols, and additional atmospheric variables at high spatial resolution on a daily basis, it enables continuous environmental monitoring across a wide range of scales, from local pollution events to global climate trends.

When combined with the surface, thermal, and structural information provided by the other Sentinel missions, Sentinel-5P contributes the atmospheric dimension to a comprehensive and multi-layered picture of the Earth system. Together, these missions demonstrate how modern satellite infrastructure is enabling a new generation of integrated environmental intelligence, capable of supporting informed decision-making across air quality management, agricultural sustainability, urban planning, and climate science.

ECMWF

https://www.youtube.com/embed/w8Wt2-vB6lE?si=U2JXLUCd5z_Fmyym

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ECMWF and the Copernicus Ecosystem

Welcome. In this video, we explore the significance of weather forecasting and climatic condition monitoring within the context of satellite systems and ECMWF, the European Centre for Medium-Range Weather Forecasts. The global need for accurate weather predictions is growing, driven by climate change, agricultural dependencies, and disaster preparedness. Understanding the systems that deliver these forecasts has therefore become crucial for many industries, including agriculture, urban planning, and emergency response. ECMWF produces some of the world's most accurate weather models and represents a pivotal component of climate research and weather prediction. Its medium-range forecasts are among the most reliable global predictions available. Its strength lies not only in short-term forecasting, but also in its ability to model the atmosphere and the climate system with a medium-term horizon, helping meteorologists understand weather patterns and phenomena over longer timeframes.

This capability is built on a global numerical weather prediction model that uses vast amounts of data from satellites, weather stations, and radiosondes, which are balloon-borne instruments, to simulate atmospheric conditions. These data sources provide real-time observations of temperature, humidity, wind speed, cloud cover, and precipitation, all feeding into ECMWF's models. The system produces global weather forecasts for up to fifteen days ahead.

Satellite Data in ECMWF Weather Forecasting

Satellite data plays a vital role in ECMWF's predictions. Satellites from the Copernicus Programme, including Sentinel-1, Sentinel-2, and Sentinel-3, provide comprehensive data about the Earth's surface, oceans, and atmosphere. They allow global observation of climatic conditions by tracking key variables such as sea surface temperature, snow cover, airborne pollutants, and vegetation conditions. All of these are essential inputs for climate modelling and the monitoring of long-term climatic trends. Sentinel-1 helps monitor surface deformations and flooding, and its observations are also useful for analysing geophysical phenomena and potential risks related to seismic activity. Sentinel-2 offers high-resolution multispectral imagery to track vegetation health, soil moisture, and land use.

Sentinel-3 provides thermal and oceanographic data, supporting a better understanding of sea temperature and the effects of thermal radiation on the Earth's climate. Integrating data from all these satellites with ECMWF's models greatly improves the accuracy of weather forecasts and climate projections. For day-to-day forecasting, ECMWF models use data gathered by both polar-orbiting and geostationary satellites. Polar-orbiting satellites, such as those in the MetOp series, orbit the Earth at different latitudes and capture high-resolution measurements across the entire planet. Geostationary satellites, such as MSG and Himawari, continuously observe the same area of the Earth, enabling real-time monitoring of weather systems like hurricanes, storm fronts, and cloud formations.

The combination of both types is crucial. Polar-orbiting satellites provide global atmospheric measurements at higher resolution, while geostationary satellites deliver real-time information on rapidly changing weather systems. Together, they ensure both global coverage and high temporal resolution. For long-term climate monitoring, ECMWF uses satellite data to assess climatic trends over time. Sea surface temperature, or SST, is a major climatic variable for studying ocean circulation and its influence on weather patterns. By incorporating satellite observations of SST into climate models, ECMWF can better predict large-scale weather phenomena like El Niño or La Niña, which significantly affect global rainfall and temperature distributions.

Weather Variables in the EagleArca Platform

The Weather service available on the EagleArca platform provides daily updates on a wide range of atmospheric variables. These measurements are crucial for understanding both immediate and longer-term environmental factors, affecting everything from urban planning to agriculture. The following sections describe each variable category and its significance.

