EARTH OBSERVATION & THE GLOBAL ENVIRONMENT FACILITY

TECHNICAL GUIDE

A REPORT PREPARED FOR THE SCIENTIFIC AND TECHNICAL ADVISORY PANEL (STAP) OF THE GLOBAL ENVIRONMENT FACILITY (GEF)

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ABOUT STAP
The Scientific and Technical Advisory Panel (STAP) is composed of seven Panel Members, and advisors, supported by a Secretariat, who are together responsible for providing independent scientific and technical advice to the Global Environment Facility.

COVER IMAGE
Copernicus Sentinel-2 image of agriculture plantations in the Santa Cruz Department of Bolivia. Contains modified Copernicus Sentinel data (2019), processed by ESA.

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FOREWORD

In the 28 years since the Global Environment Facility (GEF) was created, a digital revolution has taken place. Data from satellite remote sensing and other Earth observation technology have become much more regular, widespread, less costly and accessible. Together with scientific and technological advances such as cloud computing, machine learning, and data sharing, these data offer more opportunity to observe, monitor, and predict environmental and social phenomena with greater efficiency and precision.

Sometimes known as “Big Earth Data,” information is being used to highlight and analyze the extensive and complex ways in which human beings are altering the planet’s terrestrial and marine ecosystems, and the atmosphere. Big data analysis produces robust, science-based information which enables a better understanding of what is happening and is indispensable in developing mitigation and coping strategies - “you can’t manage what you can’t measure[a].” Earth observation data greatly enhance the ability to mine, organize, analyze, simulate, and represent information about the Earth system to allow informed decisions to be made about how to prepare for and adapt to environmental change, and how to sustainably manage and conserve natural resources.

Many GEF projects and programs are using Earth observation and other geospatial data to design, implement, monitor, and evaluate interventions; this document highlights several case studies. The uptake and use of Earth observation technology by GEF agencies is uneven. This document aims to encourage greater use of Earth observation data, along with other geospatial technologies, by GEF Agency project managers and in-country counterparts.

Earth observation is an area of rapid development and innovation and this document covers the basic science and characteristics of Earth observation, recent advances, and the future directions of the technology. However, it is not exhaustive, and readers are encouraged to review the external resources that are cited throughout the document.

The document includes 1) an introduction to the different types of Earth observation technology and key characteristics; 2) how these data and tools can be used at various stages across the GEF project cycle; 3) Earth observation thematic applications and case studies; and 4) summary of Earth observation data and information portals, platforms, and software tools.

[a] This famous quote is attributed to both quality and process control guru W. Edwards Deming and management consultant and thought leader Peter Drucker.

1.0 INTRODUCTION

The Global Environment Facility's (GEF) mission is to safeguard the global environment by supporting developing countries in meeting their commitments to multiple environmental conventions and by creating and enhancing partnerships at national, regional and global scales – to generate global environmental benefits. The GEF is also an innovator and catalyst that supports multi-stakeholder alliances to preserve threatened ecosystems on land and in the oceans, build greener cities, boost food security, and promote clean energy for a more prosperous, climate-resilient world[1].

Tackling complex, interrelated global environmental challenges requires wide-ranging social, economic, and environmental data and information, including on what pressures are occurring, where they are happening across vast geographic areas, and how they are changing over time.

Earth observation technology provides up-to-date, multi-disciplinary data of the Earth's physical and biological systems – and socio-economic information through proxies. Earth observation data enhance visualization, analysis, and communication of environmental issues, and ultimately aid in decision-making, including understanding whether GEF interventions are having a positive impact. The key benefits of Earth observation for GEF programming are:

Earth observation technologies have existed for decades but are now much more accessible to the public due to investments in new systems, lower costs and policy change (e.g. open data), improvements in computing power and Internet, and innovation in data integration and analytical methods. These technologies are now indispensable for GEF projects and GEF implementing agencies, and their government and non-governmental organization (NGO) partners. Improved knowledge and understanding of Earth observation technology will enable agencies to apply it appropriately and effectively in GEF projects and programs to improve their design, implementation, monitoring, and evaluation.

This document aims to support GEF implementing agencies and their partners who are designing, implementing, monitoring, and evaluating projects in GEF's focal areas or impact programs. It targets experts in GEF's focal areas who are not necessarily experts in Earth observation or geospatial technology but recognize its value and important contribution to projects, are eager to learn how to make greater use of available information to improve project outcomes.

The primer provides information on Earth observation data and technology and helps users to understand how global environmental challenges can be investigated and effectively addressed using information derived from EO information. The primer covers:

- fundamentals of Earth observation technology and science opportunities, as well as challenges for their use;
- guidance on how Earth observation technologies and datasets can be incorporated across the GEF project cycle;
- case studies and examples to illustrate effective use of Earth observation, particularly in GEF projects; and
- recommendations for how to accelerate the mainstreaming of Earth observation information into GEF operations.

2.0 WHAT IS EARTH OBSERVATION?

Earth observation includes remote sensing technologies, such as satellites images, unmanned aerial vehicles or drones, underwater sensing, and aerial surveys. It also includes other *in-situ* technology such as floating buoys for monitoring ocean currents, temperature, and salinity; terrestrial air quality and rainwater sensors; sonar and radar for estimating fish and bird populations; and GPS technology. Citizen science is a unique and emerging approach to Earth observation.

Remote sensing is arguably the most important and widely accessible Earth observation technology and is synonymous with Earth observation for many users. For this reason, much of this document focuses on satellite remote sensing. Remote sensing is formally defined as "the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation"[2].

Earth observation technology is closely linked with several complementary geospatial technologies for the management, analysis and visualization of geospatial data, the most important being geographic information systems (GIS), which increasingly encompass mobile and web applications for data collection and visualization. Other emerging technologies and important considerations include satellite-based video capture, cloud-based data analysis systems, methods of analysis (e.g. machine learning), and integration of Earth observation with other datasets.

For more information on Earth observation:

- What is Earth observation?
- Earth observations in service of the 2030 Agenda for Sustainable Development
- Group on Earth Observations

2.1 TYPES OF EARTH OBSERVATION

Before considering the use of Earth observation information for a project or program, it is important to understand the basic scientific principles and characteristics of the technology. These do not fundamentally change, even during a period of rapid technology innovation. Basic knowledge of the characteristics of remote sensing systems can enhance the value of information that a user can obtain from the remotely sensed data and associated derived products. It can also enable the user to understand how to select the most appropriate product and some of the potential tradeoffs.

The science of remote sensing is based on the physics of wave theory, which describes how electromagnetic energy takes the forms of waves[3]. Electromagnetic energy is classified into several types according to the wavelength or frequency of the wave, e.g. visible light, infrared, or microwaves. The full range of wavelengths of electromagnetic energy is the electromagnetic spectrum and classes of wavelengths are spectral bands (see Figure 1 below). There are two general types of remote sensing instruments – passive and active, both of which are commonly deployed using satellite, aircraft, and drone platforms.

