FOREST MONITORING:

A REMOTE SENSING APPROACH

SWIFT GEOSPATIAL

EXECUTIVE SUMMARY

Forests are crucial components of the Earth's natural system. Forests not only provide the natural processes crucial for maintaining life on Earth, but they also provide essential products and services to support human society. However, forests are under threat from illegal logging, increased forest and agriculture product demand and poor forest management practices, leading to deforestation and forest degradation. Tropical forests encompass nearly 45 percent of the global forest cover. They are under threat, and urgent action is required to curb deforestation and degradation.

The production of high-quality and reliable forest data is crucial to the fight against deforestation and forest degradation. The application of remote sensing technologies to forest monitoring further improves the efficiency and accuracy of forest-related information. This handbook aims to provide a concise introduction to the application of remote sensing for forest monitoring, with a particular focus on the tropics.

This handbook provides a brief but concise introduction to the state of forests, with particular emphasis on the advantages derived from forests in the tropics. The concepts of deforestation and forest degradation are also discussed and compared to support the need for forest monitoring. An examination of existing forest monitoring technologies is provided following a discussion of these forestry concepts.

As a critical tool for producing efficient and accurate forest-related data and information, a brief introduction to remote sensing and its introductions is provided. The basis for remote sensing (the electromagnetic spectrum), the various platforms and sensor types are discussed for readers unfamiliar with the technology.

The handbook then focuses on forest monitoring using remote sensing. The data processing workflow for a forest-related analysis is described from data acquisition to analysis. Three practical examples of remote sensing for forest monitoring are then established for three crops that are drivers of deforestation and forest degradation in the tropics.

CONTENTS

BACKGROUND

Forests cover 31% of the earth's surface and are a critical component to the maintenance of the world's biodiversity. However, forests are not equally geographically distributed. Indeed 45% of the global forest area is in the topics (FAO, 2020).

Tropical forests are closed-canopy forests located between 28° north and south of the equator. These forests are found in Asia, Australia, Africa, South America, Mexico and the Pacific Islands and are typically very wet (200+ cm of rain per year) and warm (25°C-35°C).

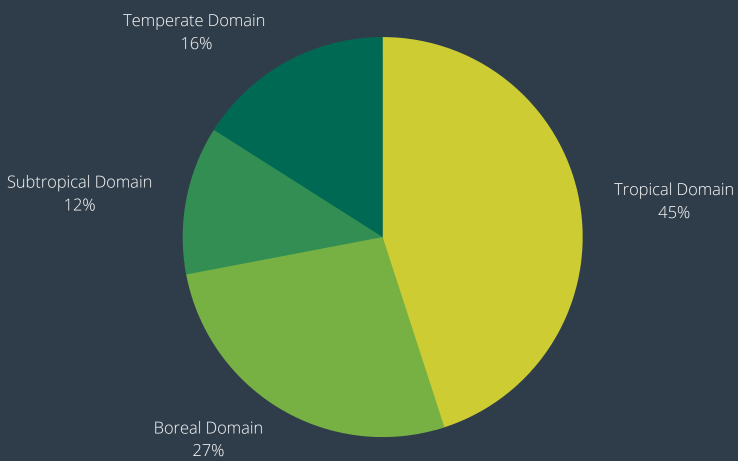


Figure 1: Percentage forest cover per biome

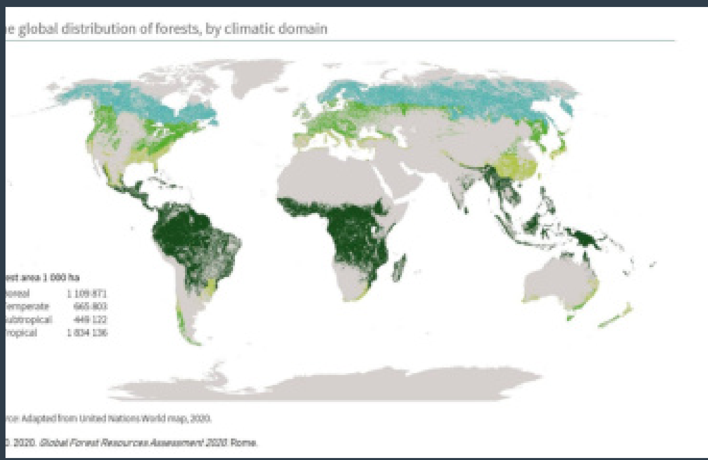


Figure 2: Map of the forest cover by biome

Forests provide ecosystem services that are crucial to maintaining life on earth. By absorbing greenhouse gasses, forests combat climate change by acting as carbon stores. Forests also aid in the filtering of water and protect against erosion. Not only do forests provide habitats to more than half of the world's land-based species, but they also serve as buffers against natural disasters (WWF).

Forests provide over 2 billion people with shelter, water, food, and fuel. Furthermore, forests provide employment and income to millions of people whose livelihoods are dependent on forests and their resources. Many cultures and religions consider forests to be sacred places with specific trees, plants and animals bearing significant meaning. Tropical forest plants also produce compounds crucial to the formulation of life-saving medicines.

Figure 3: The various benefits of forests

STATE OF THE FORESTS

An estimated 178 million hectares of net forest area have been lost since 1990. While the rate of net forest loss was 4.7 million hectares per year between 2010-2020, this rate of loss has decreased markedly than that experienced between 1990-2000 (7.8 million hectares per year) and 2000-2010 (5.2 million hectares per year).

The decreased rate of net loss has been attributed to a reduction in deforestation in certain counties and an increase in forest areas in others through afforestation and natural forest expansion (FAO, 2020).

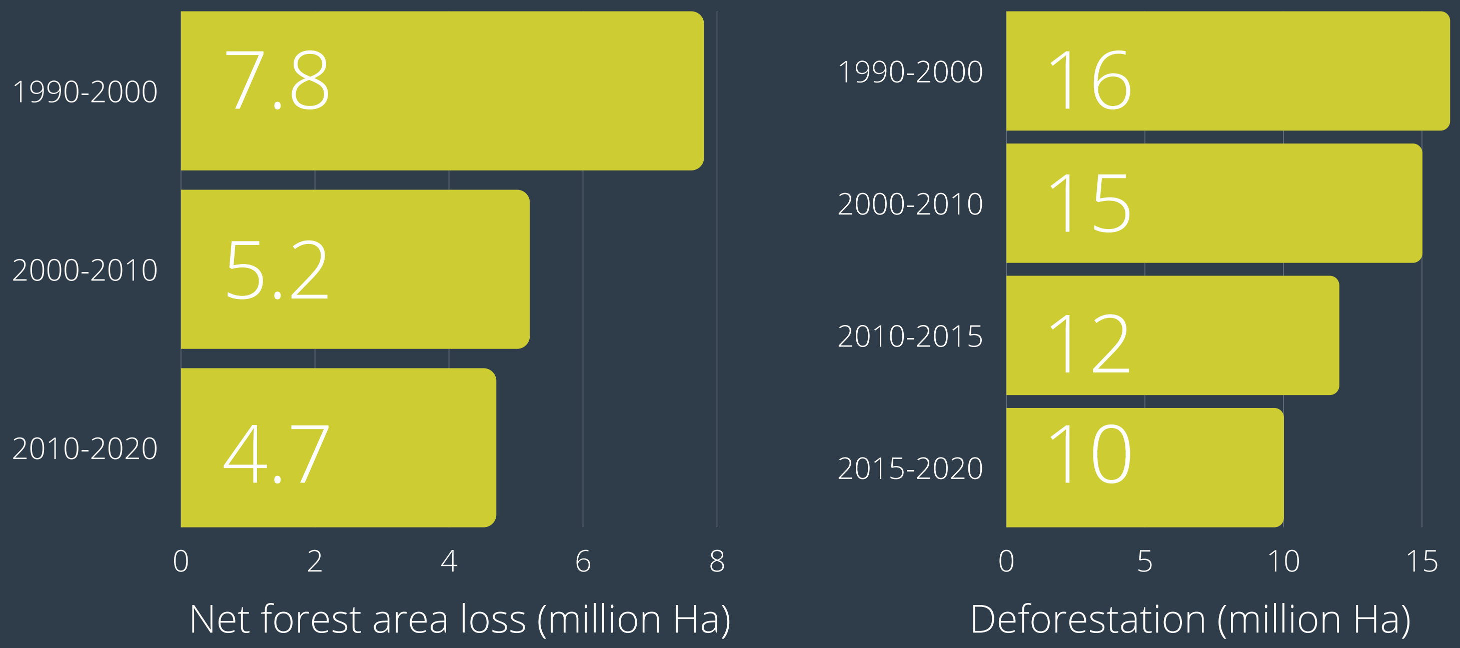


Figure 4: Net Forest loss and deforestation between 1990 and 2020 (FAO)

Deforestation has led to an estimated 420 million hectares of forest loss since 1990. The primary driver of deforestation and forest degradation is agricultural expansion. Large-scale commercial agriculture and local subsistence farming accounted for 40% and 33% of tropical deforestation, respectively (FAO). Much like the rate of net loss, the rate of deforestation has declined significantly.

Between 2010 and 2015, 12 million hectares of forest were lost to deforestation each year. While the rate of deforestation has decreased to 10 million hectares per year between 2015 and 2020, deforestation is still occurring at unsustainable rates, particularly in the tropics.

Deforestation in the tropics is largely attributed to the conversion of previously non-agricultural land to agricultural lands. This agricultural expansion, mainly that of soy, palm oil, beef, paper, coffee, and rubber crops, is responsible for the large-scale clearing of land and degradation of forests. Not only does the loss of forests threaten the overall biodiversity of species, but it also reduces the ability of forests to perform essential environmental services, such as the filtering of air and water, the provision of healthy soils and the regulation of climates. Furthermore, the livelihoods of 1.6 billion individuals worldwide are dependent on forests.

Urgent action is required to curb the extent of deforestation and degradation in the tropics. The production of high-quality and reliable forest data is crucial to the fight against deforestation and forest degradation. The introduction of remote sensing technologies to forest monitoring further improves the efficiency and accuracy of forest-related information.
While many definitions exist for forest monitoring, deforestation, and forest degradation, this handbook utilizes those most applicable to the study of forests and the purposes of this handbook.

Figure 5: Tree loss in a tropical forest by unnatural means

DEFORESTATION

> Deforestation is the conversion of forest to another land use or long-term reduction of tree canopy below the 10% threshold.
>
> — FAO

Essentially deforestation refers to the deliberate removal of forest cover for agricultural or development purposes. It can also be an unintentional consequence of unrestricted grazing and even fires. Deforestation is a permanent conversion of forest to another land use and the removed trees are not expected to regrow. Deforestation results from complex socio-economic processes but has been largely attributed to exploitation activities, such as commercial logging, forest farming, wood gathering for fuel, clearing of pastureland for cattle rearing, urbanization and mining and oil exploitation. Over-exploitation of forests is common in developing countries where high population growth has resulted in an increased need for agriculture.

