DIASCA
Digital Integration of Agricultural Supply Chains Alliance

Forest Monitoring

Phase 1 & 2: Semantics and Syntax

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Published by:
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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Programme/project description:
Sector Programme Initiative for Sustainable Supply Chains and Standards (INA)

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Photo credits/sources:
Shutterstock

On behalf of
German Federal Ministry for Economic Cooperation and Development (BMZ)
Division 122 Agriculture, rural development

Bonn/Berlin, July 2024

On behalf of

Federal Ministry
for Economic Cooperation
and Development

Acknowledgments

Special thanks to these organizations and experts and all other contributors and participants to the DIASCA Forest Monitoring working group.

Andres Ferreyra (Syngenta / ISO TC 347)
Amir Ebadi
Baptiste Monnier
Dr. Flavia de Souza Mendes
Martin Schüller
Hannelore Beerlandt
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Introduction

The efficient exchange of data between different entities relies on the interoperability of their systems. Interoperability incorporates multiple components such as semantics (what is being measured), syntax (how it is measured), and structure (how data is stored and transmitted). Interoperability is particularly lacking in agrifood and supply chain systems. This results in significant difficulties in achieving traceability for products and fair compensation for producers. Regulations like the European Union Regulation on Deforestation-Free Products (EUDR) rely heavily on data from multiple actors, further demonstrating the need for interoperability.

This paper focuses on the semantics and syntax related to forest monitoring. Much of the current forest monitoring approach is based on compliance with the EUDR, a reality which is reflected in this paper. This report, as well as the collaborative approach used to create it, aims to promote a shared understanding of forest monitoring among diverse stakeholders such as supply chain partners (from producers to retailers), and service and data providers. Regulators and authorities tasked with reviewing and verifying due diligence statements may also find this reference useful, as it represents the culmination of insights from many experts representing producers, traders, and service providers among others.

The DIASCA community has published separate papers addressing topics related to farm income and traceability and is exploring additional themes such as data structure, governance and ownership.

EUDR, Traceability and Geodata - Background

The EUDR[1] establishes a framework aimed at **minimizing the EU´s contribution to global deforestation and forest degradation linked to supply chains**, aiming to reduce greenhouse gas emissions and biodiversity loss. The regulation currently applies to **cattle, cocoa, coffee, oil palms, rubber, soy and wood**. (Art 2.)

Under the EUDR, operators must demonstrate that the goods they sell on the EU market have been legally produced on land that was neither deforested nor degraded after 31 December, 2020. This means that operators must be able to trace commodity supply chains back to the specific farm(s) or forest(s) where they were produced and demonstrate that no deforestation occurred on those sites after the cutoff date. The regulation does not specify who is responsible for implementing traceability systems and monitoring deforestation however, so even though operators are responsible for the data,

[1] Regulation (EU) 2023/1115: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L:2023:150:TOC

several public and private implementation and monitoring systems are being developed in producing countries. These and additional efforts ideally will facilitate the capture of the required point/polygon data, which otherwise would be beyond the resource capacities of many smallholder farmers.

Georeferencing Plots

It is necessary to collect the geographic coordinates for specific plots where qualifying commodities are produced. Operators are required to report the points or polygons where their products were produced to the EU's Information System, as follows:

- Plots of land **under 4 hectares** and cattle establishments require at least a **single geolocation point** (latitude and longitude), although polygons are ideal.
- For plots **larger than 4 hectares** used for commodities other than cattle, **polygons** are required.

Single real estate properties are often comprised of one or more plots where relevant commodities are produced. The EUDR requires that each individual plot must be reported on rather than the larger property as a whole. This requirement differs from some certification schemes and national cadastres which record the entire real estate property.[2]

There are multiple ways to collect the required points or polygons of plots. The EUDR does not specify which method to use, allowing practitioners to adapt their choice to the specific context. There are three prominent methods for collecting polygons:

1. Walking the perimeter with a GPS-enabled device with mapping functionality or applications (e.g. using EGNSS4ALL or Open Foris Ground),
2. Drawing polygons using a digital map program (e.g. QGIS, ArcGIS, OpenStreetMap and Asset Registry), or
3. Machine learning that automatically detects field boundaries based on satellite images.

There is also the question of *who* should collect the point or polygon location(s). Should farmers self-report? Should buyers or cooperatives collect the data along with producers? What role should local government play in curating this data? The optimal method, and which entity is best placed to collect the data will depend on the context, as discussed below.

[2] This definition of plot is evident in the description "land within a single real estate property, as recognized by the law of the country of production, which possesses sufficiently homogeneous conditions to allow an evaluation of the aggregate level of risk of deforestation and forest degradation associated with relevant commodities produced on that land." https://green-business.ec.europa.eu/deforestation-regulation-implementation/traceability_en

Experience by some actors suggests that asking farmers to provide their field boundary information does not always yield reliable information, leading some to advocate for empowering local entities to support data collection (e.g. cooperatives, aggregators, and local authorities). These entities should have the capacity to organize, store and transmit the information properly, including, for example, maintaining six decimal digits to describe the perimeter of each plot of land. However, having third parties collect point or polygon data should not bypass farmers' rights to control their data and its use. The image below provides a summary of the technical requirements for this process.

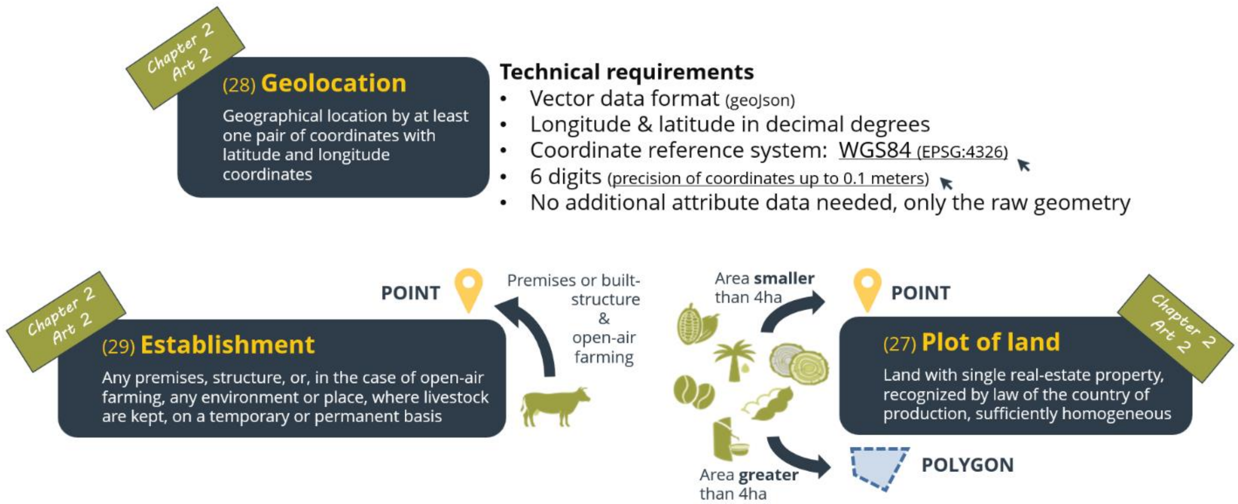


Image by INA/GIZ

Walking Polygons

When walking a field boundary, it is more accurate to use a survey-grade GPS-enabled device (e.g. Trimble handheld GPS) rather than a device that relies on cell-towers. Timing the collection of points for when satellite positions are optimal also produces more reliable results. Some tools (e.g. Kobo Toolbox), indicate the best time to walk a field boundary based on satellite location.

Walking plot boundaries has the obvious limitation of requiring someone to visit each plot and walk the full perimeter. This can be challenging when the plots are extremely large, unless a suitable vehicle can be used rather than walking. Walking field boundaries may also be challenging if a third party is collecting the data, as it requires visiting each plot. In some cases, farmers will have a plot near their house, as well as one or more plots that are more remote. Experience shows that farmers may be understandably reluctant to make a dedicated trip to these remote sites so a third party can capture their polygons. This obstacle may be overcome if the third party makes plans to meet farmers at remote sites when the farmers are already planning to be there. However, this approach increases complexity by adding a step to the process: the third party must first identify the location and time the farmer will be at a given plot and then return to that plot at the pre-arranged time.

Drawing Polygons

Digitally tracing polygons overcomes some of the challenges of walking large or remote polygons. A farmer, working on their own device or that of a field technician or collection site, can easily trace all their plots, including large and/or remote plots. However, some argue that drawing field boundaries is far less precise than walking them. Inaccuracy in hand-drawn boundaries may arise from the fact that the base-map onto which the polygons are drawn may be outdated; it is not always evident in common mapping tools how recent images are. This may cause users to draw inaccurate polygons based on visible features, such as field boundaries, that have moved since the image was taken.