For remote sensing tutorials and webinars:

- Remote Sensing Tutorials, Natural Resources Canada
- Applied Remote Sensing Training, National Aeronautics and Space Administration (NASA)
- EO College, Friedrich-Schiller University in Jena
- Earth Data webinars and tutorials, NASA

2.1.1 Passive remote sensing – Multi-spectral

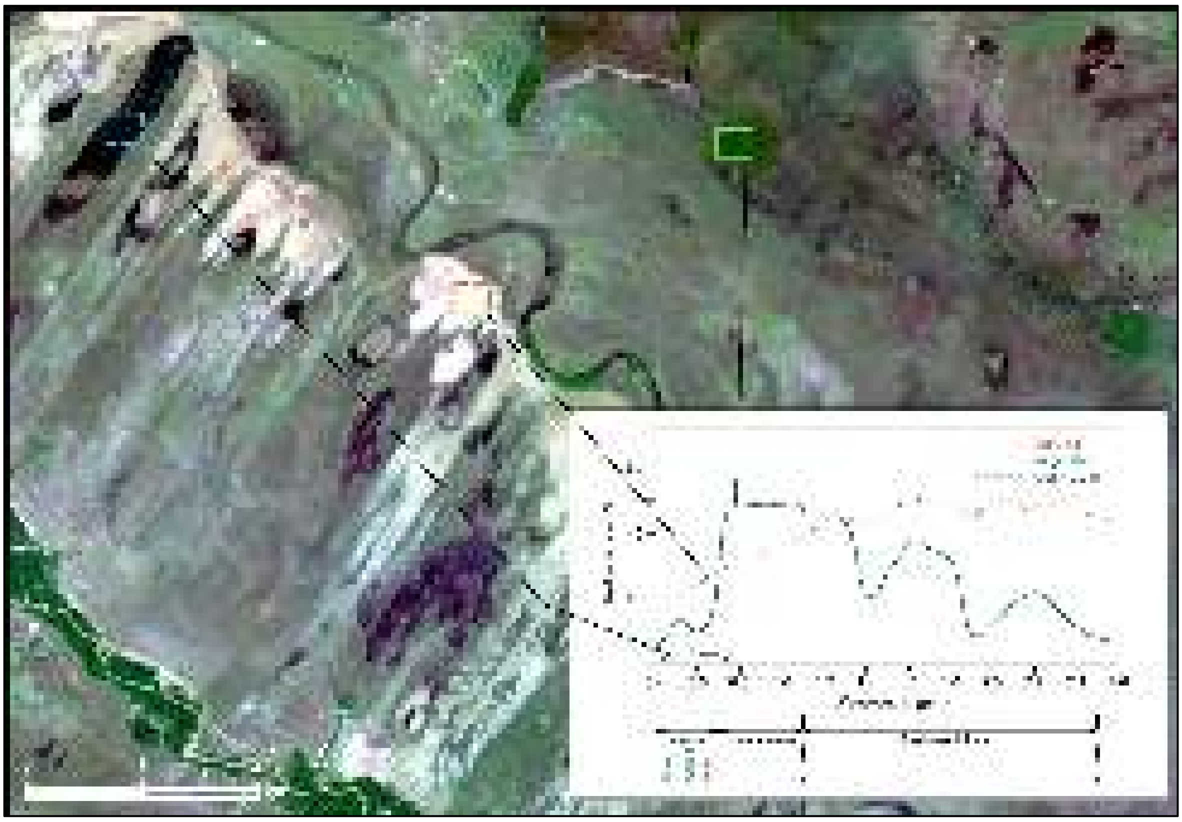
Passive instruments detect electromagnetic energy that is reflected or emitted from the observed surface. Reflected sunlight in the visible and infrared bands is the most common external source of electromagnetic energy sensed by passive instruments.

Multi-spectral sensors measure the reflected electromagnetic energy of several bands in the visible (0.4–0.7 µm), near-infrared (NIR) (0.7–1.1 µm), and shortwave-infrared (SWIR) (1.1–3.0 µm) part of the electromagnetic spectrum (see Figure 1). Features on the Earth's surface, such as water bodies or a forest, absorb, reflect, and emit electromagnetic energy differently due to differences in their bio-physical and bio-chemical compositions. This interaction is predictable and repeatable, giving features distinct properties or responses to electromagnetic energy which can be called a "spectral signature" – this is the fundamental basis for land cover mapping using multi-spectral remote sensing (Figure 1). Due to these same properties, multi-spectral wavelengths are affected by atmospheric scattering and absorption due to dust, smoke, and water vapor (particularly clouds).

Visible wavelengths are separated into blue, green, and red spectral bands. Blue light is useful for seeing water features since water reflects blue light. Green light is useful for bathymetric mapping because green light penetrates the water column. Visible and NIR wavelengths are useful for assessing the type of and health of trees, grasses, shrubs, and crops. Healthy vegetation absorbs visible wavelengths as a source of energy in the process of photosynthesis. Vegetation reflects the NIR energy such that green plants appear relatively dark in the visible wavelengths and relatively bright in the NIR. This principle is the basis of the normalized difference vegetation index (NDVI), which calculates the ratio of the difference in the intensity of reflected light in the red and NIR band and the sum of these intensities[4].

NIR wavelengths are absorbed by water making them useful for discerning land-water boundaries that are not obvious in visible light. Water also absorbs SWIR energy in specific bands and the more water there is, even in soil, the darker the image will appear at these wavelengths. This means SWIR measurements can help estimate how much water is present in plants and soil[5]. The most readily available sources of multi-spectral data are from the Landsat Program (Landsat satellites from 1972-present) and Copernicus (Sentinel-2 satellites from 2015-present), both of which are freely available (also see Section 2.2.3).

Figure 1 Multi-spectral Sentinel-2 image and spectral signatures.



Source: Hatfield Consultants, using Copernicus Sentinel-2 data (true color image presented), Orinoquía region, Colombia.

2.1.2 Active remote sensing – Radar and Lidar

Active instruments provide their own source of energy. They send a pulse of electromagnetic energy from the sensor to the observed surface and then receive the energy that is reflected or backscattered. Active instruments include radio detection and ranging (**radar**) that operate at radio or microwave frequencies to emit electromagnetic energy and receive reflected or backscattered microwave pulses. Light detection and ranging (**lidar**) typically uses near-infrared light in the form of a pulsed laser and records the return pulse to measure the distance to the Earth surface for a variety of applications, including topographic and bathymetric mapping, and forestry.

Remote sensing with imaging radar can be more difficult to understand than multi-spectral imaging because the technology itself is more complicated and the image data recorded is more varied[6]. A typical active imaging radar system measures the strength and round-trip time of the microwave signals that are emitted by its radar antenna and reflected off the Earth's surface. Radar systems operate at specific wavelengths within the microwave spectrum and polarizations. At the Earth's surface, the energy is scattered in all directions with the "backscatter" being the portion reflected toward the radar antenna. The strength and polarization of the backscatter will vary depending on the structure of surface features, moisture content of the target area, polarization of the pulses, and observation angles. Backscatter will also differ when different wavelengths are used[7,8].