Figure 6: Clearing of large tracts of previous forest cover for agriculture

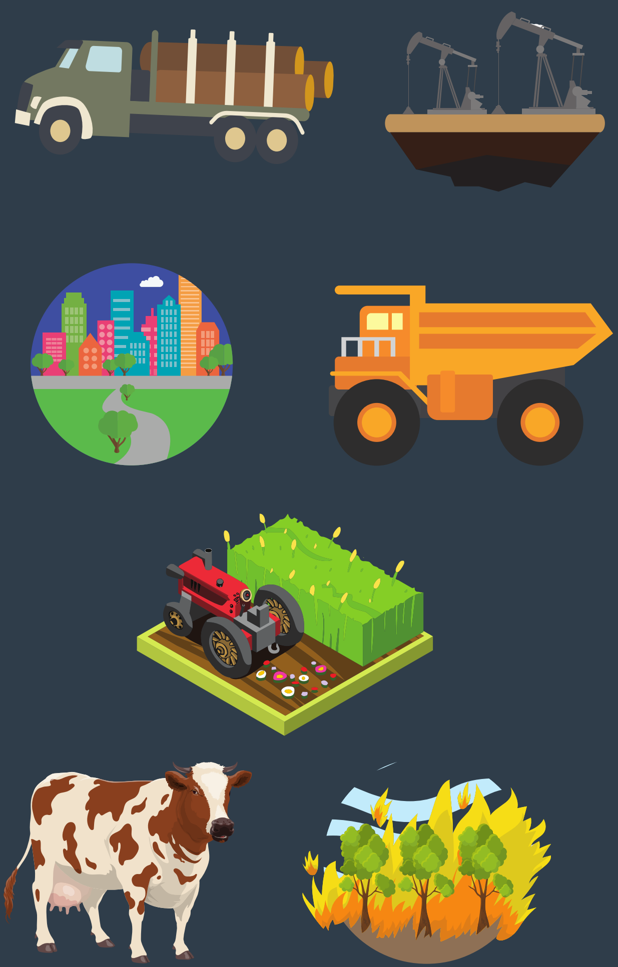


Figure 7: Drivers of deforestation

FOREST DEGRADATION

> "Forest degradation is a process leading to a temporary or permanent deterioration in the density or structure of vegetation cover or its species composition" — FAO

Forest degradation occurs when disturbances result in a change in forest attributes that leads to decreased productive capacity. Essentially, forest degradation is the long-term reduction of forest cover and the supply of forest benefits. Forest degradation can occur over a few years to a few decades (FAO). Forest degradation can be caused by climate change, wherein extreme alterations in temperatures and extended periods of drought create unfavourable environmental conditions for the maintenance of healthy forests. These conditions increase the risk of fires which are major initiators of forest degradation. Pest infestations and diseases can also reduce the quality of biodiversity and food chain relationships due to the loss of certain plants and animals. Forest degradation is further driven by poor agricultural practices, such as overgrazing and shifting agriculture. While these notable drivers of forest degradation, the primary cause of forest degradation in the tropics is unsustainable and illegal logging. The increased demand for cheap lumber, fuel and paper products has led to irresponsible logging practices resulting in bare clearings, spiderweb roads and ravaged vegetation (WWF).

Figure 8: Tree felling

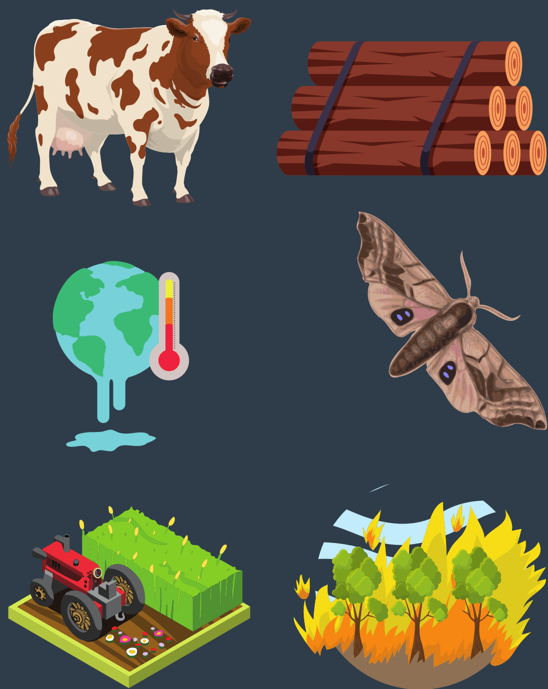


Figure 9: Drivers of forest degradation

DEFORESTATION VERSUS FOREST DEGRADATION

Deforestation and forest degradation are not interchangeable terms. Deforestation refers to the complete removal of trees to convert forest to another land use. The trees are not expected to regrow. On the other hand, Forest degradation refers to the thinning or reduction of the canopy but without a change in land use. This change is temporary, and the forest should regrow (Ritchie and Rozer, 2011).

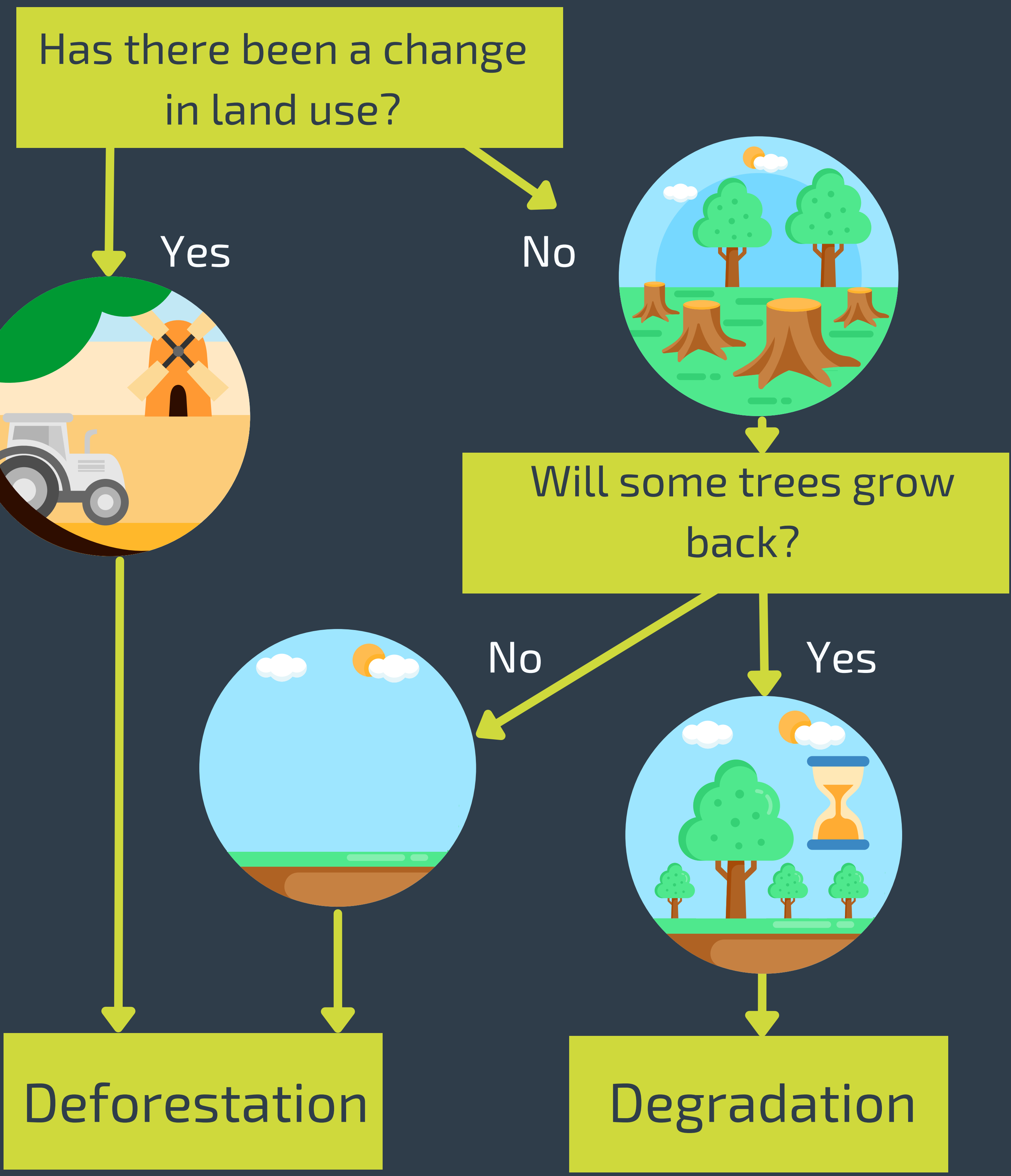
Higher diversity and carbon loss are experienced through deforestation than forest degradation. Although degradation has major impacts on the health of forests (decline in animal populations, death of trees, and increase in CO2), when deforestation occurs, almost all the carbon stored in trees and vegetation is lost (Ritchie and Rozer, 2011).

Deforestation

Forest Degradation

Figure 10: Aerial images of deforestation caused by land use change (top-agriculture conversion; bottom-urbanisation) and forest degradation (top- fire; bottom- tree clearing)

IS IT DEFORESTATION OR FOREST DEGRADATION



FOREST MONITORING

> “Forest monitoring systems include measurement, reporting and verification functions and aim to produce high-quality, reliable data on forests, including forest-carbon estimates, that are critical to the battle against climate change caused by among others deforestation and degradation of forests.” — FAO

Forest monitoring involves the collection of data for use in the protection of forests against deforestation and degradation. Disturbances in forest cover, land cover change, loss of biomass, tree canopy volumes, species identification and even canopy structure and health can provide users with crucial information. This information is necessary for conservation areas where deforestation and degradation are of particular concern.

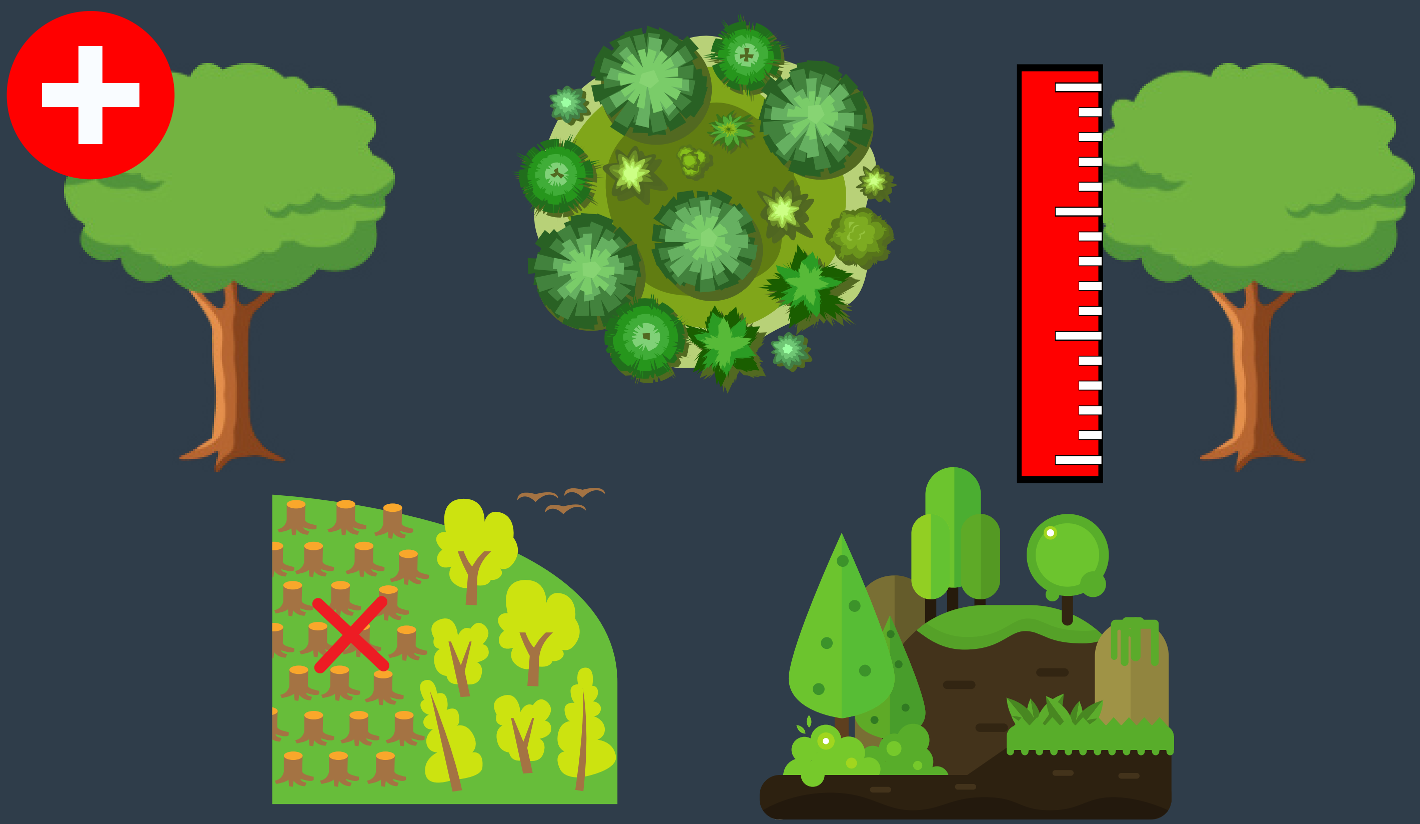


Figure 11: Forest monitoring outputs

REMOTE SENSING

> “Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance, typically from satellite or aircraft.” — USGS

Remote sensing is concerned with obtaining information about an object or land surface through sensors mounted on aerial or satellite platforms. Remote sensing technologies have been applied in numerous fields to derive information and knowledge. The field of remote sensing has continued to develop and will continue to do so.