Detecting Polygons with Machine Learning

Machine learning algorithms also remove the need to walk the field boundary and can be deployed at scale with limited human intervention. Consultation with plot owners is not necessary, contributing to the method’s scalability, however this potentially introduces concerns around data ownership and sovereignty.

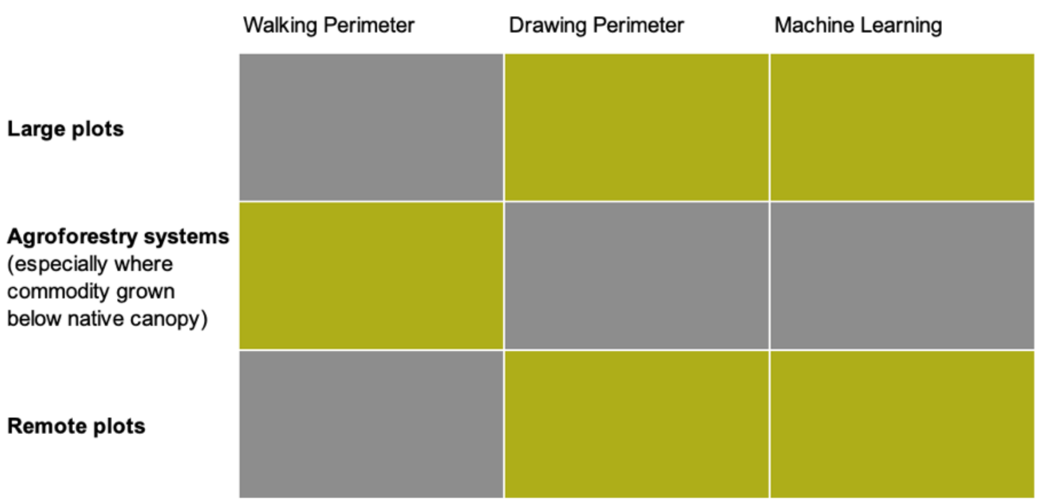
Machine learning algorithms are increasingly able to identify plot boundaries. However, at the time of writing the machine learning models that are widely available are less reliable at identifying agroforestry plots, especially when the canopy over these plots cannot be easily distinguished from the surrounding area using optical imagery. An example of this would be where a commodity like coffee or cocoa is grown under the native tree canopy that continues uninterrupted beyond the plot.

Scenarios where there are no clear demarcations visible on a map also make manually drawing polygons on maps difficult. In these contexts, methods using current machine learning models and using maps to draw boundaries, may be less reliable than walking the perimeter or capturing the coordinates of the center of the plot.

Another issue that can affect the accuracy of polygons, regardless of the method used to derive them, is the map Coordinate Reference System (CRS) used at that specific location. This distortion may lead to polygons erroneously appearing to overlap with a neighbor's land, a road, a conservation area, or a deforested area.

Selecting Method(s) for Polygon Detection

The following table provides a simple overview of considerations when selecting a method of capturing polygons.



The rationale for the selected method, along with any associated risks, should be described in due diligence statements. Optimally more than one method should be used, or even the same method implemented by different parties as a means of verification. Such double work requires additional resources, and so may be deployed ad hoc depending on the risk involved. For example, when a polygon borders a deforested area additional methods or verification should be employed to be certain of where the border is.

In some cases, multiple parties may already have begun collecting polygons, which can be shared through pre-competitive collaborations. In the long term, producing country governments might find it more efficient to lead or support the registry of plots. However, setting up this kind of public system may take some time, and is likely to introduce other complexities related to property rights, taxation, and coordination among different government agencies.

Forest (Change) Monitoring

Compliance with the EUDR also includes Forest (Change) Monitoring. This means that operators must compile conclusive and verifiable evidence that products were not produced in forest areas that were changed to agricultural use after 31 December 2020.

Forest Definition

The EUDR applies the forest definition from the Food and Agriculture Organization of the United Nations (FAO[3]), characterizing forests as land exceeding 0.5 hectares (ha) with trees higher than 5 meters (m) and a canopy cover over 10%. Land predominantly under agricultural or urban use is not considered forest and is excluded from the definition. The term "agricultural use" in the context of the EUDR pertains to the utilization of land for agriculture, encompassing agricultural plantations and set-aside agricultural areas.

It is worth mentioning that, as it stands, the EUDR focuses solely on forests, but a significant portion of grain production (such as soybeans in Brazil) occurs in areas of sub-forests, classified as 'other wooded land' (OWL) under the regulation. The inclusion of OWL has been a frequent demand from researchers and civil society, arguing that some of these areas are as rich in biodiversity as forests. It is likely that OWL will be a central theme in the first revision of the regulation.

It is also worth noting that the 0.5 ha threshold sets a minimum mapping unit for defining land that is forest, but this minimum does not apply to defining deforestation or changes within a forest. In other words, activities on small patches of land which lead to a land use change (e.g. conversion to agricultural use) within a larger span of forest land is still considered deforestation.[4]

Earth Observation

Role of Spatial Information for EUDR Compliance

According to EUDR, operators need to provide the points/polygons for each plot of land they sourced from and have a due diligence statement explaining the process used to ensure that there was no deforestation. However, there is no explicit requirement to include remote sensing (also known as earth observation) in EUDR due-diligence statements. While the EUDR does not include a requirement for operators to use remote sensing or any other method, in practice most actors in the near term will likely use remote sensing to monitor deforestation at scale, due to its relative cost effectiveness, ability to be implemented at scale and because it is one of the only ways to evaluate the

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[3] https://www.fao.org/4/ad665e/ad665e03.htm

[4] According to Article 2(3) of EUDR 'deforestation' means conversion of forest to agricultural use and should be understood as a change in the use of the land from 'forest' as defined in Article 2(4) of EUDR (discussed in detail in Section 3) to 'agricultural use' as defined in Article 2(5) of EUDR (discussed in detail in Sections 4, 4.C and 4.D). In this regard, the extent of the conversion to agricultural use is irrelevant, and such conversion renders the commodity in scope produced on such land non-compliant if the deforestation occurred after 31 December 2020.

forest state at a historic moment in time. The European Forest Institute offers additional details on the role of geospatial information for EUDR due diligence.

2020 Forest Baseline

Detecting changes to a forest requires comparing forests at a given time to a baseline from the cut-off date of 31 December 2020. On 7 December, the EU Forest Observatory launched the Forest 2020 ("Base") Layer. This combines data from multiple global datasets on tree cover, tree height, land cover, and land use into a single harmonized global representation of where forests existed in 2020[5].

However, some experts acknowledge that the resolution of this mapping (10m) is not ideal, requiring further refinement for deforestation detection. Several producer countries have undertaken mapping at higher resolutions, which will aid in both more accurate forest monitoring and eventual definition of risks by the EUDR (benchmarking).

Most applied and publicly available maps only classify the land cover *type* and not the land *use*. That is, maps identify tree cover but not forest status. Therefore, additional contextual data is needed to determine the forest status of a particular location at a particular point in time. For example, a tree cover map might classify a particular area as being forest on the 2020 cut-off date, but a farmer may have been cultivating crops below the canopy long before 2020. Failing to differentiate between land use and land cover may lead to the misclassification of many agroforestry systems as having been forests, which would then lead to false reports of deforestation or degradation when it is discovered that farmers are cultivating there.

Compliance with Local Laws

Another critical nuance to understand for EUDR compliance is legality, wherein the regulation requires that production be in accordance with local laws. Governments in producing countries are uniquely suited to simplify this element by providing, at least partially, official documentation that can aid in verifying legality claims for forest-risk commodities. Legality concerns will differ depending on the location but may include issues such as ownership, protected territories, and land use and occupation. Remote sensing can be used to evaluate some legal issues such as illegal encroachment on indigenous or protected lands.

[5] Here is a technical paper about how the dataset was produced https://op.europa.eu/en/publication-detail/-/publication/f9baaa45-e73f-11ee-9ea8-01aa75ed71a1

Convergence of Evidence Approach

A whole range of satellite-derived forest, land use and tree cover maps are available publicly. However, these maps are often inconsistent, or even contradictory, because of differences in the definitions and land cover classification systems used. Rather than choosing a single dataset, the various datasets should be used together. While no single definitive source of geospatial data can tell the whole story about any given plot of land, various datasets can contribute to understanding what most likely occurred at that location. A 'convergence of evidence' approach reduces the impact of individual biases or errors present in any single piece of evidence or data source and provides more nuanced and complementary details on a specific plot. This approach is supported by the Team Europe Initiative Technical Facility and the Sustainable Agriculture for Forest Ecosystems (SAFE) project.