For more information on radar remote sensing:

- Radar Basics Remote Sensing Tutorial, Natural Resources Canada
- "Echoes in Space" Massive Open Online Course on Radar Remote Sensing, Friedrich-Schiller University in Jena
- SAR Handbook, SERVIR-SilvaCarbon

Radar systems and images provide unique Earth observation information, such as detected flooded vegetation, are not affected by cloud cover, and images can be acquired at night. However, limitations include the complexity of interpreting radar interaction with Earth surface features and image distortion in hilly terrain. Copernicus Sentinel-1 satellites (2014-present) represent one of the most readily available sources of radar data. The example Sentinel-1 radar image in Figure 2 covers the same area of the Orinoquía region, Colombia, as the Sentinel-2 image in Figure 1. The image is from a single date with the polarization information used to create a color composite. The boxes on the image show the same water, bare, and tree covered areas shown in the earlier Sentinel-2 image and demonstrate the unique way that radar interacts with Earth surface features.

Other types of radar systems are used to provide specific information such as radar altimeter measurements that scientists use to publish global data on the water levels of large lakes and rivers[9] and the Global Precipitation Mission (GPM) used to measure precipitation from space[10].

Figure 2 Dual polarization Sentinel-1 radar image.

Source: Hatfield Consultants, using Copernicus Sentinel-1 data (red channel: VV; green channel: VH; blue channel: VV), Orinoquía region, Colombia.

> **For more information on LIDAR:**
>
> - Lidar 101: An Introduction to Lidar Technology, Data, and Applications, NOAA

Lidar is an established method for collecting very dense and accurate elevation data across landscapes and in shallow-water areas[11]. Lidar systems are typically flown on planes. The lidar instrument fires rapid pulses of laser light at a surface and a sensor on the instrument measures the amount of time it takes for each pulse to bounce back. The systems generate a dense datasets of highly accurate georeferenced elevation points – often called a point cloud – that can be used to generate three-dimensional representations of the Earth's surface and its features. Users of lidar data typically receive the processed point cloud, which provides ground surface points and full feature points, which can be used to determine ground surface and vegetation canopy heights. Lidar offers several advantages over most other remote sensing techniques: high resolution due to low altitude acquisition, centimeter-level elevation accuracy, vegetation structure information, and ground detection in forested terrain[11]. Lidar data can be used to model forest biomass and vegetation structure providing important information for biodiversity management and climate change mitigation[12].

Acquiring airborne lidar data can be expensive due to aerial mobilization costs, hence there is interest from remote sensing scientists in lidar systems on spaceborne satellites or UAV platforms, despite limitations and challenges from both platforms. The Global Ecosystem Dynamics Investigation (GEDI) mission deployed a high resolution lidar instrument on the International Space Station (ISS) in 2018 and will complete precise measurements of forest canopy height, canopy vertical structure, and surface elevation. The GEDI sampling approach will deliver gridded products at 1 km resolution[13]. GEDI datasets will be valuable for applications in water resource management, forest management, and help to characterize vegetation canopy, vertical structure, and habitat quality for applications in biodiversity conservation and climate change mitigation. The data from GEDI are complemented by data from the NASA ICESat-2 Mission (2018-present), which in turn built on the earlier NASA ICESat Mission (2003-2009).

2.1.3 Airborne and drone technology

Unmanned aerial vehicles (UAVs), commonly known as 'drones,' are an area of rapid innovation in remote sensing. The companies, platforms and capabilities of systems, not to mention the rules around their use, are evolving rapidly. Drones can be deployed rapidly and easily, but most systems available to the public have limited flight endurance and are therefore most appropriate for acquisition of very high-resolution images (e.g. 5-20 cm) over small areas (a few square kilometers). Using digital photogrammetry, drones can be used to capture very detailed surface topography models. Example drone applications include wildlife surveys[14], climate change hazard monitoring[15], and forest health monitoring[16].

Aircraft surveys and aerial photography remain common for topographic mapping by national mapping agencies. Aerial photos often provide very high-resolution images (e.g. 10 to 30 cm), better than the highest resolution satellite imagery. Where available, even if several years old, ortho aerial photos can provide excellent base imagery to plan the acquisition of new data from drones or satellite remote sensing.

2.1.4 In-situ technology

In-situ data collection is an essential part of the application of remote sensing for environmental assessment and monitoring. Ground-based sensors can provide the necessary benchmarks and cross-calibration on a continuous basis. Significant advancements in Earth observation are expected to come about by systematic fusion of remote sensing observations and *in situ* measurements[17]. *In situ* Earth observation technology encompasses a range of terrestrial and oceanographic sensors such as floating buoys for monitoring ocean currents, temperature, and salinity and terrestrial air quality and meteorology sensors. A network of sensors linked by software and the Internet is referred to as a sensor web or the Internet of Things and has applications from urban sustainability to agriculture[18].

Most users rely on existing services and projects to access required *in situ* information. For example, national meteorological services as part of the World Meteorological Organization (WMO) established networks of observing stations to provide national, regional and global weather and climate data. Argo is an example of an international project to collect information on the temperature and salinity of the upper part of the world's oceans using robotic floats that drift below the ocean surface and regularly transmit data to satellites[19].

2.1.5 Crowdsourcing and Citizen science

Crowdsourcing uses the knowledge and observations of the general public and can generate important data that might otherwise be impossible to obtain. Crowdsourcing can include contributions from anywhere in the world through online applications. Citizen science is a subset of crowdsourcing where the public participates voluntarily in the scientific process to address real-world problems. This may include forming research questions, conducting scientific experiments, collecting and analyzing data, interpreting results, making new discoveries, developing technologies and applications, and solving complex problems[20].

The United States Government created a Federal Crowdsourcing and Citizen Science Toolkit covering the basic process steps for planning, designing and carrying out a crowdsourcing or citizen science project[21]. The prevalence of location-enabled mobile devices, particularly smartphones, connected to the Internet is a critical factor in the growth of citizen science. OpenStreetMap is a well-known crowdsourcing initiative where a community of mappers contribute and maintain data all over the world, which is made available under an open database license. Box 1 introduces the Global Biodiversity Information Facility (GBIF) and the contribution of citizen science towards international biodiversity monitoring.

Box 1 – Citizen science and the Global Biodiversity Information Facility

GBIF works to provide biodiversity data-holding institutions, such as natural history museums, around the world with common standards and open-source tools that enable them to share information about where and when species have been recorded. Publishers provide open access to their datasets using machine-readable Creative Commons license designations. This global aggregated data on over 1.5 million species is available and GBIF data are core data used to link species distribution to remote sensing data.

Volunteer collectors and recorders have made significant contributions to on-the-ground knowledge about biodiversity, and recent improvements in technology have helped increase the flow and quality of occurrences from citizen sources.