Remote sensing is applied extensively in environmental studies and has proven particularly useful in the monitoring of forests.

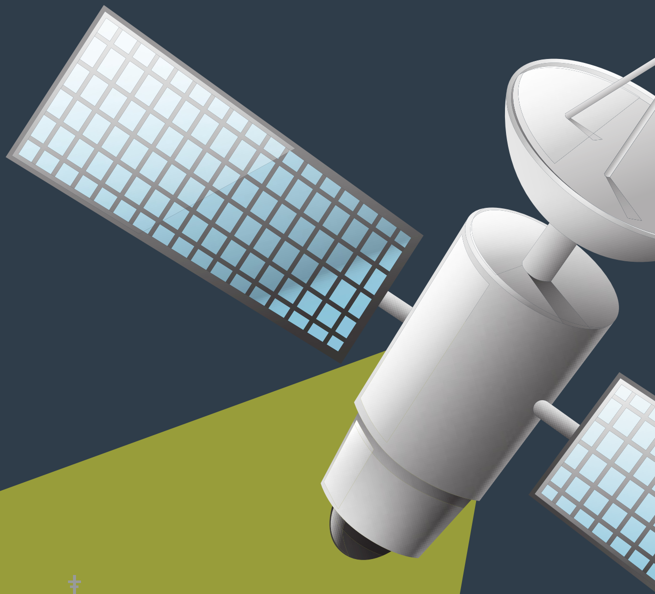


Figure 12: Applications of remote sensing

THE ELECTROMAGNETIC SPECTRUM

The basis for remote sensing is generally accepted to be the electromagnetic spectrum (EMS). The EMS includes all the wavelengths of electromagnetic radiation from gamma rays (high frequency and long wavelength) to radio waves (low frequency and short wavelength). Remote sensing relies on the fundamental physical principle that different targets on the earth's surface will interact with specific wavelengths in the EMS in different ways (Horning, 2019). Indeed, different objects will reflect different amounts of energy in different bands of the EMS, incident upon it. The properties of objects, surface roughness, angle of incidence, intensity, and the wavelength of radiant energy all affect how this energy interacts with the surface and is then reflected (Aggarwal, 2004).

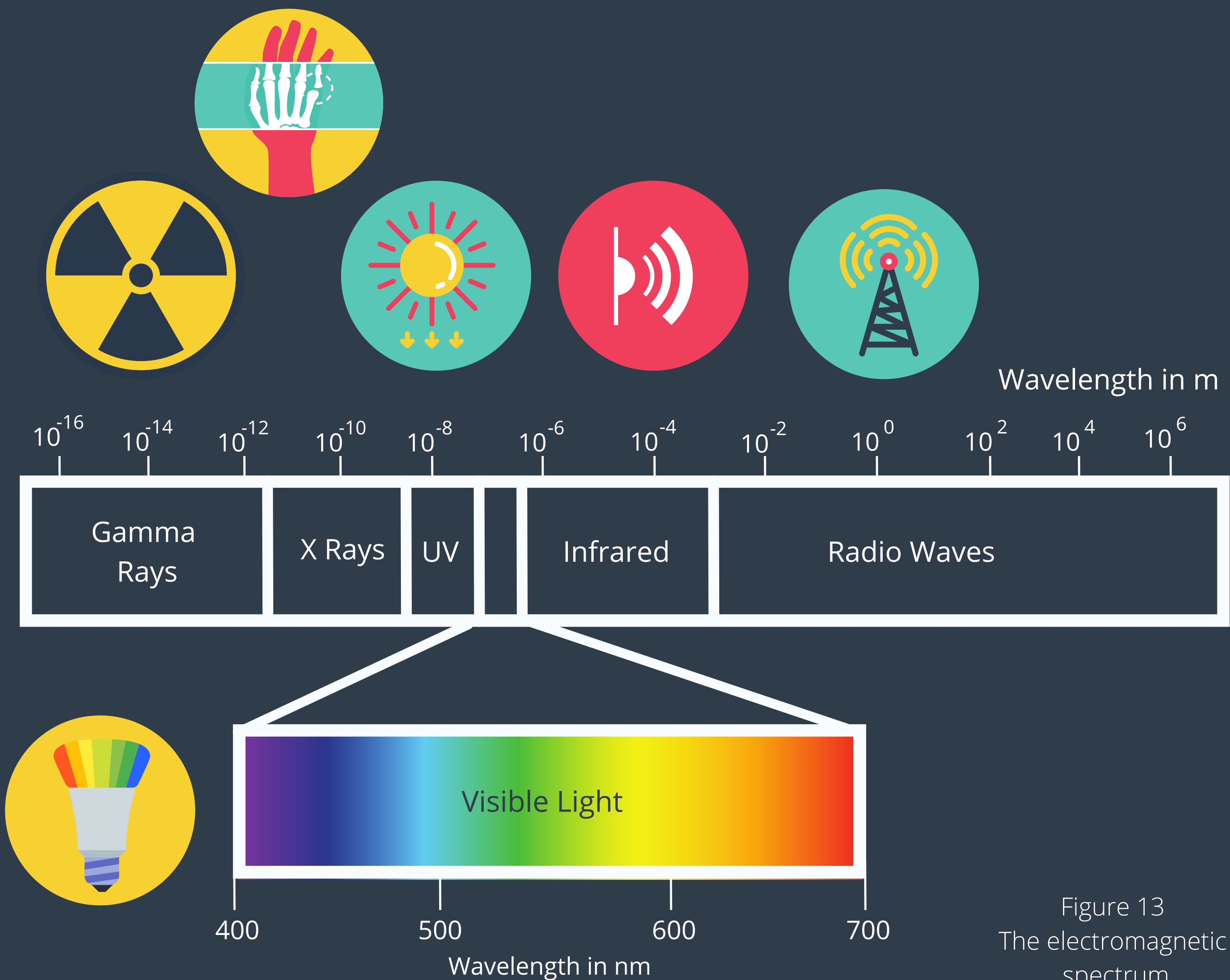


Figure 13
The electromagnetic spectrum

A reflectance spectrum plots the amount of energy reflected from a target in any given wavelength on the EMS, producing essentially a unique signature for that target. A target should be identifiable from its spectral reflectance signature. This spectral signature will vary as different materials reflect and absorb differently at different wavelengths of the EMS.

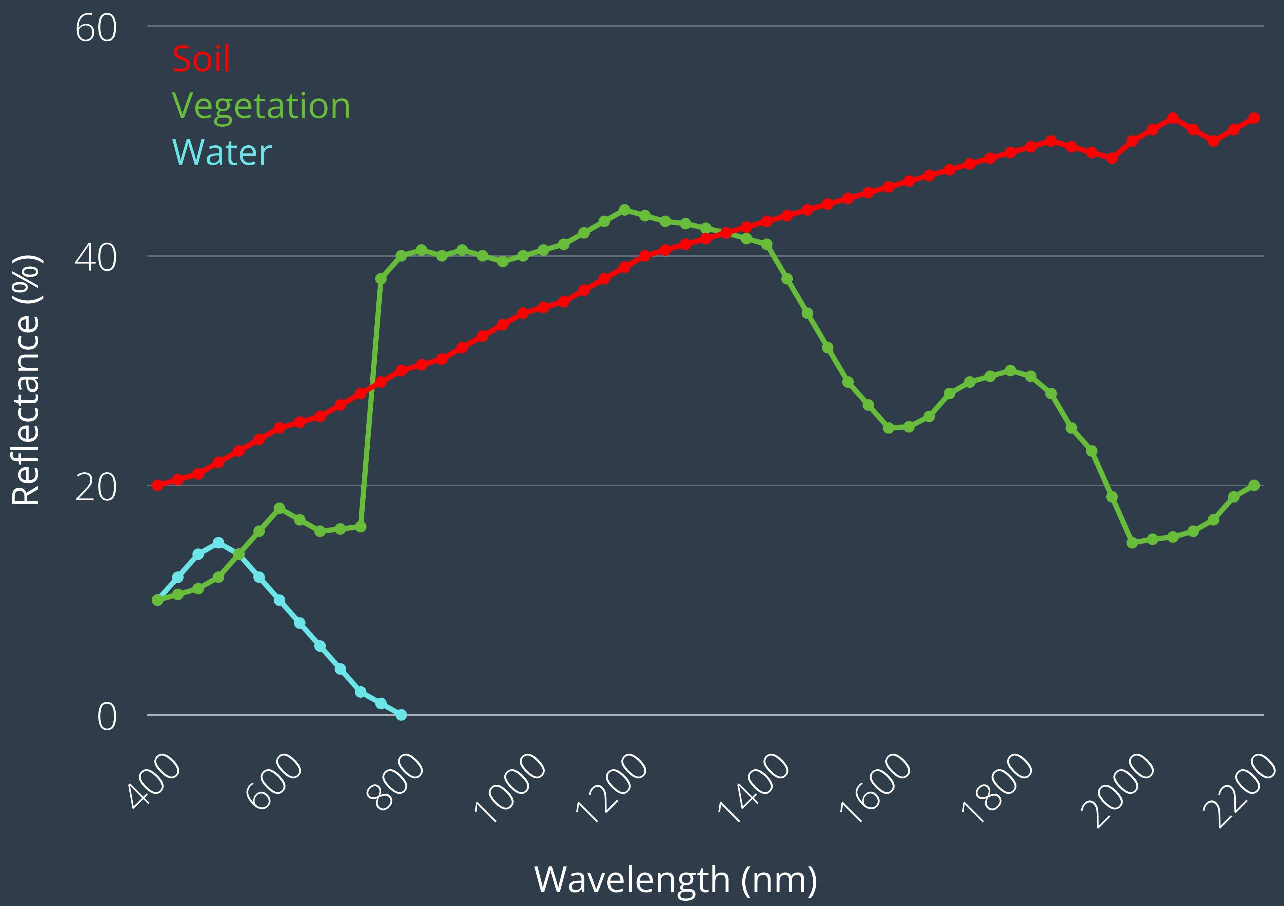


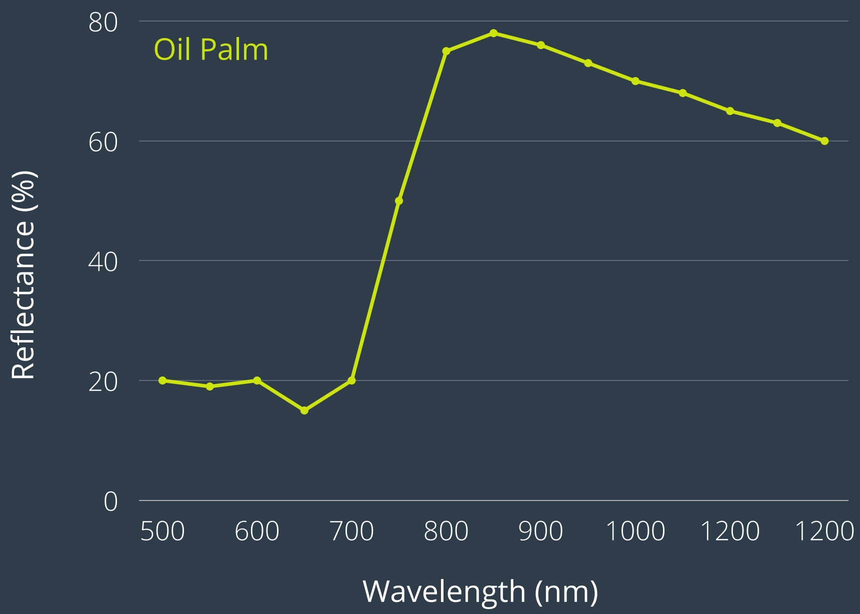
Figure 14: The spectral signatures of soil, vegetation, and water

The reflectance spectrums below show the different spectral signatures for water, soil, and green vegetation. The reflectance of clear water is generally low as it absorbs the majority of the energy incident upon it and, as such, reflectance will decrease as the wavelength increases. Sediment will change the spectral signature of a water body depending on the type of material suspended within it.

The spectral signature of soil will vary depending on its composition. Very little energy can be transmitted through soil or bare ground, so the majority of energy is reflected, resulting in the level of reflectance increasing with wavelength.