Earth Observation Data Sources

Spatial information may consist of either vector data or raster data. Vector data is defined as points, lines and polygons that represent geographic features and provide the location information about a place (e.g. a plot of land). Raster data includes images, either taken from satellites or occasionally from other flying platforms such as planes or drones, along with other information like elevation, land use type, etc. For more information about Vector and Raster data see Annex 4: Vector and Raster Data. Monitoring deforestation reliably using remote sensing may require combining multiple geospatial data types, due to canopy cover, cloud cover[6] and other challenges such as temporal and spatial resolution.

Optical and Radar Data

Satellite sensors vary in their specifications, capabilities, and characteristics, and these differences impact their effectiveness in forest monitoring applications. Optical and radar data are two distinct types of satellite remote sensing data, each offering unique advantages and characteristics for forest monitoring. The choice between optical and radar data for forest monitoring depends on the specific objectives of the monitoring task, environmental conditions, and the information needed. Integrating data from both sources can provide a more comprehensive understanding of forest dynamics. For more details on the distinction between active and passive sensors please refer to Annex 1: Summary of Characteristics of Optical and Radar Data

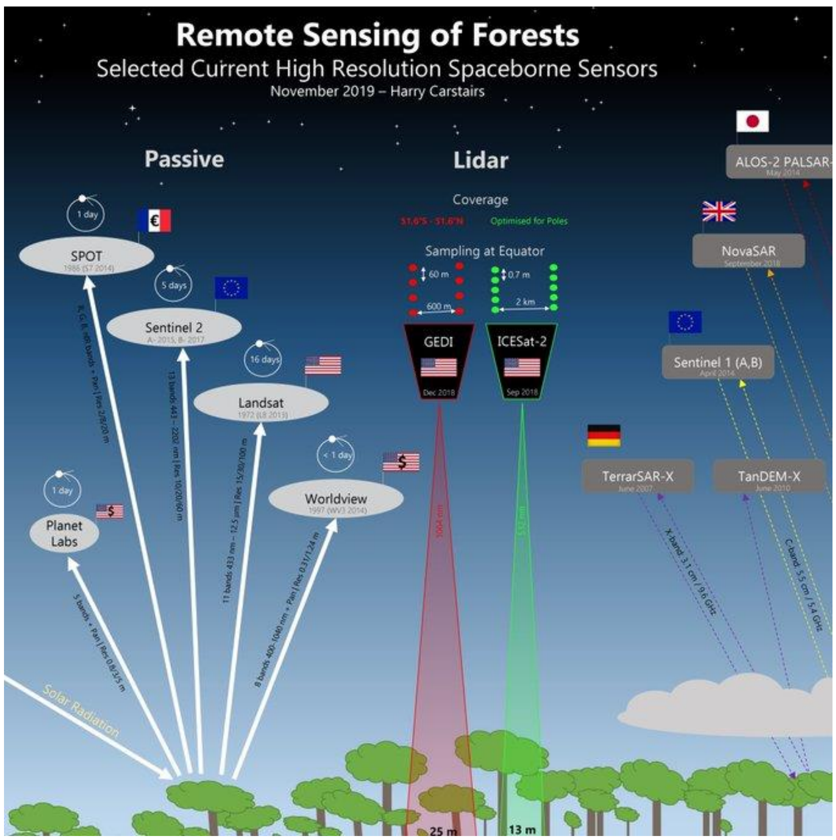
6 For example, if one commissions Planet images but there is cloud cover in that location on the date specific specified.

Resolution of Satellite Data

Satellite data comes in various resolutions, representing the level of detail that can be observed on the Earth's surface. The resolution is commonly categorized into three main types:

1. Spatial resolution
2. Temporal resolution
3. Spectral resolution

The following figure provides a sample of some of the different satellites, along with their spatial resolution, revisit times, and other details.



Different satellites and sensors are designed to meet specific objectives, and the choice of resolution depends on the intended applications. For example, high spatial resolution is crucial for detailed land cover mapping, while high temporal resolution is important for monitoring dynamic processes like vegetation growth or changes in land use over time. Spatial and temporal resolution are discussed below. Details about spectral resolution can be found in Annex 5: Spectral Resolution.

Spatial Resolution

Spatial resolution refers to the size of the smallest discernible feature in an image. It is typically measured in meters per pixel. For example, 10m resolution imagery captures finer photographic details compared to 30m resolution imagery. The choice of resolution depends on the specific requirements of the application, balancing the need for detailed information with considerations such as data processing capabilities and cost. Sensors with high spatial resolution can capture fine details and are suitable for monitoring small-scale features within forests, such as individual trees or small clearings. Moderate to low-resolution sensors may cover larger areas, however, they might not provide the necessary detail for certain types of forest monitoring, especially when precise information on individual trees or small patches is required.

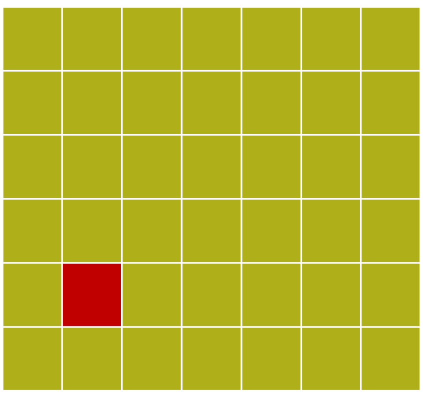
The three main categories of spatial resolution are:

- **High Spatial Resolution**: Sub-meter to a few meters per pixel. Examples include 0.3 meters or 5 meters per pixel.
- **Medium Spatial Resolution**: Ranges from around 5 meters to 30 meters per pixel. Common examples are 10 meters, 20 meters, or 30 meters per pixel.
- **Low Spatial Resolution**: Coarser than 30 meters per pixel, often measured in kilometers. Examples include 100 meters or 1 kilometer per pixel.

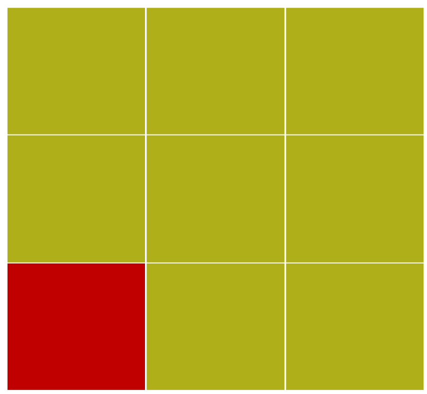
Spatial resolution has been the subject of considerable scrutiny with debates around whether one can effectively detect deforestation using the 10m resolution that is freely available from data sources such as Sentinel 2.

Image by INA/GIZ

The optimal spatial resolution may differ based on what the images are being used for. Some uses include detecting field boundaries (polygons) using machine learning, monitoring deforestation, and differentiating native versus planted trees. Higher spatial resolution can also be used to reveal deforestation false positives, such as when the pruning of a coffee tree is falsely flagged as degradation/deforestation by lower resolution spatial images. Some believe that high resolution (e.g. 0.5m) is needed for machine learning algorithms to automatically detect field boundaries. However, once these boundaries have been determined (regardless of method), lower resolution (e.g. 10m) may be sufficient to detect deforestation, as changes in the forest are still detected even with less granularity, as depicted in the figure below.



Tree removal depicted
at high resolution



Same tree removal depicted
at lower resolution

While some commercial sensors provide outstandingly high spatial and temporal resolutions, they are very costly because they take ad hoc images of areas specifically requested by the customer. At the time of writing, it costs 44 USD to acquire one square kilometer of WorldView-3 imagery with all spectral bands. This makes it prohibitively expensive for continuous monitoring of large areas such as the Amazon, which covers roughly six million square kilometers. NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) has an outstanding temporal and spectral resolution given that it offers free, continuously-taken imagery, however, the spatial resolution is low (only 250-1000 meters). Alternatively, Landsat and Sentinel provide continuous imagery of decent spatial, temporal, and spectral resolution for free, which are easily useable in automatized algorithms. Furthermore, Landsat and Sentinel archives are filled with past imagery useful for historical change detection.

Medium-resolution public free-of-charge imagery is a great resource for continuous automatized monitoring of large-scale areas and is promising for the quick development of new methods, especially in the field of artificial intelligence and machine learning.

