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.