The spectral signatures of vegetation are easily discernable from other land cover types. Reflectance is usually low in the blue and red regions of the visible light portion of the EMS and peaks in the green region. This is due to the high amount of energy absorption by chlorophyll during the process of photosynthesis. The cell structure of green vegetation causes an increase of reflection in the near-infrared (NIR) portion of the EMS. Essentially, the spectral signature of green vegetation will display higher reflection in the NIR than the visible portion of the EMS. The shape of the reflectance spectrum aids in the identification of the type of vegetation. These 'shapes' change according to leaf moisture content, physical and chemical compositions, as well as the health of plants (Mohamed et al, 2018).

The spectral signature of a palm oil tree is pictured below with the requisite increase in absorption in the green portions of the EMS. A false colour composite image is created when the display arrangement (RGB) of an image is arbitrarily assigned to highlight certain characteristics of the target surface. The accompanying false colour composite pictured below allows vegetation to be easily detectable in the image. In this false colour composite of an oil palm plantation, trees appear in different shades of red due to the high reflectance in the NIR band (750-1100nm), as indicated in the spectral reflectance signature.



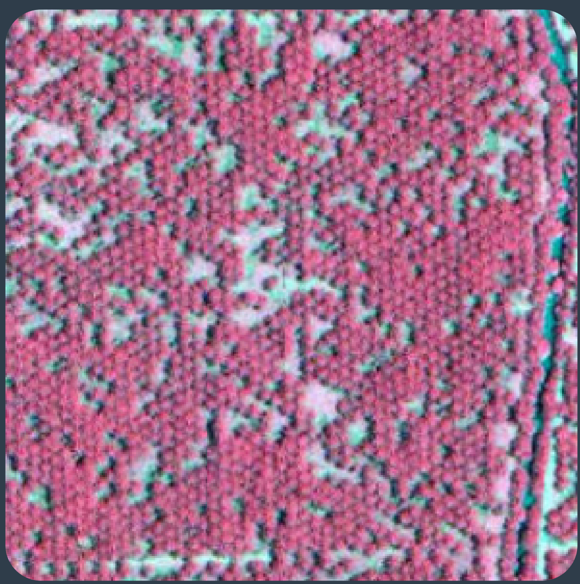


Figure 15: The spectral signatures of oil palm (left) and (right) a false colour composite of an oil palm plantation (Hong & Shukor, 2021)

PLATFORMS AND SENSORS

Remote sensing systems are designed to measure the absorption characteristics of targets across all portions of the EMS. Traditional aerial photography typically works in the visible portion of the electromagnetic spectrum. Remote sensing systems, however, produce digital data in the visible, infrared, and microwave portions of the electromagnetic spectrum with differing spatial, spectral, temporal and radiometric resolutions. Indeed, the visual interpretation of aerial photographs still provides useful information, but remote sensing methods can provide far more in-depth and accurate information. These methods encompass activities such as theoretical modelling of surface properties, spectral measurements of targets, and digital image analysis, among many others (Dong & Chen, 2017).

PLATFORMS

There are three primary structures onto which remote sensing devices are mounted: ground-based, airborne, and satellite.

Handheld devices, tripods, towers, and cranes are all examples of ground-based platforms. Ground-based platforms are usually utilised for the close-range study of objects or the long-term monitoring of atmospheric phenomena and terrestrial features.

Airborne platforms, such as aeroplanes, helicopters, tethered balloons, unmanned aerial aircraft (UAVs), and drones, can collect data over virtually any portion of the Earth's surface at any time but have restricted altitudes. Airborne systems are beneficial in that they can be flown to specific user requirements (time of day, flying direction and spatial resolution), and only the required wavebands are recorded. Airborne systems are, however, more costly than space-borne (satellite) systems as they are generally single-use missions.

In space-born or satellite remote sensing, sensors are mounted on spacecraft that are orbiting the Earth. Despite being extremely costly to build and launch, spaceborne platforms subsequently have relatively low costs per coverage area. These platforms allow sensors to collect data at a frequent or repetitive coverage depending on their orbit parameters (Dong & Chen, 2017).

Figure 16: Various remote sensing platforms

SENSORS

There are two types of main types of remote sensors: active and passive. Passive sensors need an external energy source, which in most cases is the sun. An active sensor has its own source of energy. Both types of sensors measure the transmission of energy from the target in different portions of the electromagnetic (EM) spectrum.

Satellite sensors, regardless of energy source, all collect data as they orbit the Earth. This data can be described according to three types of resolutions: spatial, spectral and temporal. Spatial resolution is the size of the ground area that forms a single pixel in a satellite image. The higher the resolution, the more detailed the collected data is. The spectral resolution indicates the number and width of the spectral bands measured by a sensor. Temporal resolution is the frequency with which a sensor collects data about the same part of the Earth's surface (Dong & Chen, 2017).

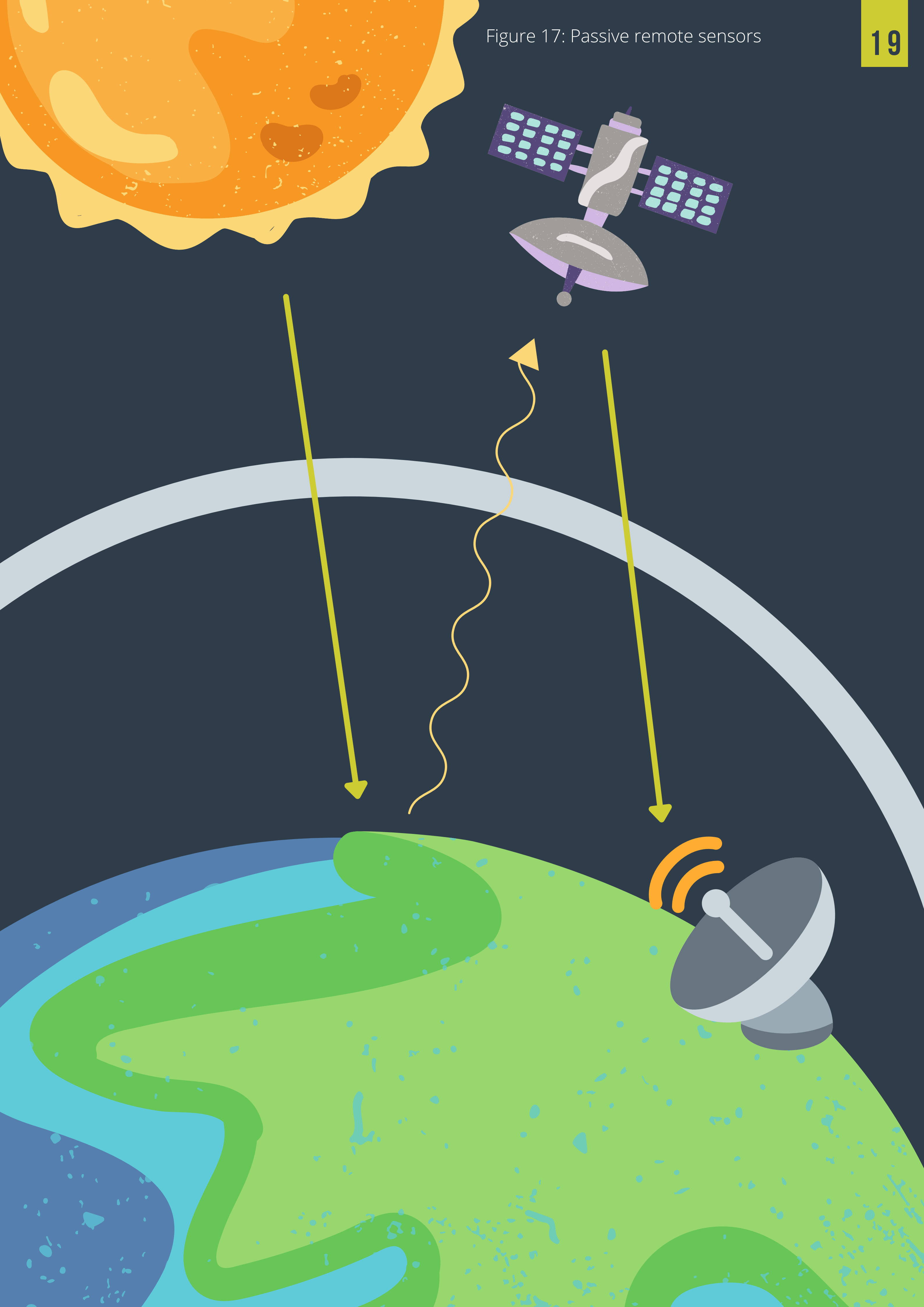
PASSIVE SENSORS

Passive sensors utilise reflected solar radiation in the visible, near-infrared, mid-infrared, and thermal infrared portions of the electromagnetic spectrum (Dong & Chen, 2017).

A passive remote sensor requires an energy source, usually the sun, to illuminate or emit electromagnetic energy to a target on the Earth's surface. This energy travels through the atmosphere to the target, with which it interacts. Several interactions are possible depending on the properties of the target. After this interaction, radiation could be transmitted (passed through the target), absorbed, scattered (deflected in all directions and lost) or reflected. The reflected energy then travels back through the atmosphere to the sensor, where it is recorded and transmitted in a digital form to a receiving and processing station on Earth, where data is processed and stored in a digital format.

Two types of passive remote sensors will be discussed in this handbook: Multispectral and hyperspectral.

Figure 17: Passive remote sensors



MULTISPECTRAL SENSORS

Multispectral sensors collect visible and reflected infrared images by recording the reflection of solar radiation from the target surface using sensors. Thermal infrared images are collected by recording the thermal radiation emitted from the earth.
Multispectral sensors collect a selection of optimal bands depending on the mission requirements. They are not contiguous and typically number from five to ten bands with large bandwidths (70-400nm) (Pettorelli, Safi, and Turner, 2014).

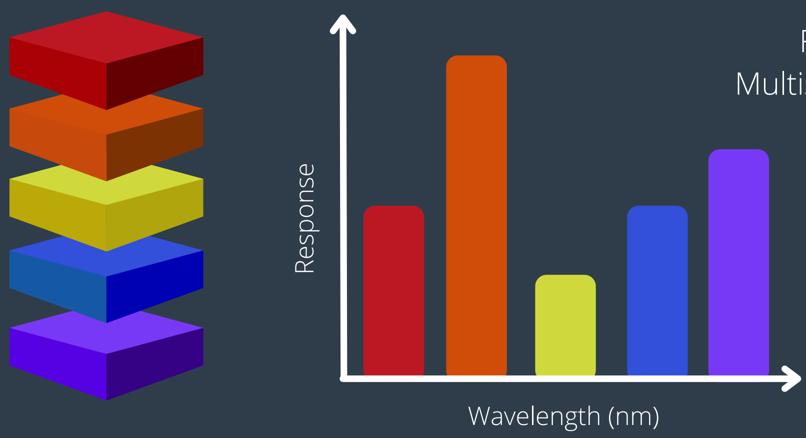


Figure 18:
Multispectral bands

HYPERSPECTRAL SENSORS

Hyperspectral sensors use imaging spectrometers to collect images in far greater and narrower spectral bands than those collected using multispectral sensors.
Hyperspectral sensors produce a complete spectral signature with no omission of any wavelength. Essentially, these sensors measure a continuous spectral range across the electromagnetic spectrum. Hyperspectral sensors typically collect between 100 and 200 very narrow (5-10 nm bandwidth) bands (Pettorelli, Safi, and Turner, 2014).