High-resolution commercial imagery on the other hand is a great resource for organizations requiring analysis with higher resolutions. For example, private companies inspecting individual plots of land or research entities piloting projects in smaller areas. High-resolution commercial imagery can even support intermediate analyses that improve algorithms for free public imagery providers. However, acquiring high-resolution satellite imagery can be prohibitively expensive for operators with composite products who need to conduct checks on numerous plots of land. While high-resolution imagery offers a valuable means of accurately identifying false positive detections of deforestation, there is a pressing need to develop alternative tools that are cost-effective yet provide improved accuracy compared to moderate and low-resolution products.

Commercial imagery is sometimes available for free for non-commercial institutions through sponsored programs. For example, Norway's International Climate and Forests Initiative (NICFI) Satellite Data Program offers high-resolution (<5m per pixel) imagery of the tropics by PLANET for non-commercial use. The program will be continued for another 4+2 years and will also represent a continued source of publicly available information.[7]

The optimal spatial resolution needed also depends on the overall traceability approach. Important details to consider are whether a larger contiguous region is declared as deforestation-free (also known as "declaration in excess") or if individual polygons are being monitored in a more traditional chain of custody approach. The proximity of the polygons that are included in the supply chain to areas where deforestation is occurring is also an important consideration.

Another factor that must be considered along with the spatial resolution is the amount and rigor of ground-truthing (discussed in the Risk-Based Ground Truthing section below). The approach to ground-truth is often heavily influenced by the traceability approach. For example, the area included in landscape approaches may be too vast to make robust ground-truthing feasible, so greater reliance may be placed on remote sensing.

Temporal Resolution

Temporal resolution refers to the frequency with which a satellite can revisit a specific area. It is often expressed in terms of revisit intervals. Note that some satellites (e.g. Sentinel and Landsat) continuously take images from all points on earth (with some exceptions in the polar latitudes), while others, especially those with very high temporal and spatial resolution, only take images of areas requested by the customer. High temporal resolution sensors provide frequent images of the same area over time. This is crucial for monitoring changes in forests, such as deforestation, disturbances, or forest

[7] https://www.nicfi.no/2023/12/02/nicfi-and-bezos-earth-fund-providing-free-satelite-images/

regeneration. Low temporal resolution sensors may miss short-term or rapidly changing events, especially forest degradation or fires. Some low temporal resolution sources have revisit intervals greater than one year, potentially missing many changes such as the clearing of trees, planting of a perennial crop, and the first harvest. Land cover maps leveraging multiple satellites are beginning to provide some degree of joint temporal resolution (for example HLS - https://hls.gsfc.nasa.gov/) However, they are still limited in spatial resolution.

A list of satellite imagery platforms can be found in Annex 7: Satellite Imagery Platforms

Ground Truthing

Ground truthing is the practice of confirming information through direct observation. Ground truthing is generally thought to complement, rather than replace or be replaced by remote sensing. In the context of EUDR, ground truthing will likely often be used to validate the accuracy of field boundaries detected using machine learning, especially in areas with dense forest canopies, as well as to verify changes in land use (e.g. deforestation).

Ground truthing can be seen as a valuable Risk Mitigation approach, that can be used to refute both false positives (a detection of deforestation where none occurred) as well as false negatives (a failure to detect deforestation). However, it is important to note that just as the EUDR does not specify a requirement for remote sensing, the regulation does not explicitly require ground-truthing either. Operators are to determine and justify their own approach to due diligence. It is worth noting that depending on the amount of ground truthing (e.g. the sampling method) and who performs ground truthing (e.g. existing field staff vs 3rd party auditors) the cost of traditional ground truthing can be quite high.

There are several promising approaches to ground-truthing that are less expensive than using a traditional third-party auditor. A common approach is “desk audits”, which review additional information that does not require going to the field to capture additional information. Another approach is “agile” ground truthing, where a farmer, or other representative with a smartphone submits geo and time-stamped photos facing north, south, east and west, as well as upwards towards the canopy. This technique is demonstrated by The EU Agency for the Space Program’s EGNSS4ALL app[8] as well as OpenForis Ground, which is part of the FAO toolkit[9].

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[8] Available on Google Play (https://play.google.com/store/apps/details?id=com.erasmicoin.euspa.gsa.egnss4all&hl=en_US&pli=1) and Apple App Store (https://apps.apple.com/ai/app/egnss4all/id1628843978)

[9] https://openforis.org/solutions/ground/

Sample Questions for Ground Truthing

The following are a sample of questions that operators and their supply chain partners may consider during desk and field audits:

Desk Audit Questions

- Confirm whether disturbance was after the cut-off date
- Check if a field audit was already conducted after the disturbance event
- Visually inspect high-resolution time series e.g. from Planet or Maxar
- Check additional remote sensing tools
- Check national registries of farm fields (if present) at the cutoff date or visually inspect baseline, to determine if there was a misclassification of forest or evidence that the event predates cutoff
- Check internal records to see if volumes sourced from farm have remained consistent with levels prior to the disturbance, or if there are any known activities that could have triggered a false-positive, such as renovation of perennial crops

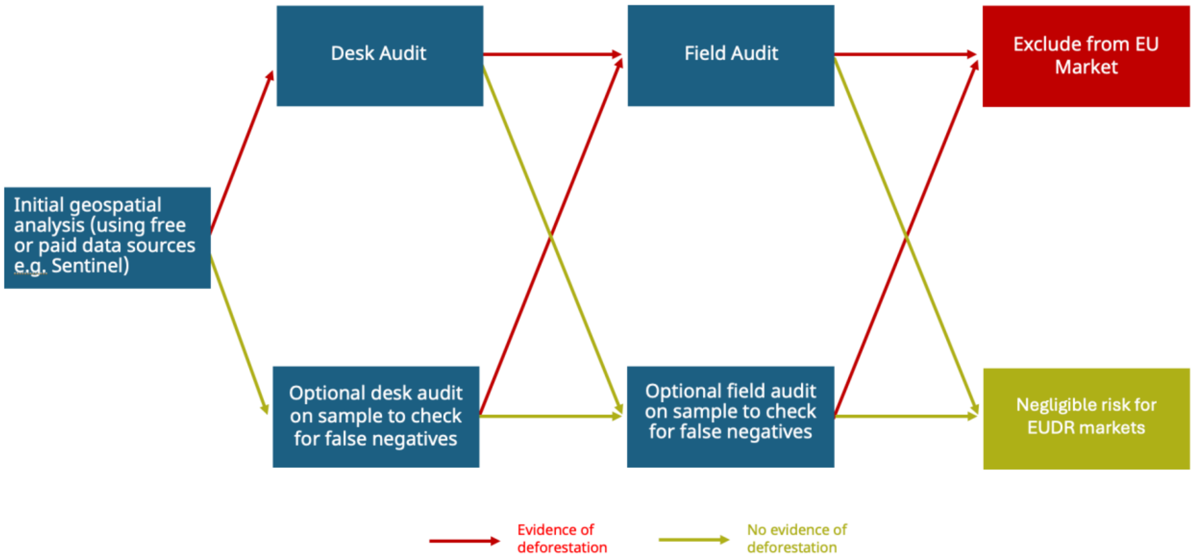
Field Audit Questions

- Ask farmer if they removed any trees from forested areas
- Ask farmer if they pruned crops or trees growing within agricultural plots
- Confirm any recent changes in ownership. If farmer recently sold land, for example, so long as the farmer is no longer producing on that land, they should not be negatively affected if the new owner deforests some of that land.
- Document with photos/videos presence or absence of disturbance in location where disturbance detected. Photograph to north, south, east, west and towards canopy. Are there any breaks in canopy or clearings on forest floor? Measure the diameter of the trees growing there.

Risk-Based Ground Truthing

Fairtrade is adopting a workflow that helps farmers identify the root cause of any deforestation alerts. These causes could include poor quality satellite imagery or the farm being incorrectly mapped so that a nearby violation is wrongly interpreted as on-farm deforestation. Introducing this step and engaging farmers and their organizations before conducting ground-truthing reduces the need to go to the plot to collect ground-truthed evidence. Nevertheless, ground truthing may be necessary to refute potential false positives and avoid unjustifiably excluding producers from EU markets based on false remote sensing results.