Source: https://www.gbif.org/
Photo: https://www.gbif.org/occurrence/1253313270

2.2 KEY ASPECTS OF EARTH OBSERVATION SYSTEMS AND DATA

It is critical for users of Earth observation information to understand and consider key characteristics of the sensor and system, in order to determine which is most appropriate to address their specific needs. This includes careful assessment of each of the technical and practical tradeoffs. Users should consider the following important features of systems and sensors when deciding which is most appropriate for their needs:

What a sensor or system detects: What information can be obtained? For example, multi-spectral optical systems are well suited to detect vegetation status and health.

Coverage: How large an area can the sensor image at one time? Systems may cover only a few square kilometers to thousands of square kilometers.

Revisit period: How frequently does the sensor revisit the same area? Linked with coverage and spatial resolution, revisit may vary from multiple acquisitions per day a single application every few weeks.

Spatial resolution: What is the level of the detail discernible in an image? Satellite images can be acquired with spatial resolution of 30 cm to 1 km.

Vintage and time series: How long and dense are the time series of images? Some systems have a very good archive, which can help in environmental change assessment.

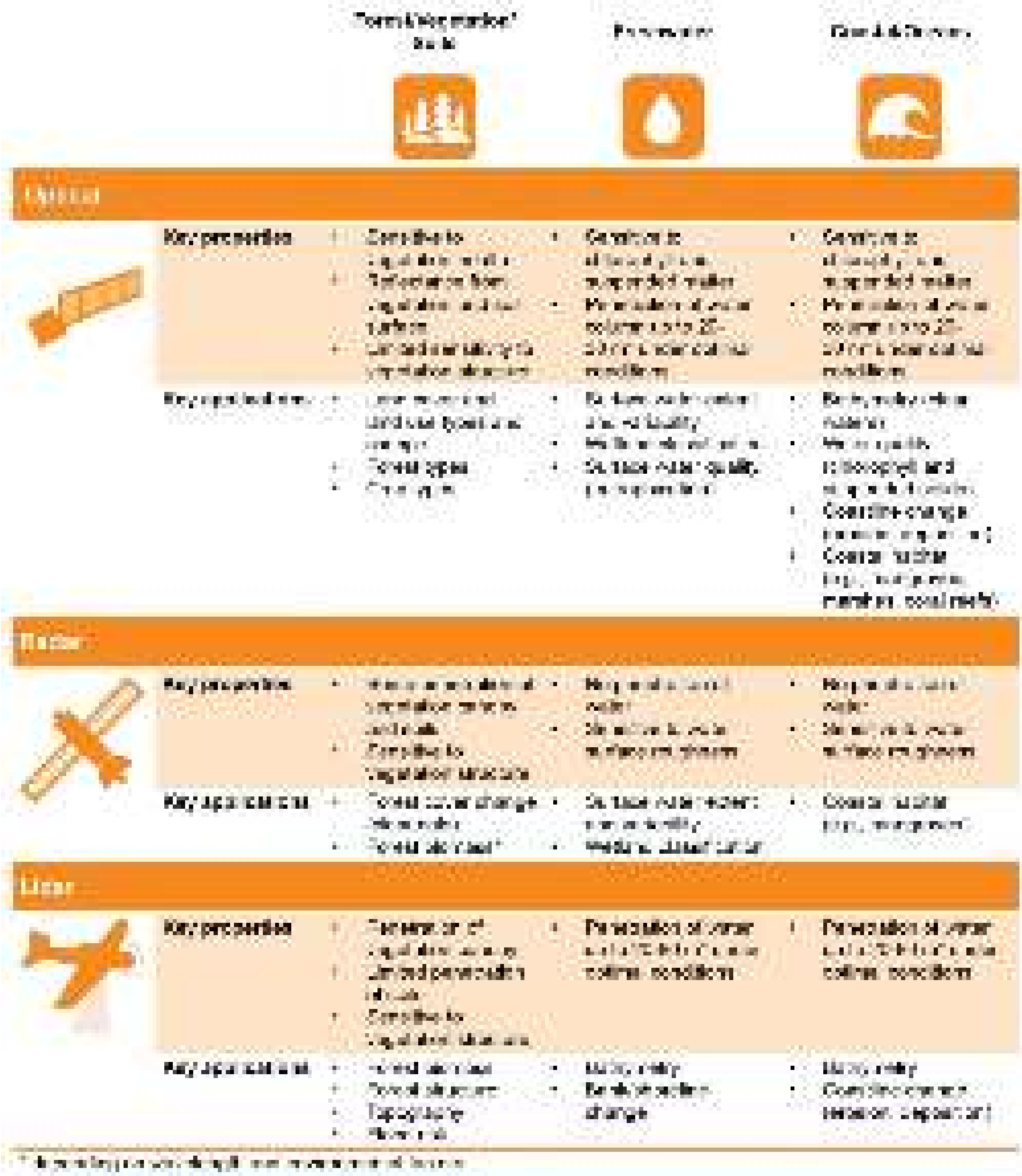
Cost and license: Are the data or products available under an open license or commercial terms? More data are now available free-of-cost.

Data processing and derived products: What level of pre-processing calibration is applied to the data? Are products available with published specifications and accuracy reports?

2.2.1 What a sensor or system detects

The first consideration in using Earth observation data, particularly remote sensing data, is to understand what the sensor or system can detect. Figure 3 summarizes the key properties of the three main types of remote sensing systems – optical, radar, and lidar – when considering three major types of application in terrestrial vegetation/soils, freshwater, and marine environments. Several other applications of Earth observation are described in detail in Section 3.2

Figure 3 Key properties of remote sensing system and applications.



Source: Hatfield Consultants.

2.2.2 Swath coverage and revisit period

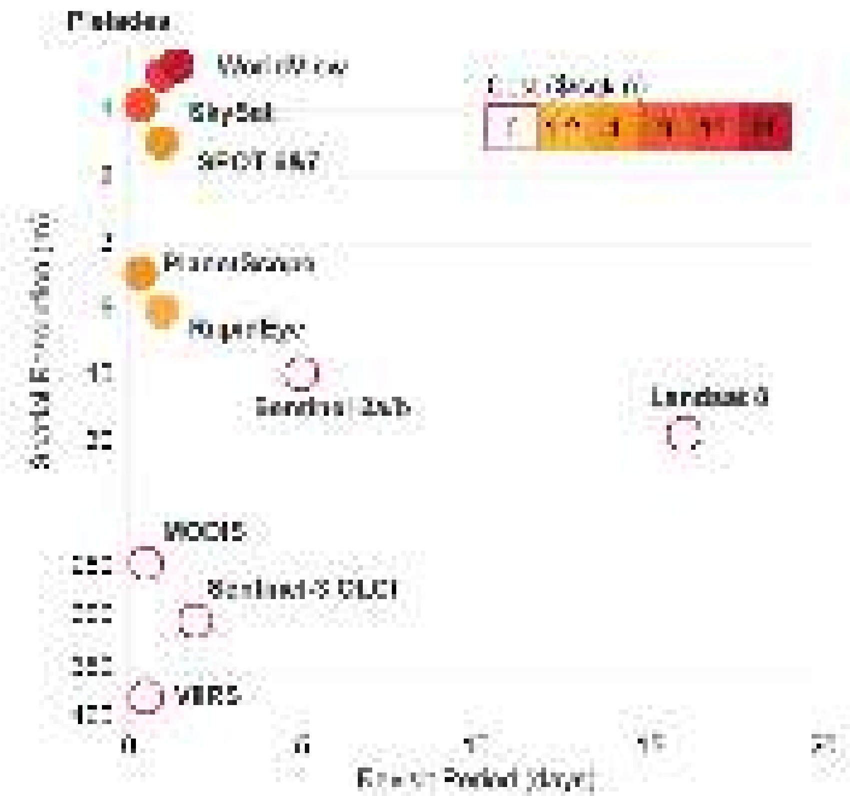
Many satellite remote sensing platforms are **polar orbiting** moving from north-south which, in conjunction with the Earth's rotation, allows them to image most of the Earth's surface over a certain time period. Some satellites orbit around the equator at speeds which match the rotation of the Earth, so they are **geostationary** relative to the Earth's surface and image the same area of the Earth's surface at all times.