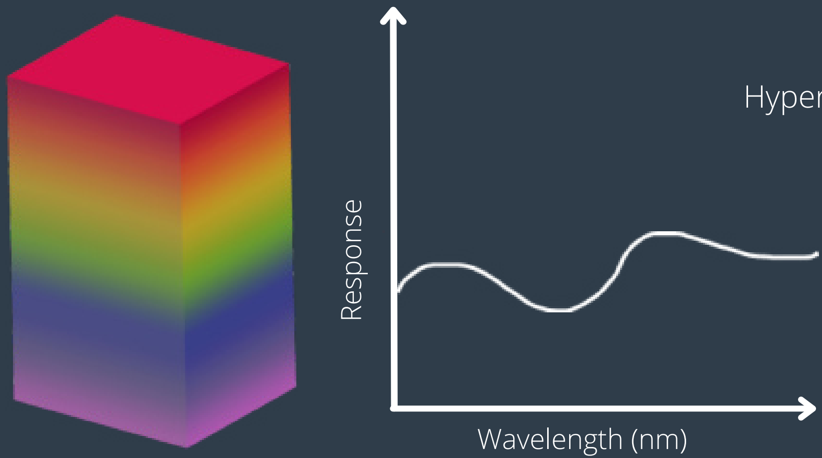


Figure 19:
Hyperspectral continuous bands

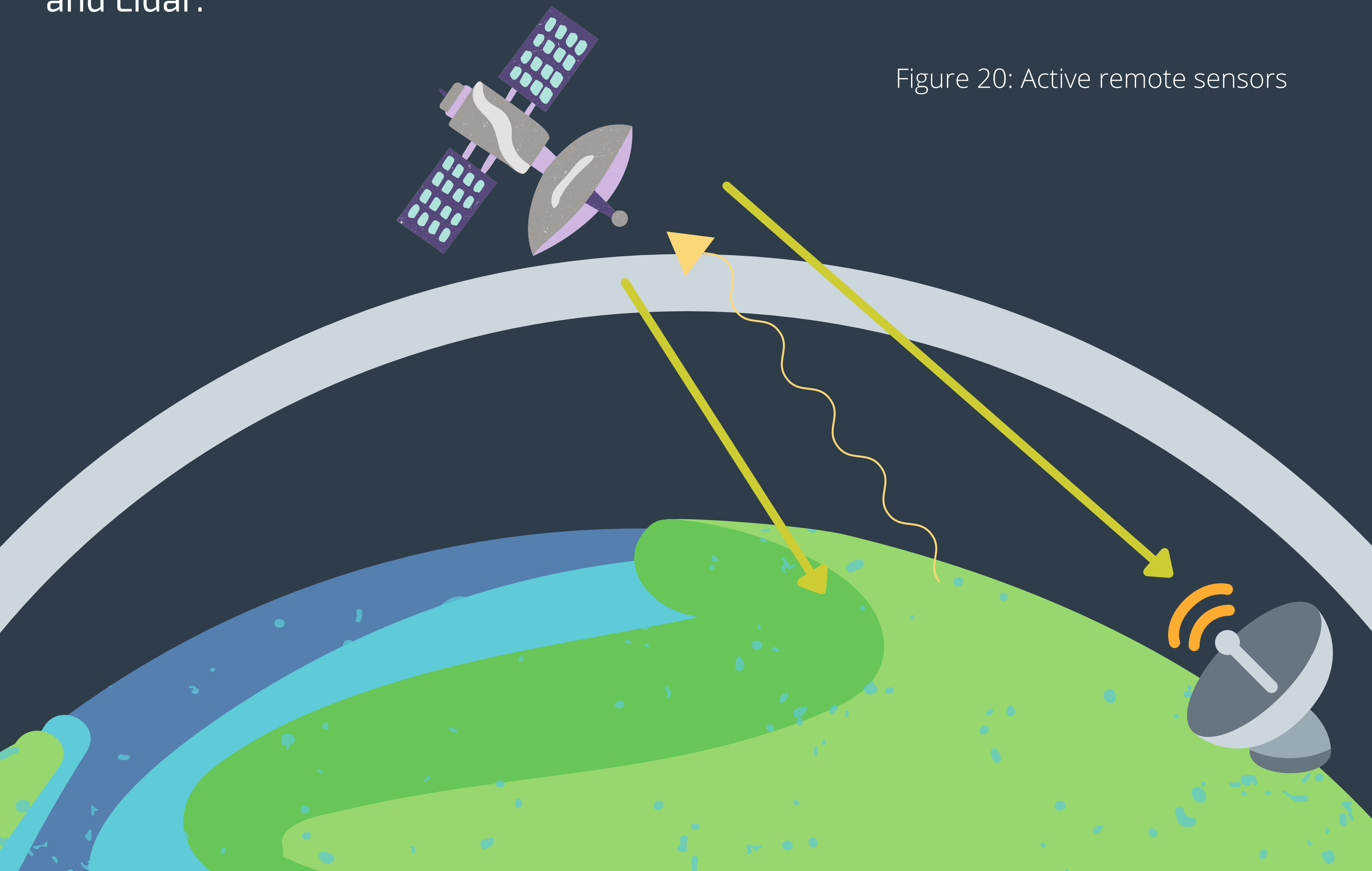
ACTIVE SENSORS

Active sensors emit their own source of radiation toward the target surface and detect radiation that is reflected from the target. As they utilise their own source of energy, active sensors have the advantage of being able to obtain measurements independent of the weather conditions and time of day (Dong & Chen, 2017).

An active remote sensor emits electromagnetic energy to a target on the Earth's surface. This energy travels through the atmosphere to the target, with which it interacts. Several interactions are possible depending on the properties of the target. After this interaction, radiation could be transmitted (passed through the target), absorbed, scattered (deflected in all directions and lost) or reflected. The reflected energy then travels back through the atmosphere to the sensor, where it is recorded and transmitted in a digital form to a receiving and processing station on Earth, where data is processed and stored in a digital format.

Two types of active remote sensors will be discussed in this handbook: Radar and Lidar.

Figure 20: Active remote sensors



RADAR

Radio Detection and Ranging is an active remote sensing system that does not require sunlight, so data can be acquired regardless of weather or time of day, as well as being able to penetrate cloud cover. This type of sensor will emit radio impulses from an antenna, and based on the amount of scattering received back to the sensor and travelling time, the distance to the target can be calculated. The background scatters detected by the sensors can also yield information about the natural surfaces of the Earth. Radar methods are cost-effective and can cover large areas.

Derived from Radar, Synthetic Aperture Radar (SAR) is a technique that creates high-resolution images of the Earth's surface. However, SAR imagery does not look like the optical imagery usually intuitive to humans. SAR imagery is utilised to create Digital surface models, for geological mapping, crop monitoring, forest classification, and importantly, forest monitoring (Le Toan, 2007). There are numerous earth-observing radar satellites in orbit, including Sentinel-1, Envisat, RADARSAT, and ALOS PALSAR.

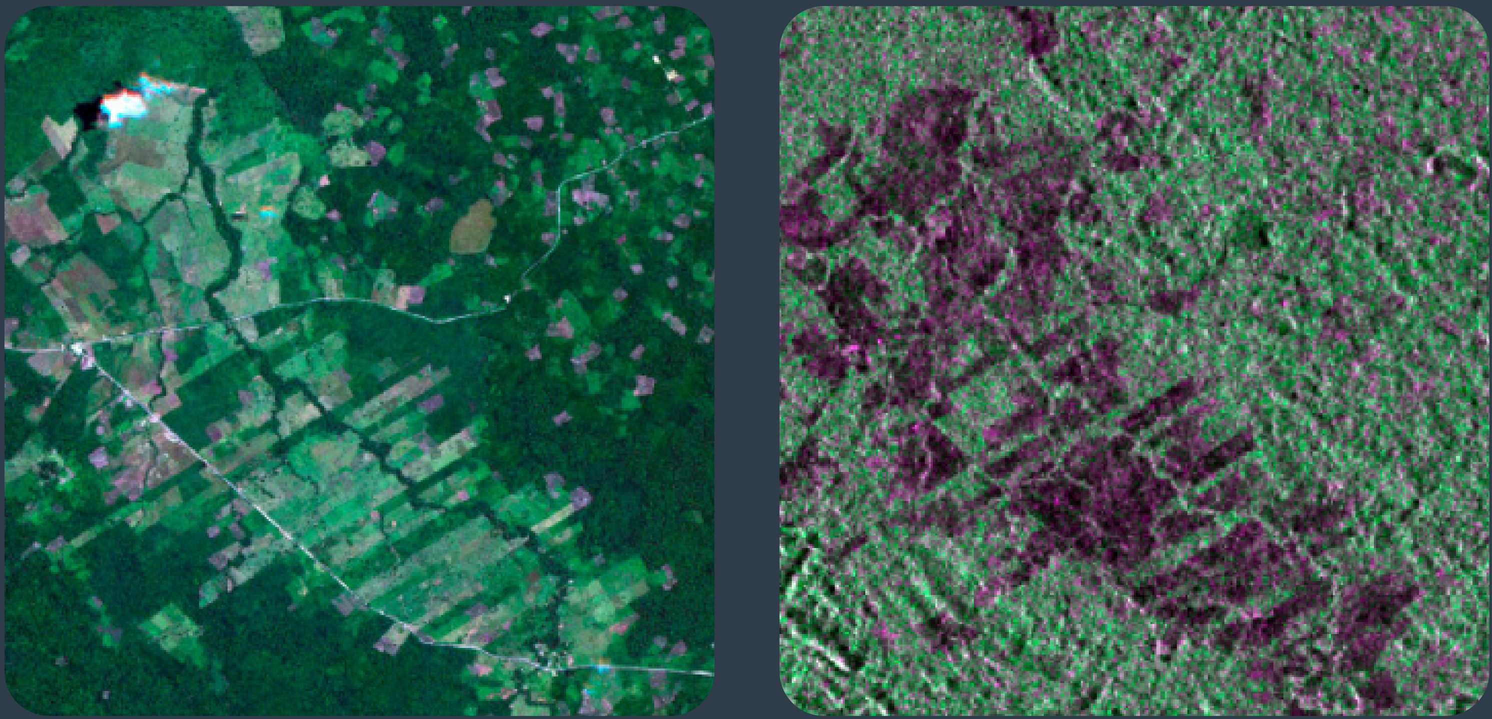


Figure 21: RapidEye true colour composites (left) and ALOS PALSAR image (right) of sub-tropical forest cover in Chiapas Mexico (Sirro et al., 2018)

LIDAR

Light Detection and Ranging is an active remote sensing system that emits laser pulses to measure exact distances of targets from the surface of the Earth. The data collected by these sensors can generate highly accurate three-dimensional information about the earth surface. Lidar is utilised in oceanography to determine ocean depth and to locate targets. Lidar collects data in three dimensions facilitating the creation of digital elevation or terrain models. Lidar is also extremely useful in agriculture for analysing crop yields (Wasser, 2014). There are numerous earth-observing radar satellites in orbit, including CALIPSO, GEDI and Sentinel-3.

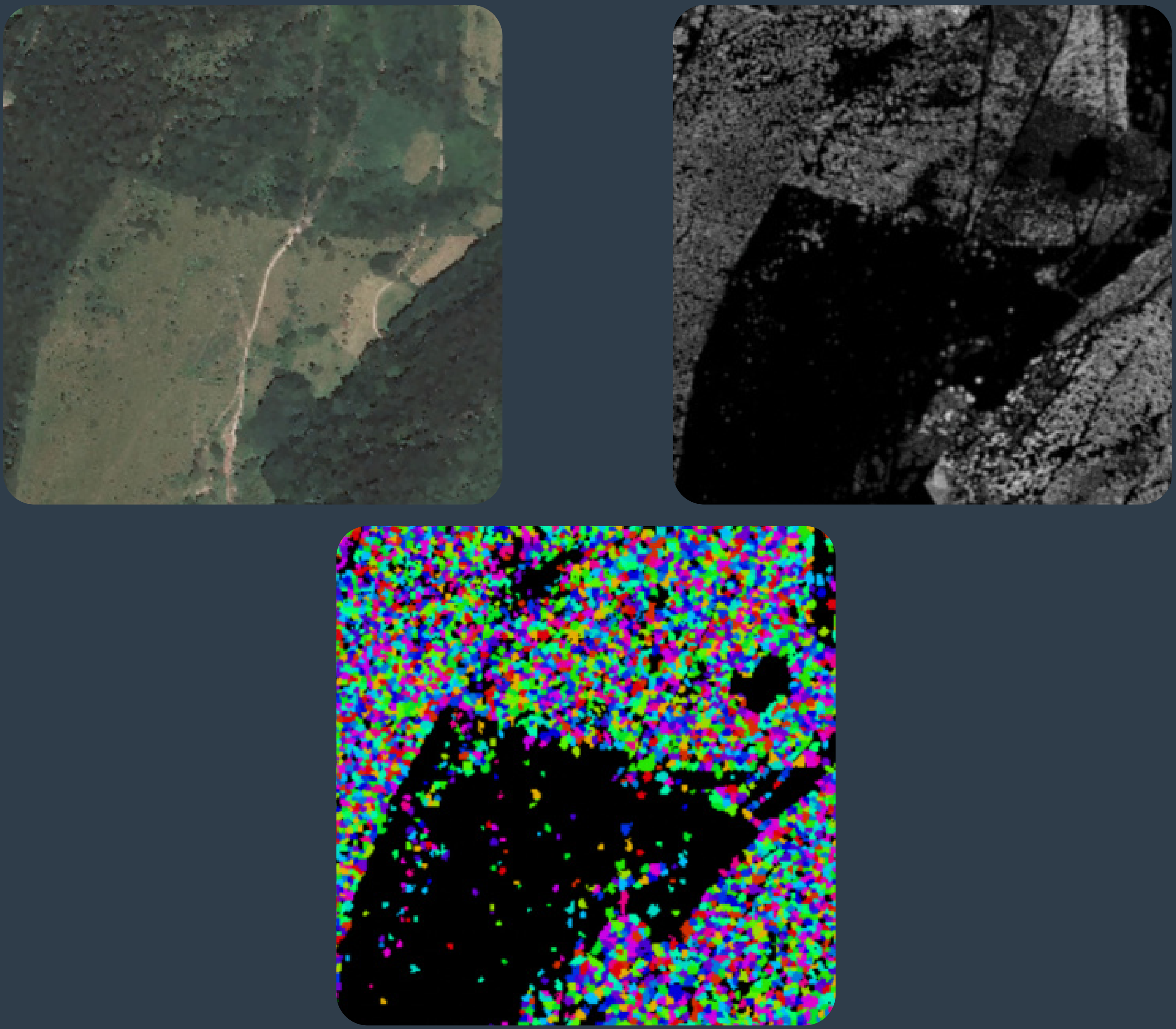


Figure 23: Satellite image of a forest (top-left), LiDAR point cloud (top-right) and extracted individual trees (bottom)
(Dechesne,2016)