The following is a sample workflow that organizations along the supply chain might use to determine when and how to ground-truth:



Operators and/or their upstream suppliers will likely need to verify all detected risks (namely found through remote sensing) using additional analysis (namely through desk and field audits). Even where remote sensing has not detected any deforestation, ground truthing can still strengthen an operator's due diligence process, which is why optional desk and field audits are suggested. The sampling for optional audits on plots where no deforestation was detected could be based on the risk category of the country of production and the quality of remote sensing data used as depicted below:

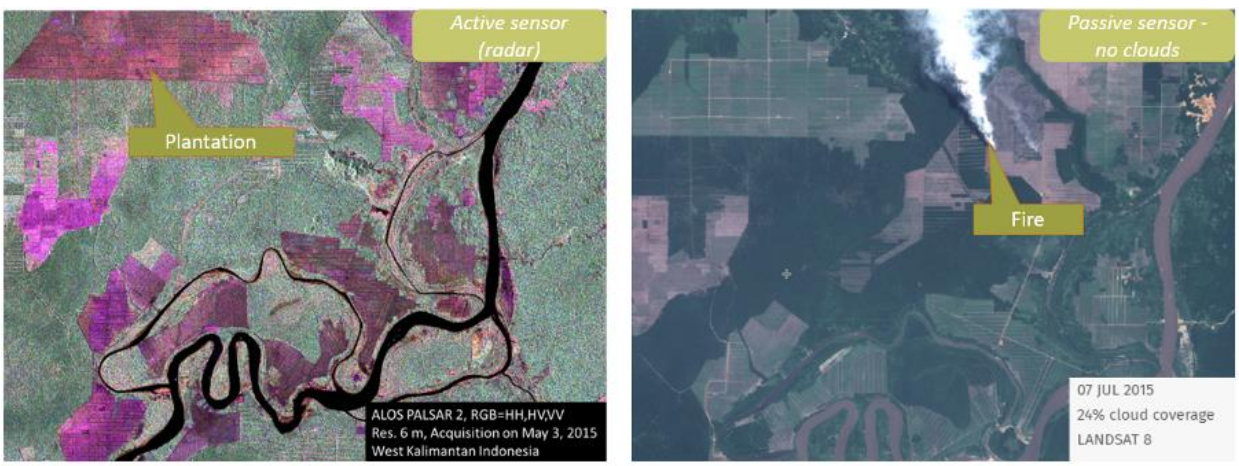
Risk of False Negatives.	**Ground Truthing**
Low risk, either because very credible remote sensing (high spatial and temporal resolution) and/or because there are very low regional risks	Little or none (e.g. just spot audits)
Medium risk, e.g. some deforestation known to occur in region and reasonable remote sensing employed (e.g. 10m resolution)	Some (e.g. square root or representative, spread over a 3-year audit cycle, assuming the supplier base is relatively consistent)
High risk, due to high regional risk of deforestation coupled with unreliable or nonexistent remote sensing	Initially a census, with additional checks after the first year (e.g. square root or representative). If the supplier base is relatively consistent, this could be spread over 3-year audit cycle

Annexes

Annex 1: Summary of Characteristics of Optical and Radar Data

Integrated analysis involves combining information from both radar and optical data sources to capitalize on their complementary strengths. Their fusion can enhance the accuracy of land cover classification, change detection, and monitoring applications, helping to overcome limitations in deforestation monitoring. Optical data is effective for visual identification of deforested areas and specialized analyses using the invisible infrared spectrum, while radar data provides insights into structural changes and is less affected by cloud cover.

Example of an Oil Palm Plantation – Radar vs Optical Sensors



https://www.eorc.jaxa.jp/SAFE/prototyping/lineup/idn/201512/index.html

Landsat via GFW

	Optical Data	Radar Data
Technology	Capture data in the visible, near-infrared, and sometimes shortwave infrared portions of the electromagnetic spectrum. Rely on sunlight reflection. Are sensitive to the color and reflectance properties of surfaces.	Operate in the microwave portion of the electromagnetic spectrum. Emit microwaves and measure the backscattered signals.
Penetration through Clouds	Sensitive to cloud cover. Performance can be hindered in cloudy conditions.	Capable of penetrating through clouds, making them advantageous for monitoring regions with frequent cloud cover.
Penetration through Canopy	Face challenges in areas with dense canopies, as they rely on the reflection of sunlight, which may not reach the forest floor.	Can penetrate through forest canopies, providing information about forest structure and ground conditions even in areas with dense vegetation.
Day/Night and All-Weather Capability	Require sunlight for illumination, limiting their effectiveness to daytime observations.	Operate day and night, providing data in all weather conditions.

	Optical Data	Radar Data
Spatial Resolution	Typically offer higher spatial resolution, allowing for detailed mapping of features on the Earth's surface, such as individual trees or small clearings.	Spatial resolution can vary, but it is often coarser than optical data. However, newer radar satellites provide higher spatial resolution.
Deforestation Monitoring	Effective for visual identification of deforested areas, changes in land cover, and mapping land-use changes. Bands in the infrared-spectrum especially can provide more land cover detail detectable by machine-learning. Vegetation indices help to identify deforestation and degradation.	Can detect changes in the structure of vegetation, making them suitable for identifying deforestation, clear-cutting, and logging activities even in cloudy regions.
Vegetation Structure and Biomass Estimation	Can assess vegetation health, identify species, and monitor changes in color and leaf cover.	Penetrate through the forest canopy, allowing for the assessment of forest structure, biomass estimation, and detection of changes in terrain beneath the vegetation.
Sensitivity to Surface Roughness	Sensitive to surface roughness and may encounter challenges in areas with dense vegetation.	Less affected by surface roughness, however radar d has challenges in steep terra (layover, foreshortening, shadow) and surface roughness is a key determin of radar backscatter (depending on band wavelength of SAR used).

	Optical Data	Radar Data
Temporal Resolution	Often have high revisit frequencies, providing frequent observations of the same area over time.	Revisit frequency varies, but some newer radar satellites offer more frequent revisits.
Cost	Generally, optical data acquisition and processing are more cost-effective.	Radar data acquisition and processing may involve higher costs depending on the specific satellite and mission.
Interpretability	Visually interpretable, making it more accessible to a wider range of users.	May require expertise in radar remote sensing to interpret due to unique characteristics, such as speckle noise.

Annex 2: Definitions

Remote Sensing

“Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected[10] and emitted radiation at a distance (typically from satellite or aircraft). Special cameras collect remotely sensed images, which help researchers "sense" things about the Earth.” (USGS) Although other sensors that measure water or temperature could also be considered remote sensing, it is the radiation-based remote sensing that is most relevant to deforestation.

Earth Observation

Often used synonymously for remote sensing. Earth observation (EO) refers to the use of remote sensing technologies to monitor land, atmosphere, and marine environments (seas, rivers, lakes). Satellite-based EO relies on satellite-mounted payloads to gather imaging data about the Earth’s characteristics. The images are then processed and analyzed to extract different types of information that can serve a wide range of applications and industries. (EUSPA)

Satellite Imagery

Data collected by sensors on satellite platforms, typically of the earth. Satellite imagery often consists of multiple bands and sensors can be both active and passive. Satellite imagery metadata includes characteristics such as sensor position and pointing geometry, sensor gain and bias, acquisition date and time, and associated data. (ESRI)

GIS

“A geographic information system (GIS) is a system that creates, manages, analyzes, and maps all types of data. GIS connects data to a map, integrating location data (where things are) with all types of descriptive information (what things are like). This provides a foundation for mapping and analysis that is used in science and almost every industry. GIS helps users understand patterns, relationships, and geographic context. The benefits include improved communication and efficiency as well as better management and decision making.” (ESRI)

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[10] In most cases, especially in satellite imagery, “reflected radiation” simply means sunlight reflected from earth’s surface. Few satellite missions emit their own electro-magnetic radiation in the radar spectrum and measure its reflection. Plane and drone-based missions may also employ lasers (LiDAR).

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GPS

Global Positioning System (GPS) refers to a global system of satellites used for determining position, navigation, and time relative to objects on the earth's surface. Orbiting satellites transmit signals that allow a GPS receiver anywhere on earth to calculate its own location through trilateration. Developed and operated by the U.S. government, GPS is used for logistics, mapping, surveying, and other applications that require precise positioning. It is part of the international Global Navigation Satellite Systems (GNSS) constellations spread between several orbital planes. (ESRI)

Polygon

"On a map, a closed shape defined by a connected sequence of x,y coordinate pairs, where the first and last coordinate pair are the same and all other pairs are unique." (ESRI)

Point

"A geometric element defined by a pair of x, y coordinates." (ESRI)

Raster

"In imagery and elevation, a spatial data model organized into a matrix of equally sized cells, or pixels, and arranged in rows and columns, composed of single or multiple bands. Each cell contains a numeric value representing information such as temperature at a particular height or depth, elevation, or image brightness value. The scale can be nominal, ordinal, interval, or ratio. Unlike a vector structure, which stores coordinates explicitly, raster coordinates are contained in the ordering of the matrix. Groups of cells that share the same coordinate value represent the same geographic feature." (ESRI)

Satellite Data Processing – Land Cover Mapping & Change Detection

The processing of satellite data to create land cover products for forest monitoring involves several steps, including data acquisition, pre-processing, image classification, and validation.