The area imaged by a satellite sensor on the Earth’s surface is the **swath**, which varies from tens to hundreds of kilometers depending on the satellite system. The **orbit cycle** is the time taken for a satellite to pass over the same point on the Earth's surface directly below the satellite. This varies for different satellites, e.g. from one day to 2-3 weeks. The **revisit period** is a related concept, but this can be shorter than the orbit cycle because sensors are steerable and can be pointed to image a location before the orbit cycle is complete. In high northern latitudes swaths overlap, decreasing the revisit period. Most polar orbiting satellites are **sun-synchronous** meaning that they orbit over each area of the Earth at the same local time of day[22].

Swath width, orbit cycle, and revisit period are important considerations for monitoring applications. Typically, the larger the swath width, the lower the spatial resolution of the images. For example, NASA’s MODIS sensors have a swath of 2,330 km wide with spatial resolution of 250 m in some spectral bands; Landsat 8’s optical sensor has a swath of 185 km, but spatial resolution of 15-30 m. However, public remote sensing programs and commercial companies are launching and operating **constellations of satellites** with offset orbits to decrease revisit periods for high resolution images.

Figure 4 graphically shows the revisit period, resolution, and average cost of commonly used remote sensing systems. Recent technology trends mean that images with 5 m spatial resolution or better can be obtained daily (depending on cloud cover) on a commercial basis. Free and open data with lower spatial resolution and slightly longer revisit period are available. For example, the Sentinel-2 mission comprises two satellites which provide a revisit period of 5 days at 10-20 m spatial resolution at no cost. The company Planet has launched hundreds of **nanosatellites** to provide near daily coverage of the Earth’s surface at 3-5 m spatial resolution, which are available through subscription.

Figure 4 Revisit period, spatial resolution, and cost of commonly used Earth observation systems.



Note: Most commercial companies offer special pricing arrangements for development organizations. Source: Hatfield Consultants.

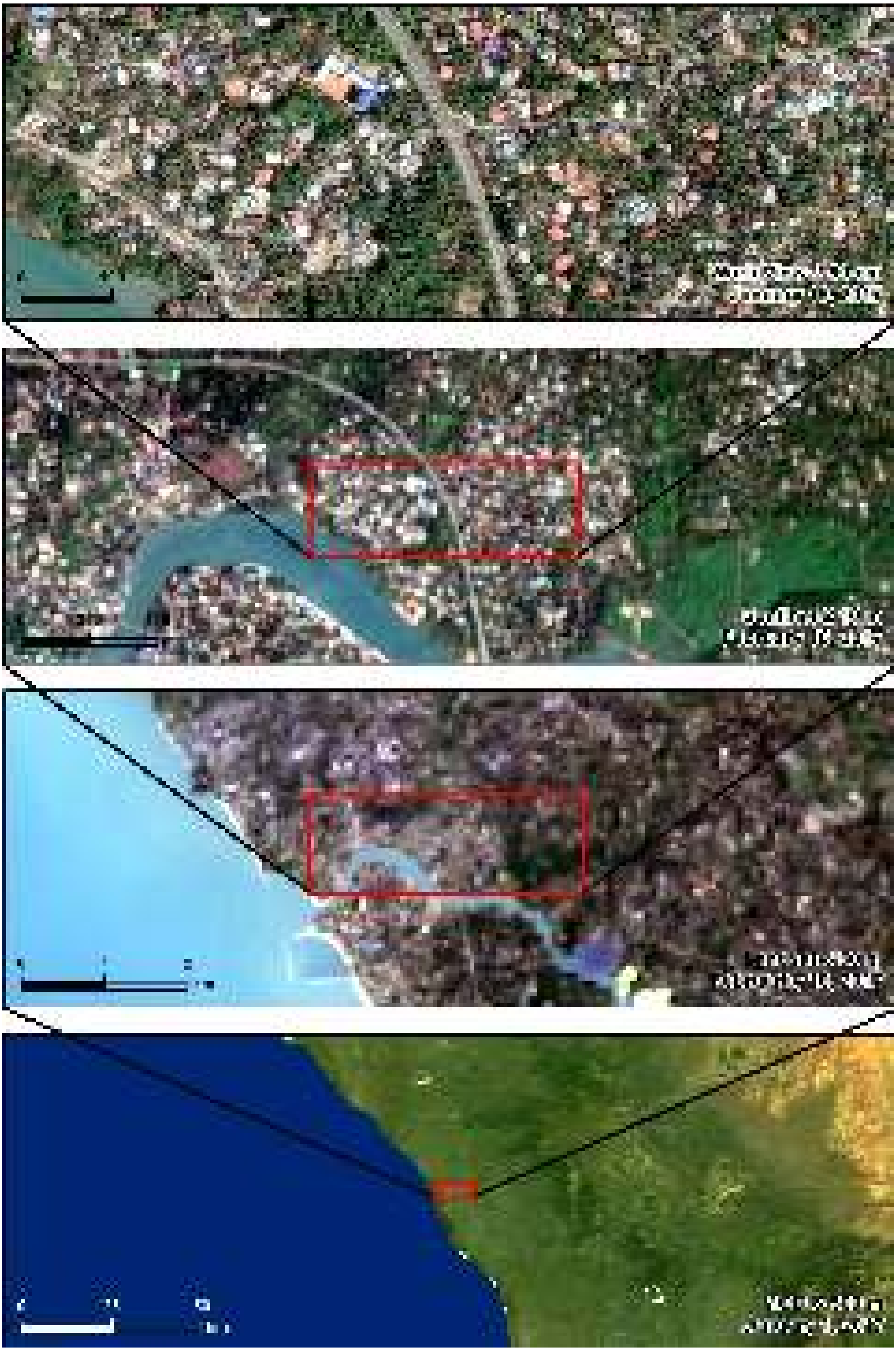
2.2.3 Spatial resolution

Spatial resolution of a sensor refers to the detail discernible in an image and the size of the smallest possible feature that can be detected. If a sensor has a spatial resolution of 20 m and an image from that sensor is displayed at full resolution, each pixel represents an area of 20 m x 20 m on the ground. In this case, the pixel size and resolution are the same[22]. Space agencies, companies, and other organizations categorize the relative spatial resolution of images differently, so “high resolution” can have a different meaning. In general, the following categories apply:

- Very coarse resolution: > 500 m, e.g. AVHRR, some MODIS and Sentinel-3 OLCI products
- Coarse resolution: 100 to 500 m, e.g. MODIS, Sentinel-3 OLCI
- Medium resolution: 100 to 20 m, e.g. Landsat 8
- High resolution 20 to 5 m, e.g. Sentinel-2
- Very high resolution (VHR): 5 m to 1 m, e.g. PlanetScope
- Ultra high resolution (UHR): < 1 m, e.g. WorldView, Pleiades, or SkySat

The spatial resolution of four commonly used types of satellite image is visualized in Figure 5. In the most detailed WorldView image, individual houses and trees can be seen. With Sentinel-2, Landsat, and MODIS the spatial resolution becomes lower and a single pixel covers a much larger area on the Earth’s surface. As a user “zooms in” to a satellite image, the pixels in the image will become discernable. It is important to understand that while having lower spatial resolution, MODIS was developed for frequent, global monitoring, whereas WorldView-2 was developed to enable very detailed monitoring on a less frequent basis. A good strategy for many GEF projects is to use free and open high or medium resolution images to provide complete coverage of a study area, which can be updated on a regular basis. Commercial UHR/VHR images can provide important information that is not possible to determine from high and medium resolutions, but this may be used in specific geographic areas or at specific time periods during a project. UHR/VHR images are often used as a surrogate for *in-situ* or field observations to guide or ‘train’ land cover classifications or for accuracy assessments (see Open Foris CollectEarth in Box 4 below).

Figure 5 Comparison of coarse, medium, high, and ultra-high resolution multi-spectral satellite images over Mahe in Kerala State, India.



Source: Created by Hatfield Consultants using WorldView-2[23] , Sentinel-2, and Landsat-8 and MODIS.

2.2.4 Length of time series

The continuity and duration of a satellite remote sensing program is an important factor for monitoring environmental change. The regular, synoptic coverage of the Earth's surface through satellite Earth observation is one of the key strengths of the technology. Several programs provide a long image time series such as the Landsat Program (see Box 2). While it is possible to combine data from different sensors to monitor environmental change over a long period, continuous programs such as Landsat and the more recent Copernicus program facilitate monitoring because image processing and change detection is less complicated when using consistent image sources.

Box 2 – Landsat Program Thematic Mapper time series (1984 to present).

The Landsat Program is a series of Earth-observing satellite missions jointly managed by the NASA and the U.S. Geological Survey (USGS). Landsat-5 was launched on March 1, 1984 and the Thematic Mapper sensor delivered multi-spectral images for nearly 29 years. Landsat 7 was launched in 1999 followed by Landsat 8 on February 11, 2013, both with similar multispectral sensors. Landsat 9 is in development, with a launch scheduled at the end of 2020.

The Landsat Program's continuous archive (particularly 1984-present) provides the longest continuously acquired medium resolution remote sensing data. Landsat captured the first views from space of the Amazonian rainforest and continued to track the area year after year, giving the world an unprecedented view of systemic and rapid deforestation. This view from space allowed users to observe an activity that was taking place in an exceptionally remote part of our world. These now iconic images of tropical deforestation spurred the global environmental community to rally in an unprecedented way and resulted in worldwide attention and action[24].

The Landsat archive dataset combined with modern cloud computing resources and new time-series analysis techniques, provides unique opportunities to assess long term land cover change and trends not otherwise possible (USGS 2019).

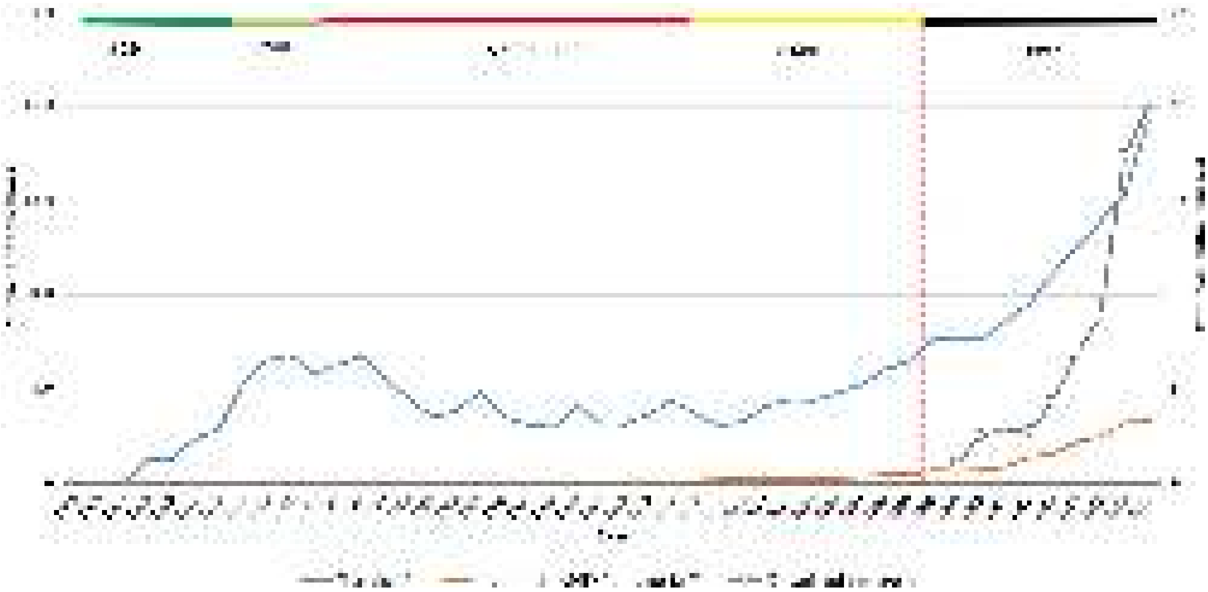
Image: Comparison of Landsat-4 image taken on December 22, 1989 and Landsat 8 image taken on March 11, 2016, shows significant deforestation in Colombia.

Image source: https://www.usgs.gov/news/earthview-landsat-chronicles-deforestation-colombia

2.2.5 Cost – Open data and commercial data

Cost of Earth observation data includes purchasing data as well as the cost of processing, storage, and analysis. Open data can be freely used, re-used and redistributed by anyone—subject only, at most, to the requirement to attribute and share-alike[25], whereas commercial data such as UHR/VHR satellite images require the user to purchase the data and follow a user license agreement. The Landsat Program became an open data program in 2008 when the USGS made Landsat data accessible via the Internet at no cost. Substantial increases in downloads of Landsat imagery ensued (Figure 6) and led to a rapid expansion of science and operational applications, serving government, private sector, and civil society[26]. For example, global mapping of annual forest change has been achieved using all available Landsat observations from 2000 to present[27]. Recognizing the value of open access for Earth observation data, the European Copernicus Program similarly provides access to all Sentinel mission data at no cost.