FOREST MONITORING USING REMOTE SENSING

This handbook has provided a brief but concise introduction to forest monitoring (and the associated deforestation and forest degradation) and remote sensing. The application of remote sensing technologies to forest monitoring will improve the efficiency and accuracy of forest monitoring, particularly in the tropics.

The use of remote sensing and geographical information systems to assist in making decisions concerning the state of resources on the earth's surface have become more intuitive proactive as the technologies continue to evolve and improve. For the monitoring of forests, several advantages and disadvantages exist across the different remote sensing technologies. The table below provides a comparison of some of the advantages and limitations of the various technologies.

Capability	UAV/Drones	LiDAR	Satellite Optical	Satellite Radar
Area coverage and time	Small areas possible at a time thus large areas can take weeks to months to cover	Large areas possible	Very large areas in one snapshot	Very large areas in one snapshot
Frequency of revisit of an area	As per request	As per request	Frequent on a varying scale depending on satellite - (for example 1 day for Planet) or as per tasking order	Frequent on a varying scale - (for example, 5 days for Sentinel 1) or as per tasking order for commercial such as Capella or Terra-SAR X.
Weather condition effects	Weather dependant	Weather dependant	Weather dependant	Captures in any weather condition as well as day and night
Pricing	Area, time, and location dependant	Area, time, and location dependant	Varying price ranges from free to prices dependant on area and capture date	Varying price ranges from free to prices dependant on area and capture date
Resolution of imagery	High resolution (up to 5cm)	High resolution (up to 5cm)	Varies from kilometers to 30cm	Varies from kilometers to 50cm
Number of Bands	Up to 5 bands: Red, Green, Blue, Near-Infrared, Red-Edge	Up to 5 bands: Red, Green, Blue, Near-Infrared, Red-Edge	Up to 16 bands for multispectral Up to hundreds of bands for hyperspectral	Up to 4 with the following polarisations: HH, HV, VV, VH

Figure 24: Table of comparisons between various remote sensing technologies for forest monitoring

It should be noted that in terms of reporting on forestry deforestation, all these technologies have one major limitation in common:
They are mostly surface technologies. Meaning they can only show what is happening at canopy cover level (apart from lidar and radar that can penetrate the canopy layer to a certain extent). Thus if any deforestation takes place below the emergent canopy, such as cocoa tree farming, it may not be successfully detected using these technologies.

THE DATA PROCESSING WORKFLOW

The data processing workflow remains largely unchanged when remote sensing is utilized for forest monitoring. Indeed, the data acquisition and pre-processing steps are not unique to forest monitoring.

DATA ACQUISITION

Raw imagery is available from several satellite service providers. This raw data is provided at various levels of processing, but users usually have access to 'Level 2' datasets that are user-friendly and ingestible into GIS software for further processing. A selection of satellite service providers and the imagery they provide is indicated below.

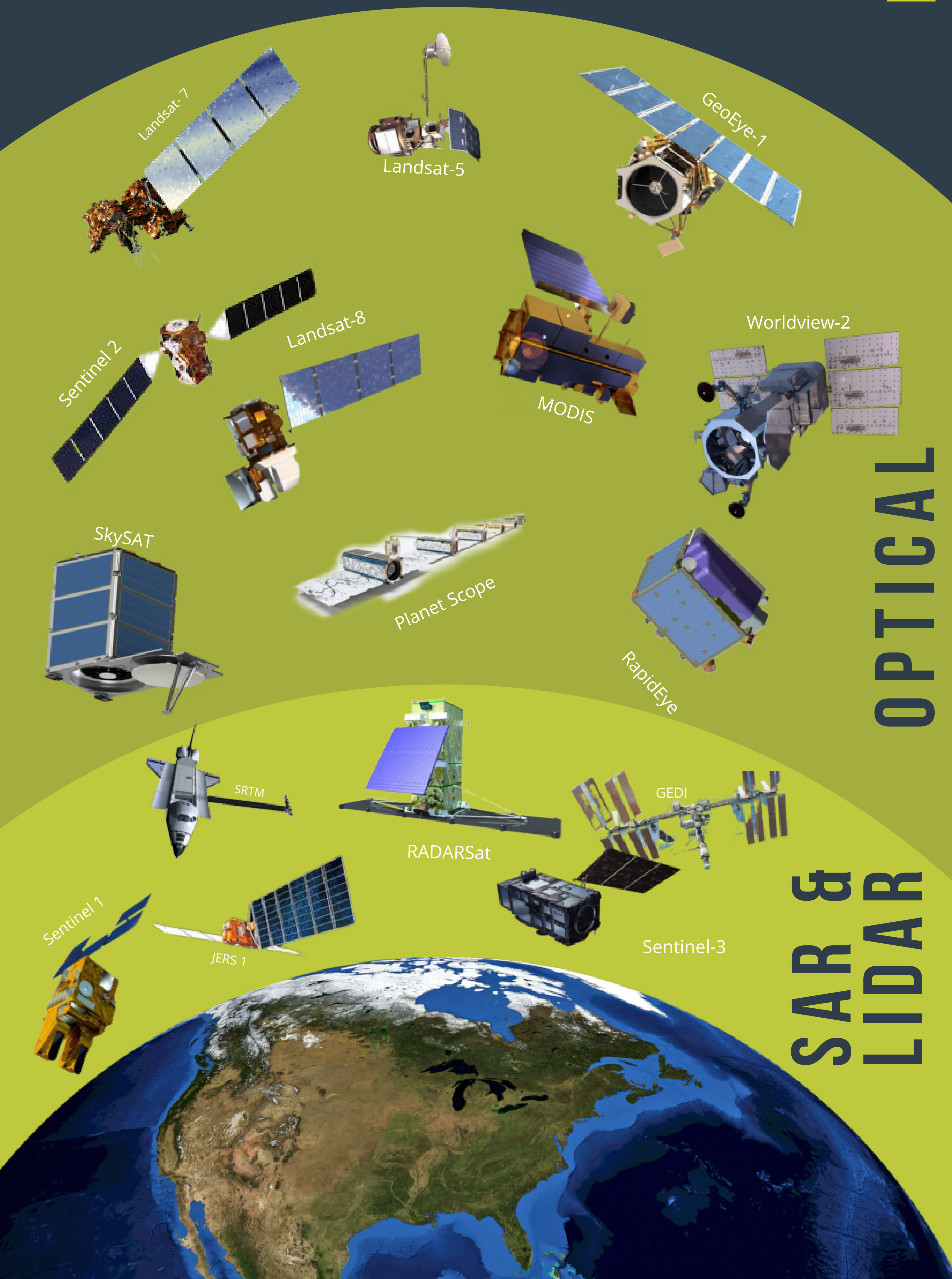
esa
Copernicus sentinel

USGS science for a changing world
LANDSAT NASA · USGS
MODIS

planet.

MAXAR TECHNOLOGIES
GeoEye
WORLDVIEW SATELLITE

Figure 25: Selection of sources of satellite imagery during the data acquisition phase



PREPROCESSING

Raw imagery is available from several satellite service providers. This raw data is provided at various levels of processing, but users usually have access to ‘Level 2’ datasets that are user-friendly and ingestible into GIS software for further processing. A selection of satellite service providers and the imagery they provide is indicated below.

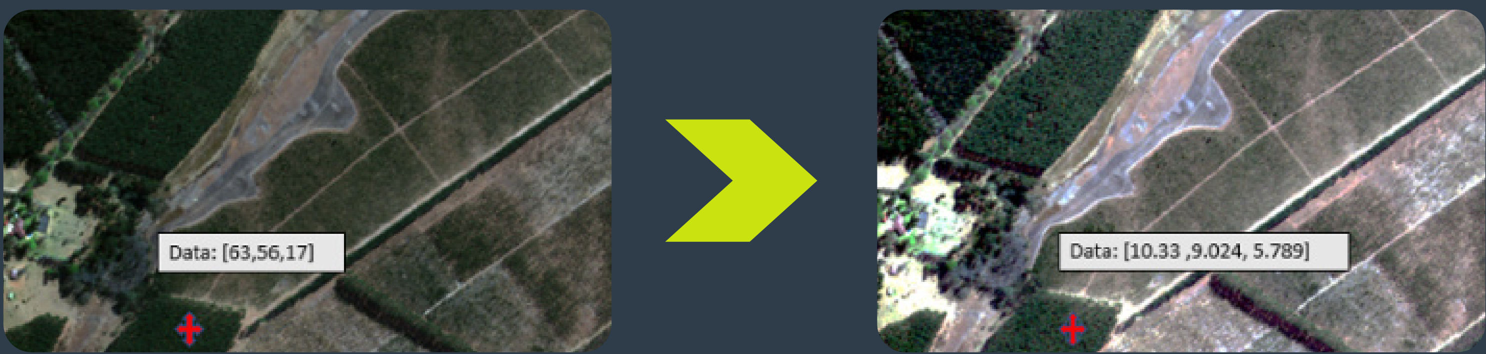
GEOMETRIC CORRECTION

Geometric calibration is a necessary step in pre-processing to ensure that each pixel in the satellite imaged is correctly georeferenced to the same position on the ground. The image below illustrates the difference between the raw non-calibrated image versus the geometrically calibrated image as overlain on Google Earth for positioning reference.

Figure 26: Geometric Correction example. Courtesy of Maxar Technologies and Google Earth.

RADIOMETRIC CORRECTION

Radiometric correction calibrates the raw satellite image data from digital numbers (DN) as captured at the satellite sensor to radiance, brightness temperatures or reflectance. This process serves to remove any spectral distortion that could alter the spectral characteristics of the captured features and thus any other post analysis such as spectral index calculation. The example below shows a raw image versus a radiometrically corrected image and how the pixel data values change.



Raw Image

Radiometrically Corrected Image

Figure 27: Radiometric Calibration example (Raw image on the left and the corrected image on the right

ATMOSPHERIC CORRECTION

The atmospheric correction step serves to remove the effects of the atmosphere such as scattering from haze and absorption from clouds and aerosols from satellite images to ensure that true surface reflectance values are assigned to the pixels in the image. The figure below illustrates atmospheric effects that need to be accounted for during the correction process.

Figure 28: Atmospheric correction example (Raw image on the left and the corrected image on the right

PAN-SHARPENING/ FUSION

This pre-processing step is optional and data specific. It mainly applies to raw data that is captured and delivered with a high-resolution panchromatic band (PAN band) such as the 50cm panchromatic band of Maxar's WorldView 2 and the lower resolution multispectral band (MUL) such as the eight 2m multispectral bands of Worldview 2 delivered separately. This fusion results in a high-resolution multispectral image that has all the spectral fidelity of the original data preserved. The images below illustrate how the images are improved through fusion.