Data Acquisition

Satellite data is acquired from Earth observation satellites equipped with sensors that capture information about the Earth´s surface. A list of common satellites and platforms to use for forest monitoring has been provided in Annexes 6 and 7.

Pre-Processing

Raw satellite data undergoes pre-processing to correct for various factors that may affect image quality.

- Radiometric Calibration: Adjusting the sensor data to account for variations in brightness and contrast.
- Geometric Correction: Correcting for distortions caused by factors like sensor position, Earth's rotation, and relief displacement.
- Atmospheric Correction: Compensating for atmospheric effects to enhance the accuracy of land surface reflectance values.

Image Enhancement

Depending on the characteristics of the data and the specific goals of the analysis, image enhancement techniques may be applied. These techniques include histogram equalization, contrast stretching, and sharpening to improve visual interpretation or analysis results.

Image Classification

Image classification is a crucial step where satellite data is categorized into different land cover classes. Supervised or unsupervised classification methods are commonly used:

- Supervised Classification: Involves training a classifier using samples of known land cover types, and then applying this classifier to the image.
- Unsupervised Classification: The algorithm automatically groups pixels into clusters based on statistical properties without prior training.

Land Cover Classes

Classes specific to forest monitoring may include categories such as dense forest, open forest, non-forest, deforested areas, and others depending on the objectives of the monitoring program.

Accuracy Assessment and Validation

The accuracy of land cover maps can vary depending on several factors, including the data sources, classification methods, and the level of detail required. The accuracy of the land cover classification is assessed by comparing the classified results with reference data (ground truth) through validation techniques. This step helps quantify the reliability and precision of the land cover products.

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Post-Classification Processing

Post-classification processing involves refining and cleaning up the initial analysis, such as land cover classification results. This may include removing classification errors, smoothing boundaries between classes, and addressing misclassifications.

Change Detection

Change detection involves comparing products from different time periods to identify areas where change has occurred, such as deforestation or reforestation. This step is crucial for monitoring temporal dynamics in forest cover.

Integration with Ancillary Data

Ancillary data, such as elevation, climate data, or socio-economic information, may be integrated with land cover products to enhance understanding of the factors influencing forest dynamics.

Product Generation and Visualization

Once the final land cover products are generated visualizations such as thematic maps or time series are created to communicate the results effectively. These products can be used for further analysis, reporting, and decision-making.

It's important to note that the specific methods and tools used in each step can vary depending on the satellite data source and the characteristics of the study area. Advances in machine learning and artificial intelligence are also increasingly being integrated into land cover classification processes, providing automated and more accurate results.

Geospatial Data Products for Forest Monitoring

Several geospatial data products are available for forest monitoring, providing information on various aspects of forest cover, health, and dynamics. These products leverage data from satellite imagery, remote sensing technologies, and other geospatial sources.

Forest Cover Change Maps

These maps highlight areas where changes in forest cover have occurred over time. They are essential for monitoring deforestation, reforestation, and other land cover changes that impact forest ecosystems.

Land Cover/Use and Change Maps

These maps categorize the Earth's surface into different classes, including forested areas and other land types. These “stable” maps provide an overview of the distribution of various land cover types using a certain class definition (e.g. FAO forest definition). Additionally, there are maps of “change” that provide forest changes (e.g. deforestation) and related follow up on land cover and land use (e.g. forest-related commodity expansions).

Real-time or near-real-time **deforestation alerts** use satellite data to identify recent deforestation events and notify stakeholders. These alerts enable timely responses to illegal logging or land-use changes.

Biomass and Carbon Density Maps
These maps estimate the amount of biomass and carbon stored in forested areas. These products are valuable for assessing the carbon emissions and sequestration capacity of forests and understanding their role in climate change mitigation.

Canopy Height Models (CHMs)
This model provides information on the height of the forest canopy by helping to assess the vertical structure of the forest. This data is useful for understanding forest structure, biodiversity, and potential timber resources.

Forest Health and Disturbance Maps
These maps indicate areas affected by pests, diseases, or other disturbances to help monitor the health of forests. They can be derived from satellite imagery or other remote sensing data.

Forest Fire Maps
These maps show active forest fires (in near real-time) and burnt areas.

Habitat and Biodiversity Maps
These maps show habitats and biodiversity hotspots within forests. This information is crucial for conservation efforts and the protection of endangered species.

Protected Area Maps
These maps delineate protected areas, help to monitor compliance with conservation regulations, and assess the effectiveness of protected zones in preserving forest ecosystems.

Annex 3: Benefits and Limitations of Remote Sensing for Forest Monitoring - Summary

Benefits

- Remote sensing enables monitoring of vast and remote forested areas on a large scale, providing a comprehensive view of deforestation patterns.
- Satellite imagery allows for timely detection of changes in forest cover, facilitating prompt response and intervention measures.
- Remote sensing is a cost-effective method for monitoring large areas compared to traditional ground-based methods, which can be logistically challenging and expensive.
- Remote sensing may provide more consistent and standardized data collection than other methods, ensuring uniformity in monitoring efforts across different regions and time periods.
- Satellite data can be used for multi-temporal analysis, allowing for the identification of trends and changes over time, such as seasonal variations or long-term deforestation trends.
- Remote sensing data can be processed to provide quantitative information, including deforestation rates, changes in forest structure, and estimates of biomass loss.
- Satellite imagery offers a synoptic view of landscapes, enabling the observation of deforestation patterns at various scales, from individual clear-cut areas to larger forested regions.
- Some remote sensing technologies, such as radar sensors, can operate in all weather conditions, overcoming limitations posed by cloud cover in optical imagery.
- Historical satellite archives allow researchers to analyze deforestation trends over extended periods, providing insights into the long-term impact of human activity on forests.
- Large scale remote sensing can be used for risk estimation, since it provides the bigger picture in relation to the specific farm or field.

Limitations

While remote sensing is a valuable tool for land-cover assessment and forest monitoring, caution is advised. Consistent terminology, clear differentiation between land cover and land use, and recognition of potential limitations in global remote sensing products at the local scale are essential considerations.

- Spatial Resolution: Freely available satellite sensors may have limited spatial resolution, making it challenging to detect small-scale features or changes in forest structure.

- Temporal Resolution: The revisit frequency of satellites might be insufficient for capturing short-term changes or events.
- It can be challenging to correlate remote sensing information with specific commodities due to the lack of complete and accurate crop maps. Organizations like Global Canopy have done some work on this issue https://globalcanopy.org/
- Atmospheric conditions may affect the quality of remote sensing data, particularly in regions prone to frequent cloud cover or atmospheric disturbances, especially in tropical regions.
- Dense forest canopies may hinder the penetration of certain electromagnetic wavelengths, limiting the ability to observe the forest floor or detect certain features within the canopy, such as agroforestry systems.
- Remote sensing may face challenges in accurately identifying tree species, especially in diverse and complex forest ecosystems.
- Non-forest features, such as agricultural areas or urban development, can be mistaken for forested areas in remote sensing analysis, leading to inaccuracies.
- Remote sensing data should ideally be validated with on-the-ground measurements, but obtaining accurate ground truth data across large and remote areas can be logistically challenging.
- The appearance of forests can change significantly across seasons, affecting the interpretation of satellite imagery.
- Monitoring forests in rugged or mountainous terrain may be challenging due to issues such as shadowing and difficulty obtaining clear and comprehensive images.
- Remote sensing may struggle to detect changes in the understory, which is critical for monitoring crops that may be grown under shade (such as coffee and cocoa) and also for understanding ecosystem dynamics
- Acquiring high-quality remote sensing data and technology may involve significant costs, limiting accessibility for some organizations or regions.
- Analyzing large volumes of remote sensing data requires sophisticated processing techniques and errors can be introduced during the data processing pipeline.

Limitations when Identifying Agroforestry Systems

Despite its usefulness, there are limitations associated with using remote sensing data for identifying agroforestry systems.

- Agroforestry systems may exhibit spectral characteristics similar to other land cover types, such as natural forests or mixed land use. This can lead to challenges in accurately distinguishing agroforestry systems from surrounding environments.
- Lower spatial resolution imagery may struggle to capture small-scale agroforestry practices or distinguish individual trees within a complex landscape.