Figure 6 Landsat image cost, number of downloads, and the number of annual publications from 1972 to 2017.



Sources: Landsat image cost (top color bar, values)[28] Number of downloads of Landsat images (gray line)[29] Number of annual publications from 1972 to 2017 in the Scopus database that have "Landsat" (blue line) or "Landsat" AND "time series" (orange line) in their title, abstract, or keywords[26]

Providing average prices for Earth observation products is difficult because the cost of an image depends on many factors, including the spatial resolution, if it is an archive or a new acquisition, the size of area, and the number of observation dates. New business models are being developed such as subscriptions and lower prices for viewing satellite images compared to downloading the raw image for further digital processing. While the cost of data has declined dramatically, the volume of data has increased, and users need to consider the costs of download, storage, and processing.

2.2.6 Data processing level and derived products

The raw data acquired by satellite sensors and downloaded to ground stations undergo different types of processing. Image providers such as the USGS or European Space Agency (ESA) provide images with several "levels" of processing that include:

- **Geometric correction** ensures that images can be overlaid with each other and integrated with other geospatial data. Geometric registration ensures image coordinates match their true positions in ground coordinates (e.g. latitude, longitude). Ortho-rectification incorporates elevation data and sensor information to ensure image coordinates match their true positions in three-dimensional space. Orthorectified data enable more accurate calculation of distances and areas from imagery.
- **Radiometric calibration** is a process whereby different calibrations are applied to bring the digital numbers that comprise an image to a comparable scale. Radiometric calibration to surface reflectance addresses the effects variable atmospheric conditions or topography have on the data recorded by the sensor. Using surface reflectance improves comparison between multiple images over the same region by accounting for atmospheric effects such as aerosol scattering and thin clouds, which can help in the detection and characterization of Earth surface change[30].

For more information on digital image processing:

- Introductory Digital Image Processing: A remote sensing perspective[31]
- A survival guide to Landsat preprocessing, providing an overview of geometric and radiometric processing for Landsat imagery.

To address issues of access, storage, and processing of large amounts of satellite Earth observation data, new cloud-based infrastructure services are emerging which enable users to access and process images in the cloud without having to download raw images. Many of these cloud platforms provide "**analysis ready data**" (ARD) that are orthorectified and radiometrically calibrated. ARD can also include composite products (e.g. monthly cloud free composite created from daily data) or derived products such as spectral indices like NDVI. With advances in computation, some platforms create ARD "on-the-fly" when a user requires the data, rather than pre-processing and storing numerous derived ARD products.

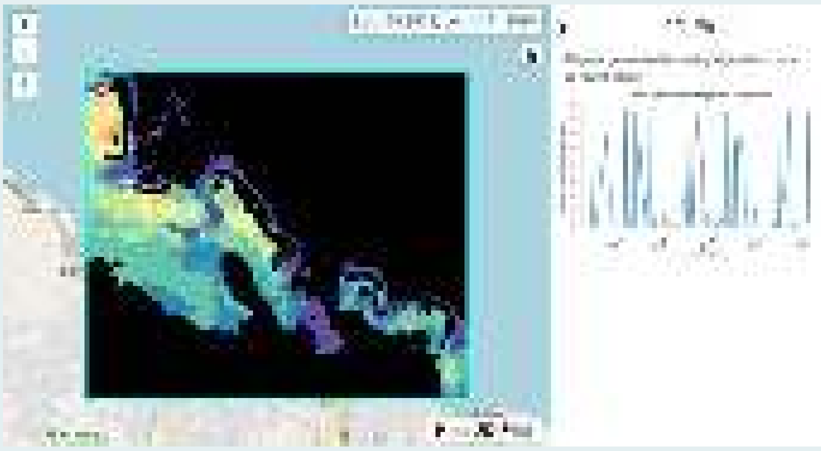
Earth observation "**data cubes**" are a new paradigm revolutionizing the way users can interact with EO data and a promising solution to store, organize, manage and analyze EO data. The main objective of a data cube is to facilitate Earth observation data usage by addressing the challenges presented by the volume, processing requirements, and computing resources needed to efficiently prepare and utilize Earth observation data (see Box 3). A data cube may address a specific user group or thematic area, and enable the integration of field observations and non-Earth observation data.

Box 3 – Open Data Cube for environmental change analysis.

Open Data Cubes (ODCs) are one method for building data cubes either on the Amazon Web Service (AWS) cloud infrastructure, or on a server managed from a specific location. There are about 50 ODCs either operating or in production around the world, including a few for some of the small islands in the Pacific region. Cloud-based ODCs can be a very effective way for regional islands to access large time series of images because they can reduce the amount of data that needs to be transferred over the islands typically expensive satellite Internet connections.

The Samoa Data Cube, for example, contains Landsat Thematic Mapper (TM) images processed to “analysis ready data” (ARD), extending in time from about 2010 to 2018. One of the applications available on the Samoa Cube is an assessment of Total Suspended Matter (TSM), which can reflect the impact of land use activities on coastal water quality. The figure below shows a subset of the spatial extent of imagery available in the Samoa Cube – the purple line is the extent of image data coverage in the cube. Left panels show the number of images analyzed.

The inset shows Total Suspended Matter (TSM) between 2 November 2013 and 6 June 2018. Blues are low TSM, red is high TSM. The inset results show average TSM between 2013 and 2018 near the Samoan capital, Apia. This extent took about 30 seconds to process on the AWS from Australia.



These results show typically low TSM levels (clear water) near the Samoan coastline in this region, with higher TSM levels occurring on the inside of reefs that are visible as dark patches within the classified results.

This may indicate small or infrequent point-sources of TSM pollution in this region, with higher TSM levels resulting from the accumulation of these pollution sources over a larger area being ‘trapped’ by the reef systems.

Source: Commonwealth Scientific and Industrial Research Organisation (CSIRO).

2.2.7 Reference data and validation

Validation and accuracy assessments are a critical aspect of studies using Earth observation data. Existing products generated by agencies have typically undergone rigorous calibration and validation and provide accuracy information. For example, the Copernicus Global Land Service publishes quality information for each product[32]. When using off-the-shelf products, GEF implementing agencies and partners can still complete their own independent evaluation of the products using local *in-situ* data.

Accuracy assessment is based on reference data and statistical sampling to deduce estimates of error in classifications. The Open Foris Collect Earth (Box 4) and LACO-wiki are useful tools to develop reference data for land cover monitoring projects. Classification accuracy assessments usually report errors of omission (e.g. a forest area was not correctly mapped as forest) and commission (e.g. a non-forest area was falsely mapped as forest) and in most situations these errors for a class are not equal. To calculate these errors as well as the uncertainties (confidence intervals) confusion matrices are generated by comparing the reference information of the samples with their corresponding classes on the map. Thematic accuracy for each class and overall accuracy is then presented in the error matrices.