Precipitation, Soil and Runoff

Rain, measured in millimetres, indicates the amount of precipitation that has fallen over a specific period. It is an essential metric for understanding weather patterns, drought conditions, and irrigation needs. Total Precipitation extends this measurement to include all types of precipitation, such as rain, snow, hail, and sleet. This provides a more comprehensive view of how weather interacts with the environment, especially in areas prone to mixed precipitation types.

Runoff, also measured in millimetres, indicates the amount of water that flows over the land surface and can potentially contribute to flooding. This variable is particularly useful for managing urban drainage systems and agricultural irrigation, and for assessing the risk of soil erosion. Soil moisture and soil temperature, labelled in the platform as soil_moist and soil_tempe, provide real-time data on soil conditions. They are key for monitoring irrigation needs, predicting drought conditions, and managing crop health. Finally, snowfall and snow depth are also provided, completing the picture of precipitation and its accumulation on the surface.

Temperature and Humidity

Temperature, measured in degrees Celsius, provides a snapshot of the thermal state of the atmosphere. Surface temperature indicates the temperature of the land surface specifically. It is important in both urban heat island studies and agriculture, where it helps assess crop development, frost risks, and heat stress. Relative humidity, expressed as a percentage, refers to the amount of moisture in the air relative to the maximum the air can hold at a given temperature. It is a key determinant of perceived comfort and directly influences the rate of evapotranspiration in crops, which makes it essential for managing water resources in agriculture.

The dew point, in degrees Celsius, is the temperature at which air becomes saturated with moisture and water vapour begins to condense. It is important for predicting fog formation and frost. In agriculture, dew point data provides early warnings about frost risks that are critical for protecting crops. Apparent temperature, also in degrees Celsius, represents the temperature as perceived by the human body. It accounts for both air temperature and humidity, and is especially relevant in urban heat island studies, where dense building structures and fewer green spaces can lead to higher perceived temperatures.

Pressure and Wind

The platform provides two pressure readings. Mean sea-level pressure, labelled in the platform as pressure_m, is expressed in hectopascals and corrected for altitude. It helps interpret large-scale weather systems: low-pressure systems are associated with storms and bad weather, while high-pressure systems correspond to clear skies and stable conditions. Surface atmospheric pressure, labelled as surface_pr, determines local weather conditions and wind patterns.

Wind speed and wind direction, labelled in the platform as wind_speed and wind_direction, are crucial for understanding weather systems and air quality. Wind affects the distribution of pollutants, moisture, and heat, particularly in urban areas and agricultural regions where airflow influences irrigation, pesticide application, and heat accumulation. Wind data also helps predict the movement of weather fronts and storm systems, and is important for industries such as aviation, shipping, and renewable energy, specifically wind power.

Cloud Cover and Atmospheric Instability

Cloud cover, expressed as a percentage, indicates how much of the sky is covered by clouds and directly affects solar radiation, temperature, and precipitation. It is also useful for predicting weather changes, such as the development of storms or the transition to clear sky conditions. The platform provides cloud fraction values broken down by altitude, labelled as cloud_co_1, cloud_co_2, and cloud_co_3, representing low, middle, and high-level clouds respectively. This layered view provides a deeper understanding of atmospheric conditions at different altitudes, supporting weather forecasting and climate modelling.

CAPE, measured in joules per kilogram, stands for Convective Available Potential Energy and is a measure of atmospheric instability. It quantifies the potential energy in the atmosphere that can fuel storm development. The higher the CAPE value, the greater the likelihood of severe weather events such as thunderstorms, hail, and tornadoes.

Atmospheric Column Variables

Total column water vapour measures the total amount of water vapour integrated vertically through the atmosphere above a given location. Water vapour is the primary greenhouse gas and plays a central role in the Earth's water cycle, influencing precipitation patterns, cloud formation, and energy transfer. Total column ozone is crucial for understanding both the health of the stratospheric ozone layer and the presence of ground-level ozone, which is a significant air pollutant.

Applications in Agriculture

Weather forecasting and climate data are vital for the agriculture sector. With Sentinel-2 data, farmers can monitor vegetation health using vegetation indices like NDVI and EVI, derived from satellite reflectance in the red and near-infrared bands. These indices provide early warnings about crop health. They help farmers decide when to irrigate, how to manage pest pressure, and how to optimise water use across the growing season. Temperature forecasting is equally critical, especially when linked with frost prediction or heat stress. Sentinel-3 land surface temperature data allows agricultural decision-makers to anticipate temperature anomalies that could harm crops, offering more time for preparation and mitigation.