- Limited revisit times of satellites and cloud-coverage obstacles may result in gaps in temporal information, making it challenging to capture short-term changes or dynamic processes within agroforestry systems.
- Agroforestry systems that involve a mix of trees, crops, and other elements may pose challenges in classifying land cover due to the "mixed pixel" problem, where a single pixel encompasses multiple land cover types.
- Remote sensing data (namely that using optical spectra) may provide limited information on the of vegetation, making it challenging to characterize the three-dimensional arrangement of trees in agroforestry systems.

To overcome these limitations, a multi-sensor, multi-scale approach combined with integrating ground-based observations and field surveys, can enhance the accuracy and reliability of agroforestry system identification using remote sensing data.

Despite these limitations, remote sensing remains a valuable and indispensable tool for large-scale forest monitoring, offering insights into forest dynamics and changes over time. Integrating remote sensing with ground-based data and other technologies can help overcome some of these challenges and enhance the accuracy of forest assessments.

Annex 4: Vector and Raster Data

Spatial information may consist of either vector data or raster data. Vector data are the location information about a place (e.g. a plot of land). They may either be a single point with x- and y-coordinates or a polygon (e.g. a square with 4 corners designated by 4 coordinates). These can be elicited in the field through GPS which is nowadays present in virtually every smartphone and does not require an internet connection.

Raster data include images, either taken from satellites or occasionally from other flying platforms such as planes or drones, or other data, such as topography, or crop(s) contained in a specific pixel. Global satellite imagery has been available since the 1980s with the Landsat missions (freely available since 2008), and accessibility and quality has been further improved with the Sentinel missions. In Geographical Information System (GIS) software, vector data and raster data can be brought together and used for a variety of analyses.

In the case of EUDR compliance, satellite images captured at different periods of time for a given location can be analyzed with well-established algorithms to detect deforestation or other land cover changes. In GIS software, overlaying the vector data of farming plots, enables companies, NGOs and authorities, to pinpoint where production areas and forests overlap and present a deforestation risk. Spatial data allow for systematic risk assessments. Companies can use these data to assess the risk of deforestation associated with specific suppliers, ensuring that the raw materials in their supply chain are sourced deforestation-free.

Satellite-based forest monitoring enhances the effectiveness of traceability systems by providing timely, accurate, and objective information about deforestation and other land-use changes. It plays a crucial role in the establishment and maintenance of traceability systems for EUDR compliance because it enables real-time or near-real-time detection as well as historical accounts of deforestation. Satellite data can even notify authorities, NGOs, or companies so they can take immediate action to stop deforestation based on real-time alerts.

Annex 5: Spectral Resolution

Spectral resolution refers to the ability of the sensors on a satellite to capture and distinguish different wavelengths electromagnetic spectra. It is determined by the number and width of “bands” in the electromagnetic spectrum captured. A band refers to the range of reflected wavelengths captured. In common satellite imagery sensors, the blue band captures waves of roughly 450 to 530 nanometers (nm) length, the green band 530 to 590nm, and the red band 640 to 680nm. There are slight variations from sensor to sensor. Additionally, the “panchromatic band” captures roughly the whole range between 450 and 680nm. This band captures vastly more photons and results in a higher spatial resolution. This information may be used later to “pan-sharpen” the red, green and blue bands and enhance their spatial resolution.

- **Low spectral resolution:** Usually consists of no more than 5 bands, commonly the wide panchromatic band, the visible blue, green and red bands, and one near-infrared band.
- **Medium spectral resolution:** Usually consists of the 5 bands mentioned above, plus additional bands in the near- and shortwave-infrared portions of the spectrum (between 8 and 12 bands total). These additional bands are highly useful in analyses related to vegetation, water, and fire.
- **High spectral resolution:** More than 12 bands. So-called “hyperspectral” sensors can register hundreds of bands, each covering a very small wavelength range. Such sensors are rare and the amount of data they produce is too large to handle for practical everyday purposes like large-scale deforestation monitoring. With technology advancing, however, they may become more common in the future. Currently, WorldView-3 has one of the highest spectral resolutions with 29 bands (called “super-spectral”).

Annex 6: Summary of Spatial and Spectral Resolution by Sensor

Different sensors may be better suited for specific forest monitoring applications. For example, sensors with high spatial resolution may be preferred for mapping forest cover changes, while sensors with specific spectral bands may be valuable for monitoring vegetation health. The choice of which sensor to use for forest monitoring depends on the specific objectives of the monitoring task, the spatial and spectral requirements, and the environmental conditions of the forested area. Additional crucial considerations include cost and ease of access. Integrating data from multiple sensors or platforms can often provide a more comprehensive understanding of forest dynamics.

The order of the table below is arbitrary and is NOT intended to rank the data produced by the sensors from best to worse.

Sensor	Cost	Temporal Resolution	# Spectral Bands	Spatial Resolution	Key Applications
Optical data					
Sentinel 2	free	5 days (continuous)	13	10m (Visible Near Infrared) 20m (red-edge bands), 60m (Short Wave Infrared).	Monitoring forest health, land cover changes, and deforestation.
Landsat 8 & 9	free	8 days (continuous)	11	30m (Operational Land Imager), 100m (Thermal Infrared Sensor).	Monitoring land cover changes, including deforestation and forest degradation.
MODIS	free	1 day (continuous)	36	250 – 1000m	Large-scale monitoring of global vegetation, including forests, and provides data for assessing forest dynamics.

Sensor	Cost	Temporal Resolution	# Spectral Bands	Spatial Resolution	Key Applications
VIIRS	free	1 day (continuous)	22	375 – 750m	
NICFI (Planet)	free in the tropics	1 day (continuous)	8	3-5m	Program sponsored by Norway for making high-resolution planet-imagery (see next row) of the tropics freely available for non-commercial use.
Planet	1.80 USD per sqkm, min. 250 sqkm	1 day (tasked & continuous)	8	0.5 – 5m, depending on product	
WorldView-3	19 to 44 USD per sqkm	Between 1 and 4.5 days (tasked)	29 bands	0.31m	Offers very high-resolution imagery suitable for detailed forest mapping and monitoring.
GeoEye-1	14 to 29.50 USD per sqkm	Between 1.7 and 4.6 days (tasked)	5 (Pan, RGB, Near Infrared)	0.41m	
Pleiades	12.50 to 32.50 USD per sqkm	0.5 days (tasked)	5 (Pan, RGB, NIR)	0.5m	
SPOT	4.75 to 5.75 USD per sqkm	1-3 days (tasked)	5 (Pan, RGB, NIR)	1.5m	

Sensor	Cost	Temporal Resolution	# Spectral Bands	Spatial Resolution	Key Applications
Radar data					
Sentinel-1	free	5 days (continuous)	Only Radar (C-SAR)	5 – 40m	Monitoring forest structure, biomass, and changes, as it can penetrate cloud cover and operate day and night.
TerraSAR-X		2.5 days (tasked)		1 – 18m	Synthetic Aperture Radar data for forest monitoring, including assessments of biomass and changes in forest structure.

Annex 7: Satellite Imagery Platforms

	Description	Data examples
Google Earth Engine[11]	A cloud-based platform developed by Google that enables users to analyze and visualize satellite imagery and other geospatial data. It provides a vast and continuously updated archive of satellite data.	A cloud-based platform developed by Google that enables users to analyze and visualize satellite imagery and other geospatial data. It provides a vast and continuously updated archive of satellite data.
FarmVibes.AI[12]	Opensourced, satellite analytics platform with relevant workflows like land degradation, deforestation, index mapping and field boundary segmentation etc. that can be run off the notebooks. Also has the efficient cloud-free image generation capability. Helps structuring the data for consumption and analysis.	Tool provides access to various sources of satellite and other data.
USGS EarthExplorer: https://earthexplorer.usgs.gov/	Longest record of collecting free GIS data (satellite images, aerial, and UAV). Optical and radar data, weather satellite photos, and digital elevation maps.	Landsat, Sentinel, IKONOS-2, OrbView-3, historical SPOT data, Terra and Aqua MODIS, ASTER, VIIRS.

[11] https://developers.google.com/earth-engine/datasets/catalog

[12] https://microsoft.github.io/farmvibes-ai/docfiles/markdown/NOTEBOOK_LIST.html

EOSDA LandViewer https://eos.com/products/landviewer/	GIS database with an easy-to-master interface free access to the most widely used open-data satellite images, offers free previews of high-resolution satellite imagery.	Most recent free satellite images from Landsat 7, Landsat 8, Sentinel-1, Sentinel-2, CBERS-4, MODIS, aerial data from NAIP, or historical satellite imagery from Landsat 4 and Landsat 5.
Copernicus Data Space Ecosystem https://dataspace.copernicus.eu/	Access to all free Copernicus data and services, including data from Sentinel satellites, along with new visualization and processing tools.	Satellite images from all active Sentinels: radar data from Sentinel-1, optical multispectral data from Sentinel-2, land products for environmental monitoring from Sentinel-3, and atmosphere and air quality data from Sentinel-5P.
Sentinel Hub https://apps.sentinel-hub.com/eo-browser/	Free access to a wide range of open-source satellite imagery data via EO Browser and Sentinel Playground.	Complete archives of all the Sentinel missions, Landsat 5-8, MODIS, Envisat Meris, Proba-V, and GIBS. Sentinel Playground, in turn, contains a satellite imagery mosaic of the globe derived from Sentinel-2, Landsat 8, MODIS, or DEM.