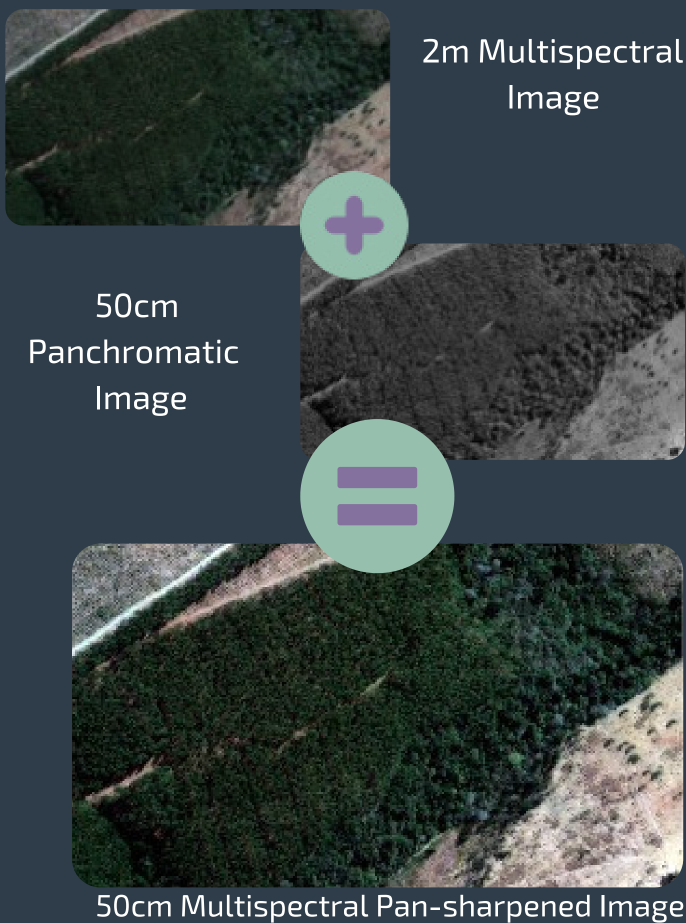
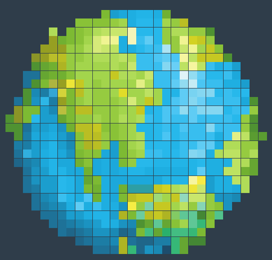


Figure 29: Pansharpening example of a WorldView 2 image

MOSAICKING



Satellite imagery is captured as strips of imagery and not as one continuous image. Depending on how big your area of interest is or where it lies within the capture tiles, before any further analysis can take place mosaicking of the different strips or tiles of imagery is necessary.

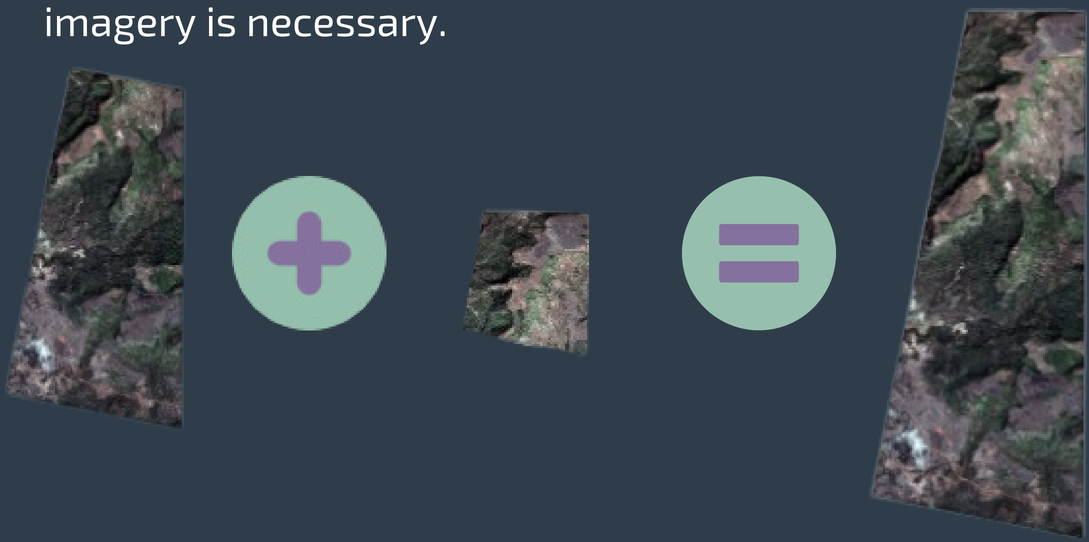


Figure 30: Image mosaicking example

ANALYSIS

Once the full area of interest has been acquired and pre-processed the analysis can begin. This is result dependant on what the goal of the analysis is. A common analysis exercise for forest cover detection and change analysis is to run the appropriate models and spectral index calculation on the image to get information on various forest aspects such as the health of the forests, the absence or presence of canopy cover as well as extent. A time stamp of when a change in the nature of the forest occurred (for example when the clearing of a certain part of the forest occurred) can also be produced. Finally, the classification of the different land use occurring in and around the forest area can also be performed.

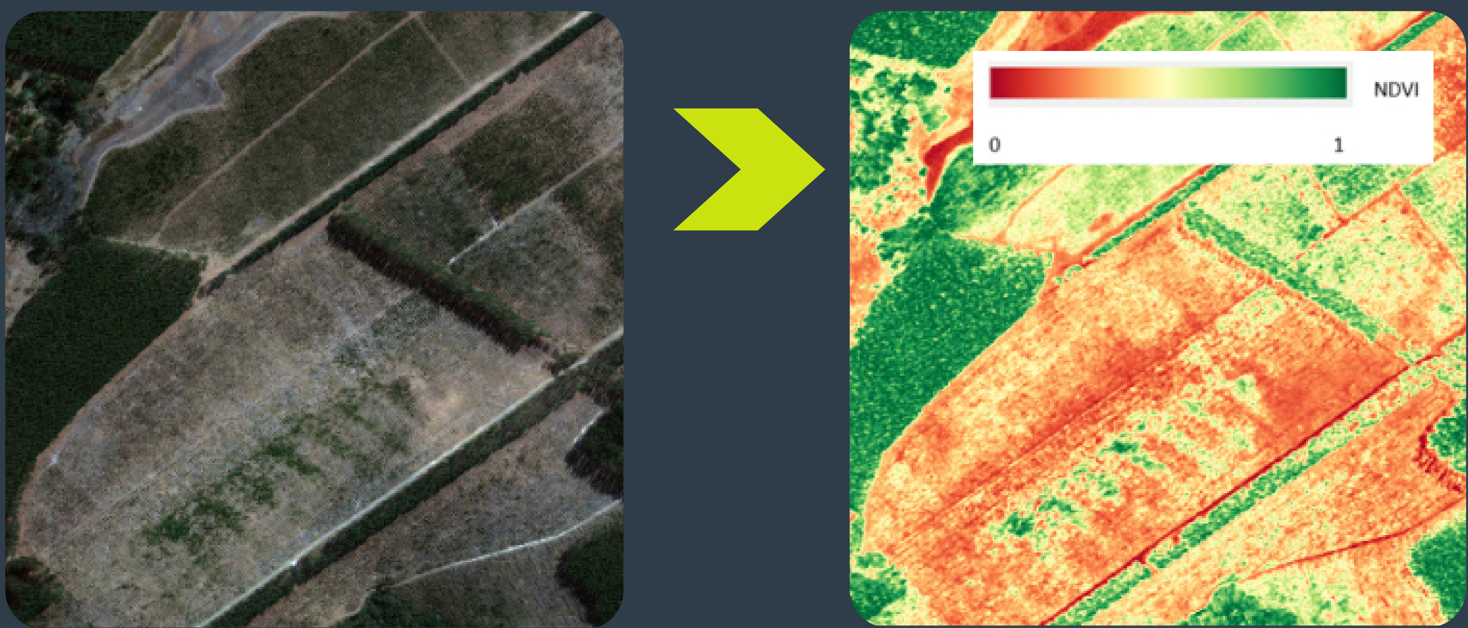


Figure 31: Composite pre-process image (left) and the derived NDVI analysis (right)

PRACTICAL EXAMPLES

Deforestation and forest degradation have been largely driven by the increased demand for palm oil, coffee and cacao. Utilising remote sensing to monitor these crops can only aid in the fight for forests.

PALM OIL

Palm oil has the highest oil yielding capability among other oil crops such as soybean, sunflower, and rapeseed (Chong et al., 2017). Palm oil is well adapted to the warm, humid climate of the tropics (Malaysia, Thailand, South America, Nigeria, and Indonesia). The growth of this industry causes environmental degradation through deforestation in these areas, thus making the monitoring of their expansion a necessity. Remote sensing methods play a major role in this, having been applied in landcover monitoring, change detection, automatic tree counting, and above-ground biomass, to mention a few.

The palm oil tree is a very distinct feature that is easily distinguishable using remote sensing, as illustrated below. However, agroforestry is a popular form of agriculture in the tropics. Smallholder plantations partaking in agroforestry, grow trees and shrubs, intermixed with crops and livestock. This combination of species and landcover type can makemapping mixed-use plantations challenging. A lot of research has been conducted to determine the best methods for detecting and mapping palm oil trees. Due to the extensive location of these trees, satellite imagery is the most popular technique used. LiDAR has been utilised in other studies. However, LiDAR has the drawback of needing an expensive high point density. The distinctive palm oil tree crowns make them easily detectable using satellite imagery. The following page will discuss a selection of monitoring methods that have been investigated by researchers:

Figure 32: A palm oil tree (above and palm oil trees from above (below)

OPTICAL SATELLITE DATA

Landsat (15m) and Sentinel 2 (10m) optical imagery is often utilised in landcover classification to identify oil palm trees. The spectral indices of the Normalised Difference Vegetation Index (NDVI) and the Soil Adjusted Vegetation Index (SAVI) are used mostly because they separate the background from healthy vegetation, with the Near-Infrared band (NIR) being the most important band for oil palm detection. Higher resolution imagery from Maxar (50cm and 30cm) has also been utilised for the detection and tree counting of these species. The figure below shows an example of palm oil trees using Worldview-2 Google Earth imagery in Malaysia.

Figure 33: Worldview-2 Google Earth Image of Palm oil trees in Malaysia

RADAR SATELLITE DATA AND DATA FUSION WITH OPTICAL DATA

There is an increased amount of cloud cover in the tropics, and as palm oil plantations are typically located in these regions, it hinders the consistency of optical satellite imagery capture. Landsat, for example, can take up to 7 years to receive suitable images with acceptable cloud cover an area (Pittman et al, 2013). Radar imagery capture, however, is independent of both weather and time of day, an advantage for monitoring in the tropics. The one disadvantage of radar data is that it is difficult to interpret on its own. Therefore, a fusion of radar and multispectral imagery over palm oil forests fosters the understanding of radar data while providing complementary data from multispectral data. The radar data sets that have been utilised in studies are Sentinel 1 from ESA, which is C-band frequency and collects data at the canopy level. ALOS-2 PALSAR-2 from JAXA, that is an L-band frequency has additionally been utilised and found to be able to penetrate the vegetation canopy to a certain extent, thus a good source for the calculation of biomass.

A study by Xu K et al. (2020) detected palm oil in Sumatra using a fusion of Landsat-8 optical imagery and Sentinel-1 SAR imagery. This study encompassed the classification of palm oil using the random forest algorithm based on improved grid search optimisation (IGSO-RF). The diagram below outlines the study workflow for the detection of palm oil using IGSO-FR and Data Fusion.