The EagleArca platform's daily updates on rainfall, humidity, and soil conditions allow farmers to continuously assess drought and flood risks and plan for pest management. The data also supports protection of crops from frost, heat stress, and other weather-related damage. The platform enables tracking of seasonal weather patterns as they evolve, supporting adjustments for climate-related risks and the optimisation of water resources across the growing season.

Applications in Urban Environments

In urban environments, weather forecasting and climate models are essential for managing heat islands. The Urban Heat Island effect occurs when built-up areas experience significantly higher temperatures than surrounding rural areas, primarily due to impervious surfaces such as roads and buildings that absorb heat. By combining ECMWF weather forecasts with Sentinel-3 land surface temperature data, cities can identify areas subject to heat accumulation and implement cooling strategies, such as increasing urban green spaces or using reflective materials on roads. The platform also supports the analysis of how green spaces, rooftops, pavement, and urban structures influence local microclimates, helping planners design more resilient environments and reduce heat-related health risks for urban populations.

ECMWF's data also supports air quality management and infrastructure planning in cities. By incorporating aerosol and pollutant data from Sentinel-5P and other Copernicus missions, urban planners can assess pollution sources, track NO2 levels, and evaluate strategies to reduce emissions and improve air quality. Rainfall and runoff data further support the planning of urban drainage systems, helping cities manage flood risk and prevent waterlogging in built-up areas.

Disaster Management and Climate Research

Real-time weather data plays a key role in disaster management. During events such as floods, heatwaves, or wildfires, the EagleArca platform can be used to track temperature fluctuations, precipitation intensity, and wind direction, providing crucial information for emergency responders. The ability to view these changes in real time enables faster decision-making and better resource allocation during critical situations.

For climate research, the long-term availability of historical weather data through EagleArca allows scientists to observe changes in climatic conditions over time, track seasonal patterns, and model future environmental changes. This data, combined with datasets such as Sentinel-1 for monitoring land subsidence or Sentinel-2 for tracking vegetation health, contributes to a comprehensive understanding of how climate change is impacting specific regions.

Visualization in EagleArca: The Weather Service

The Weather service on EagleArca provides real-time weather data refreshed daily, offering a comprehensive view of atmospheric conditions across large spatial areas. The data is sourced from advanced satellite systems and atmospheric monitoring instruments, ensuring high accuracy and global coverage. Within the platform, weather variables are visualized through the 2D view, providing an intuitive, map-based interface where users can observe the spatial distribution of atmospheric parameters. By zooming in on different geographic areas, users can track specific trends in detail, from precipitation patterns to temperature anomalies and wind dynamics. This view also helps urban planners identify where heat is accumulating and understand how elements such as green spaces, rooftops, pavement, and urban structures influence local microclimates.

The daily refresh of data ensures that users are always working with the most current atmospheric measurements, without the delays of manual reporting or outdated weather stations. This continuous update cycle improves the accuracy of forecasts, enables more reliable weather alerts, and better prepares users for extreme events such as heavy rainfall, windstorms, heatwaves, floods, and wildfires. Alongside real-time updates, EagleArca archives historical weather data, allowing users to access and analyze atmospheric conditions over extended time periods.

This makes it possible to track seasonal patterns, observe multi-year climate trends, and evaluate how specific weather events have evolved across a region. Combined with daily updates, the Weather service becomes a complete decision-support environment, whether for managing irrigation in agriculture, monitoring heat accumulation in cities, or coordinating responses to extreme weather events.

ECMWF and Copernicus: An Integrated Framework

ECMWF's weather and climate models are central to improving weather forecasts and understanding atmospheric conditions on both global and regional scales. The integration of satellite data from Copernicus missions like Sentinel-1, Sentinel-2, and Sentinel-3 with ECMWF's predictive capabilities provides an essential toolset for addressing a wide range of environmental challenges. From agriculture to urban planning and disaster preparedness, this integrated approach enhances our ability to make data-driven decisions that improve resilience to climate extremes and support sustainable development. As satellite systems and predictive modelling continue to improve, the combination of ECMWF's meteorological capabilities and Copernicus satellite data will play an increasingly important role in shaping the future of climate resilience and environmental management globally.