INPE Image Catalog http://www.dgi.inpe.br/catalogo/	The National Institute for Space Research (INPE) in Brazil maintains an online catalog of both current and historical satellite imagery. The catalog includes nearly 20 collections of free satellite data specifically curated for applications such as land cover assessment, vegetation monitoring, water resource analysis, and meteorological observations. Notably, the INPE Image Catalog serves as a primary source for free satellite imagery, particularly focusing on mapping South and Central America as well as Africa.	The service includes satellite data derived from the collaborative mission between Brazil and China, CBERS-4, as well as Earth-observing missions from the United States, United Kingdom, and India. These missions encompass Aqua, Terra, Landsat-8, ResourceSat, Suomi-NPP, DEIMOS, and UK-DMC 2. While their catalog may appear somewhat dated, users can also access additional free GIS datasets from CBERS-2, Landsat 1-3, 5, and 7 satellites within the platform.
Planet Explorer	Planet Labs operates a fleet of small satellites and offers the Planet Explorer platform, allowing users to explore and analyze high-frequency satellite imagery.	Planet satellites.

Annex 8: Available Data Products

Various datasets and platforms related to forest cover and tree canopy cover exist (see table below), ranging from freely available global and regional datasets to official nationally produced data and private service providers offering customized analyses using proprietary methodologies. There are also research data products providing data on forest-related land use changes and commodity expansion at national and continental scales.

Forest mapping products include tree cover, biomass, canopy height, tree canopy volume, canopy/vegetation health, canopy structure, species identification, land cover/use (change), forest types, and conservation value. They are used for measurement, reporting, and verification purposes in forest information, including carbon estimates, deforestation, and forest degradation. Utilizing multiple temporal results by overlaying satellite images helps identify forest changes over time, such as reforestation, degradation, and deforestation. This data forms the basis of deforestation alert products. Additionally, overlaying these maps with auxiliary data, such as crop, infrastructure, and country statistics, helps pinpoint drivers of deforestation.

Example of Forest Mapping Products

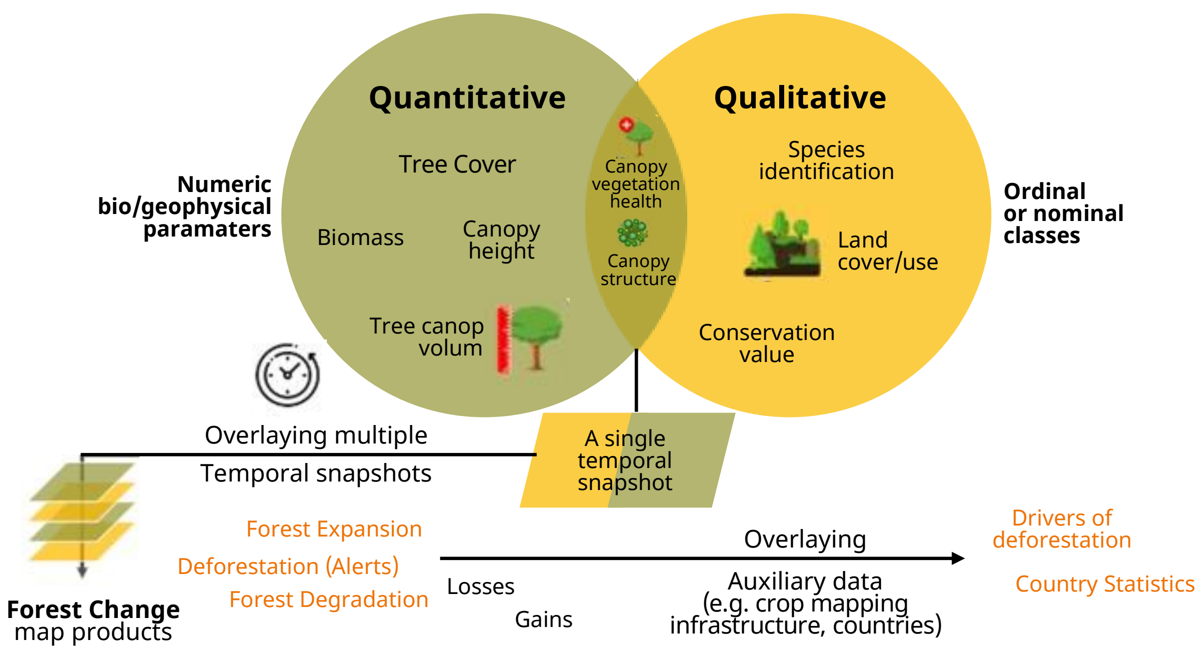

Image by INA/GIZ

Dataset	Provider	Spatial Resolution (m)	Data	Year	Aligned with FAO Definition of Forest
EU Forest Observatory Global Forest cover 2020	JRC	10	forest area	2020	yes
Natural Lands	WRI	30	natural vegetation	2020	yes
Forest/Non-Forest	JAXA	25	forest area	2017-2020	yes
Tropical Moist Forest	JRC	30 (available at 10m for 2022)	forest area	1990-2022	yes
Tree Canopy Cover	GLAD/Hansen	30	% tree cover	2000-2022	needs adjustments
Tree Canopy Height			tree height	2020	needs adjustments
Tropical Tree Cover	WRI	10	% tree cover	2020	needs adjustments
World Cover	ESA-JRC	10	land cover	2020-2021	no
Global Land Cover	Copernicus	100	land cover	2015-2019	no
RADD	Wageningen University	10	deforestation alert	alerts every 14 days	no
GLAD	GLAD/Hansen	30	deforestation alert	alerts every 14 days	no
Integrated Deforestation Alerts (RADD + GLAD + GLAD-S2)	UMD/GLAD and WUR	10	deforestation alert	daily	no

PRODES	INPE	20-30	deforestation	twice a year, since 1988	yes
DETER	INPE	50-60	deforestation alert	near real time monitoring - monthly (to the general public) and daily reports (to the authorities), since 2004	yes
Forest-Related Land Use Change	WUR, GFZ	30	land use/commodity expansion on forest land for Africa (paper / data)	considers forest changes 2000-2020	needs adjustments
Fire Information for Resource Management System (FIRMS)	NASA	375	fire alerts	daily	

Modified based on European Forest Institute (EFI) 2023

Annex 9: Additional Readings and Sources

EUDR FAQs

https://green-business.ec.europa.eu/deforestation-regulation-implementation_en

Detailed Information on EUDR

EFI - 2023: The role of spatial information for EUDR due diligence

EU Commission – 2023: Regulation (EU) 2023 of the European Parliament on deforestation-free products

EU Commission – 2023: FAQ EU Deforestation Regulation

Mapping Geolocations/Field Polygons

Sustain Coffee – 2023: Spatial Data. Quick tips for Coffee Farm Geolocation

ISEAL - 2020: Guidance on the Collection of Polygon Location Data

ISEAL – 2017: Guidelines for the Collection and Management of Location Data in the ISEAL Certification Atlas

Deforestation and Earth Observation

FAO – 2020: Forest Resources Assessment Report | Data Story | Key Findings | Main Report

FAO – 2022: Remote Sensing Survey for FRA 2020 | Pamphlet | Main Report

Swift Geospatial & GIZ – 2021: Forest Monitoring - A Remote Sensing Approach

EU – 2020: Monitoring of Forests through Remote Sensing

SERVIR (USAID & NASA) – 2019: SAR Handbook for Forest Monitoring and Biomass Estimation

WRI – 2023: Global Forest Review

FAO – 2023: How Much Do Large-Scale and Small-Scale Farming Contribute to Deforestation?

Geoinformation

Diamond, L. - 2019: Vector Formats and Sources. *The Geographic Information Science & Technology Body of Knowledge* (4th Quarter 2019 Edition), John P. Wilson (ed.). DOI: 10.22224/gistbok/2019.4.8

GISGeography – 2023: What is GIS? Geographic Information Systems

NASA ARSET - 2022: Fundamentals of Remote Sensing