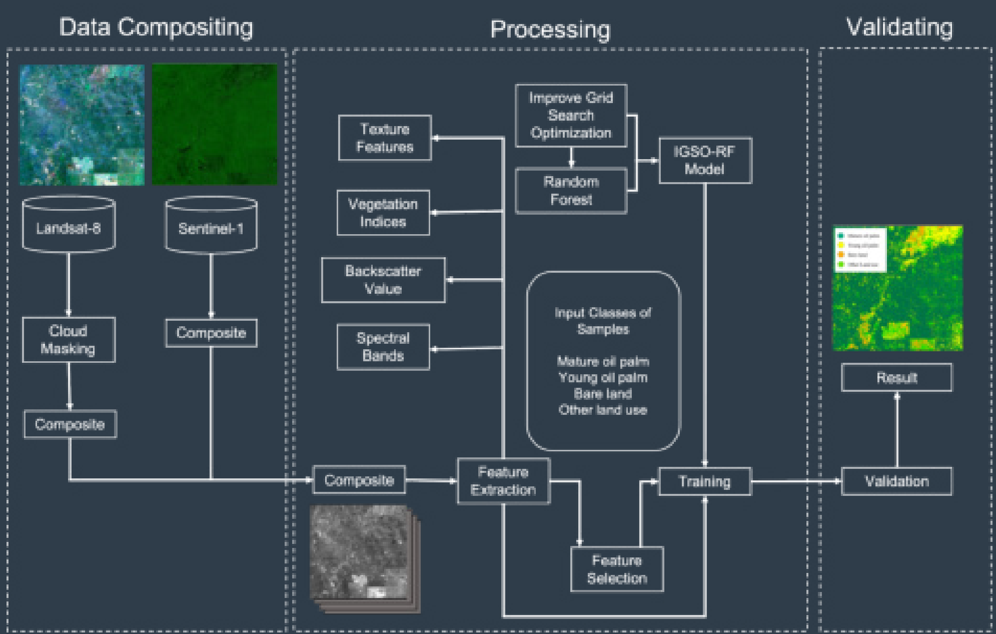


Figure 34: Workflow for Palm oil detection using IGSO-FR and Data Fusion

COCOA

Côte d'Ivoire and Ghana are the two largest producers of cocoa in the world and over time its cultivation has led to the loss of forested land at high rates. Various studies using remote sensing have been used to help detect and monitor the forests and plantations. Examples of these methods are given below:
The use of multi-temporal stacks of Sentinel 1 (10m SAR imagery) and Sentinel-2 (10m optical imagery) and a multi-feature Random Forest algorithm using NDVI (Abu, I. et. Al., 2021).

Figure 35: Cocoa fruit (top left); Plantation- Courtesy Global Forest Watch (top right); Cocoa tree (bottom)

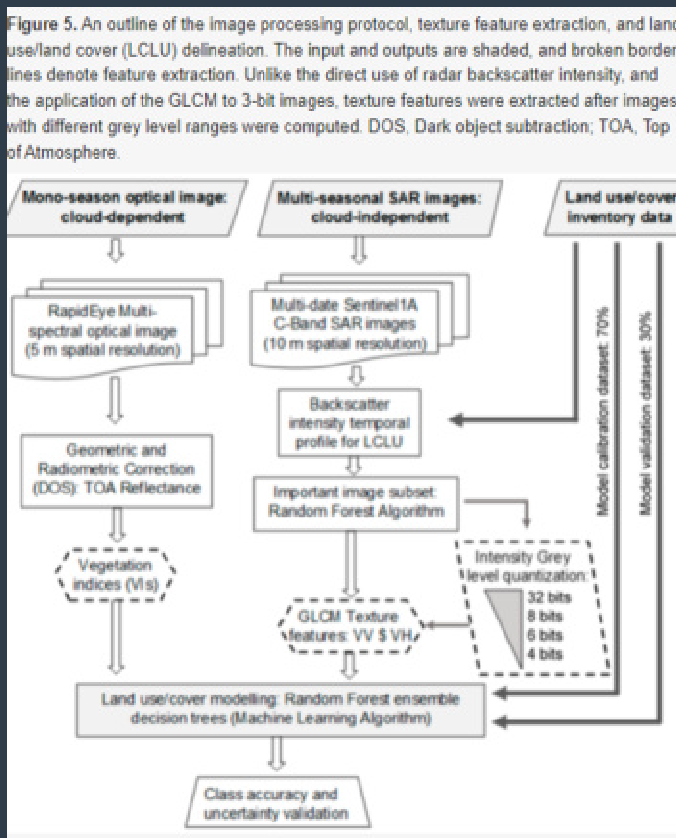


Figure 5. An outline of the image processing protocol, texture feature extraction, and land use/land cover (LCLU) delineation. The input and outputs are shaded, and broken border lines denote feature extraction. Unlike the direct use of radar backscatter intensity, and the application of the GLCM to 3-bit images, texture features were extracted after images with different grey level ranges were computed. DOS, Dark object subtraction; TOA, Top of Atmosphere.

Figure 36: Cocoa prediction workflow using Sentinel-1 GLCM

Due to the similarity in spectral characteristics between cocoa agroforests and other tropical transition forests in areas such as Cameroon it is quite difficult to map cocoa using multispectral imagery. Additionally, the frequent cloud cover makes the use of optical satellite data very limited. Thus, other studies make use of Sentinel-1 C-band radar imagery and applied the Random Forest classifier to average the SAR image texture features of a grey level co-occurrence matrix (GLCM) across seasons to discriminate the cocoa (Numbisi, F. Et.al.,2019). The results of this study were compared with the classification using optical RapidEye and the SAR texture analysis was found to outperform the optical.

COFFEE

Coffee growing is a major sector and is one of the most highly traded commodities in the world. It is well adapted to the tropics and is grown in over 70 countries in a region referred to as the "Bean Belt" (Hunt, D. et al, 2020) and takes large areas of land and thus negatively affects forest cover, biodiversity and human well-being. The need for a more sustainable approach to it's growing and monitoring of this has proven to be crucial and various studies have been conducted using remote sensing methods.

Figure 37: Coffee Plantation - Courtesy of Earthi.space (top); Coffee tree and coffee fruit (bottom)

Using satellite-based remote sensing to monitor coffee growing used to be a major problem because traditionally the crop used to be grown under the shaded canopy of other trees. This recently has changed with the growth of the industry and more and more countries have started to grow coffee in large-scale unshaded systems which enables satellite-based detection. However, it must be noted that some regions still practice the shaded growth approach which makes monitoring these plantations problematic.

The various remote sensing methods investigated are summarised below. The use of Landsat-8 (15m), Sentinel-2 (10m), RapidEye(5m) and Sentinel-1 (10m), MODIS (250m) has been widely applied. The use of high-resolution optical imagery was also applied for a more targeted approach of areas. It must be noted that from all the studies, the shaded growing practice in most regions still poses a limitation in using remote sensing for monitoring coffee growth expansion.

1. Optical satellite-based methods made use of analysis methods of Principal Component Analysis (PCI) and Tasselled Cap transformations that applied spectral indices and band ratios to distinguish coffee from surrounding vegetation. These included: Normalised difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Land Surface Water Index (LSWI), Normalised Difference Red Edge Index (NDRE) , and Moisture stress index (MSI).

2. Classification methods employing Support Vector Machines and Maximum likelihood were employed on Landsat, MODIS and SPOT imagery with the training datasets for classification being obtained as endmembers from the heterogenous landscapes on the imagery.

3. Texture-based analysis making use of Synthetic Aperture Radar data (SAR) such as Sentinel-1 and high-resolution imagery panchromatic bands from Ikonos and Quickbird. The Maximum Likelihood classifier was used on height texture indices namely mean, variance contrast, homogeneity, and contrast.

4. Data fusion methods using optical multispectral, satellite-based hyperspectral (Hymap) and SAR data to increase the classification accuracy.

5. Object-based classification approaches have also been applied using Support Vector machines has shown to increase accuracy of mapping coffee compared to pixel-based classification using maximum likelihood.

EXISTING MONITORING TECHNOLOGIES

The production of high-quality and reliable forest data is crucial to the fight against deforestation and forest degradation. The introduction of remote sensing technologies to forest monitoring further improves the efficiency and accuracy of forest-related information. Numerous forest monitoring tools exist, and several of these tools will be mentioned briefly but are limited to those that are open-source and available online.

RESTOR

Restor is a science-based open data platform to support and connect the global forest restoration movement. The platform provides a repository of 21 layers linked to biodiversity, restoration and environmental factors such as global tree cover and loss, total plant species in a region, mean precipitation and temperature and landcover.

RESTOR

GLOBAL FOREST WATCH

GLOBAL FOREST WATCH

Global Forest Watch is an online platform offering data regarding forests. The Global Forest Watch maps are freely accessible and include deforestation alert layers that identify areas of likely tree cover loss in near real-time and at a spatial resolution of 30m. Tree cover gain and loss layers are also available to identify areas of gross tree cover gain and loss at the global scale. Multiple land cover layers are also available to view on the platform.

FOREST WATCHER

Related to the Global Forest Watch platform, Forest Watcher is a mobile application that brings the monitoring and alert systems of Global Forest. It allows users to monitor an area of interest, view deforestation and fire alerts as well as geolocate to paces of interest.

FOREST ATLASES

Forest Atlases are online context platforms that assist with the management of forest resources by combining country-specific government data with forest monitoring technology. The atlases include interactive mapping and database tools that allow users to visualise, analyse and download data for decision making. There are currently eight African countries that currently have Forest Atlases. These platforms are developed in partnership with the WRI and are accessible to governments, companies, organisations ad private citizens. The atlases provide maps on forest cover, vegetation, urban areas, transportation networks, land use and hydrography.

STARLING

Starling uses optical and radar satellites to provide monitoring of forests in industry-specific interactive dashboards that offer analysis and reporting features for stakeholders. Airbus, an aerospace company, provides the platform with the necessary high-resolution imagery with the non-profit organisation Earthworm provides the on-the-ground expertise to drive the platform. Staling further provides a reference layer of forest classes and land cover change, as well as near-real-time forest cover change data to monitor forests. A free trial is available to users.

RADD FOREST DISTURBANCE ALERTS

RADD forest disturbance alert is an Earth Engine powered application that utilises Radar satellite imagery from Sentinel-1 to map disturbances in the tropical forests of South America, Africa, insular Asia, and the Pacific. RADD defines forest disturbances as the complete or partial removal of tree cover with a 10m Sentinel-1 pixel. RADD Forest Disturbance Alert was developed by Wageningen University in collaboration with the WRI's Global Forest Watch, Google, ESA, University of Maryland and Deltares (2020).

MIGHTY EARTH RAPID RESPONSE MONITORING SYSTEM

MIGHTY EARTH

Mighty Earth's Rapid Response program combines satellite imagery with supply chain data to create monthly deforestation reports for the palm oil, soy and cattle industries. These reports identify new and unresolved cases of deforestation by companies or groups. Changes in tree cover month to month are mapped using Planet imagery. Unresolved cases are tracked monthly and shown on each subsequent report. Mighty Earth additionally provides consumer reports and reports on climate change, pollution, and ocean health.

OPEN FORIS

Open Foris is a collection of open-source software tools for data collection, analysis and reporting enabling forest and land-use monitoring, reporting and management. There are currently eight tools available from Open Foris.

Collect is a desktop survey collection tool for forest monitoring surveys. Collect Mobile is an Android Application for field-based forestry surveys which allows for geolocation through the device's embedded GPS.

Collect Earth is a java-based tool that uses a Google Earth interface in conjunction with an HTML-customisable form to collect data. Collect Earth Online provides the same functionality as Collect Earth but is available online.

Calc is a data analysis and results tool that allows users to write custom R modules to perform specialised analysis.

SEPAL is a cloud computing-based platform for land monitoring using remotely sensed data. Users can query and process historical satellite data, as well as newer data from Landsat and Copernicus programs.

Earth Map is an online open-source tool developed by the FAO that allows users to visualise, process and analyse satellite imagery and global datasets on climate, vegetation, fires, biodiversity, geo-social and other topics.

CONCLUSION

Forests provide not only the natural processes crucial for maintaining life on Earth but are also paramount to the social and economic lives of humankind. Tropical forests encompass nearly 45 percent of the global forest cover and are under threat from deforestation and degradation. The production of high-quality and reliable forest data is crucial to the fight against deforestation and forest degradation. The introduction of remote sensing technologies to forest monitoring further improves the efficiency and accuracy of forest-related information. This handbook provides a concise introduction to the application of remote sensing for forest monitoring, with a particular focus on the tropics. Examples of forest monitoring studies undertaken in tropical settings are included to further highlight the strength of remote sensing in forest monitoring.

LINKS

https://www.esa.int/

https://www.usgs.gov/

https://www.planet.com/

https://www.maxar.com/?utm_source=google&utm_medium=sem&utm_campaign=maxar-brand&gclid=Cj0KCQiAnaeNBhCUARIsABEee8XH9Q2K8Rc8hJQ0IyMXnakzMD6Xwr-ZRHhrBbSHti9igAP7kVp0PWoaAqcLEALw_wcB

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FOREST MONITORING:

A REMOTE SENSING APPROACH

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