For more information on conducting accuracy assessments:

- A review of assessing the accuracy of classifications of remotely sensed data[33].

Citizen science offers great potential for involving local citizens, communities, and agencies to providing local reference and validation data to support environmental assessment and monitoring using Earth observation. The widespread adoption of mobile devices and social media platforms, coupled with the development of low-cost sensors, has made it easier for the public to contribute to and engage in scientific research and monitoring. Citizens' observations, data and information can complement official, traditional *in-situ* and remote sensing EO data sources in several areas, such as climate change, sustainable development, air quality monitoring, vector-borne disease monitoring, food security, flood, drought and natural perils monitoring, and land cover or land-use change, among other topics[34].

Box 4 – Land cover and use assessment using Open Foris Collect Earth.

Collect Earth is a free and open source application for land monitoring developed by the Food and Agriculture Organization of the United Nations (FAO). Supported by Google cloud and desktop technologies, it facilitates access to multiple freely available repositories of satellite imagery. These include very high spatial resolution imagery (Google Earth) and the full catalogue of imagery from Landsat, MODIS, Sentinel and other EO products through the Google Earth Engine cloud services.

This combination allows for both the possibility to analyze current land cover/use as well as to track its changes.

Users can easily configure Collect Earth to address specific monitoring purposes, such as landscape restoration, land degradation assessments, reporting for Reduced Emissions from Deforestation and Forest Degradation (REDD+), national forest inventories, etc., with a multi-temporal and multi-scale approach.

Collect Earth has been used extensively in developing, managing, monitoring and evaluating GEF projects. In the baseline assessment for the Drylands Sustainable Landscapes Impact Program, FAO has conducted a comprehensive remote sensing survey using Collect Earth to characterize the selected areas. Information on land use and land use changes, disturbances, cropland management, tree cover, infrastructure and others, was collected to support countries in planning interventions. These results are used as baseline information from which to evaluate the project.

The Office of Evaluation of FAO has also used the tool to support their efforts. Recently Collect Earth was used to gather information on the expansion of agricultural area after the rehabilitation of irrigation channels in Afghanistan – thanks to access to historical imagery, the project evaluation can be done even without a pre baseline study[35].

Due to its free and open source nature, Collect Earth can be use by any institutions independently. FAO provides sustainability for the long-term maintenance of the tool as well as technical support for different stakeholders. Collect Earth Online – implemented by the FAO jointly with SERVIR, the U.S. Forest Service, the Spatial Informatics Group (SIG), and Google Earth Engine – is a next generation, web-based version of Collect Earth.

Source: www.openforis.org

2.3 TRENDS IN EARTH OBSERVATION TECHNOLOGY

Earth observation technology has undergone a period of rapid development over the past five years, building on the developments in information and communications technology, including computing capacity, location-enabled and Internet-connected mobile devices, and the numerous services associated with them. Figure 6 highlights the key trends in remote sensing, including the move towards open data and improved availability of data. New approaches to using Earth observation data exploitation have evolved, with cloud computing platforms for data storage, processing, and visualization. These platforms can provide access to commercial data on a subscription basis or open data. The most well-known Earth observation cloud computing platforms in the development community are Google Earth Engine and Sepal, which provide access to big Earth observation datasets and provide processing tools. Advanced users can take advantage of cloud computing systems from Amazon Web Services, Microsoft Azure, and the European Commission supported Data and Information Access Services (DIAS). More information on Earth observation platforms is provided in Section 3.3.3. These power computing platforms enable large scale, systematic data processing and many platforms host ARD and other non-Earth observation datasets.

Numerous powerful software packages and analytics tools are available, including in the cloud, many of which are open source and allow for systematic processing. New analytical methods include machine learning, artificial intelligence, with a focus on combining Earth observation with other data such as socio-economic data for applications such as disaster risk reduction[36]. Evidence-driven disaster risk management (DRM) relies upon many different data types, information sources, and types of models to be effective. Tasks such as weather modelling, earthquake fault line rupture, or the development of dynamic urban exposure measures involve complex science and large amounts of data from a range of sources. Even experts can struggle to develop models that enable the understanding of the potential impacts of a hazard on the built environment and society.

A machine learning (ML) algorithm is a type of computer program that learns to perform specific tasks based on various data inputs or rules provided by its designer. Machine learning is a subset of artificial intelligence (AI), but the two terms are often used interchangeably. For a thorough discussion of the differences and similarities of the terms ML and AI, see Section 2. As the name implies, an ML algorithm's purpose is to "learn" from previous data and output a result that adds information and insight that was not previously known. This approach enables actions to be taken on the information gathered from the data; sometimes in near real time, like suggested web search results, and sometimes with longer term human input, like many of the DRM case studies presented in this document.

Over the past few decades, there has been an enormous increase in computational capacity and speed and available sensor data, exponentially increasing the volume of available data for analysis. This has allowed the capabilities of ML algorithms to advance to nearly ubiquitous impact on many aspects of society. Machine learning and artificial intelligence have become household terms, crossing from academia and specialized industry applications into everyday interactions with technology—from image, sound, and voice recognition features of our smartphones to seamlessly recommending items in online shopping, from mail sorting to ranking results of a search engine. The same technology is being leveraged to answer bigger questions in society, including questions about sustainable development, humanitarian assistance, and disaster risk management[33]. Organizations like Radiant Earth Foundation are enabling machine learning by creating an open repository for geospatial training data.

3.0 HOW TO USE EARTH OBSERVATION IN GEF PROGRAMMING

GEF projects require a varied range of data and information across broad landscapes and time periods that cannot be collected using field-based methods alone. Use of Earth observation technology and techniques enables identifying and detailing the biophysical characteristics of habitats and detecting natural and human-caused environmental change at scales ranging from individual projects and landscapes to the entire world. It allows users to observe and assess important biological and physical features of the Earth and to monitor change over time. This type of information can be used to understand past trends to provide information to support management decisions or monitor the impact of GEF interventions[37].

3.1 EARTH OBSERVATION ACROSS THE GEF PROJECT CYCLE

The use of Earth observation technology is not explicitly required in the design of GEF projects; however, there is compelling justification to integrate it into project preparation, implementation, monitoring and evaluation. Earth observation technology is useful at several points in the GEF project cycle, but the appropriate data sources and methods differ depending on the stage of the cycle (Figure 7). Typically, the information requirements and level of effort required in working with these data are less demanding at the concept development and project preparation stages. Information derived from Earth observation data and technology can complement data obtained using qualitative methods. Integrated, mixed method approaches (i.e. data triangulation) can be used to better understand not only the past and current state of a landscape, but also the underlying drivers of change and how interventions can change the current trajectory.

Figure 7 Using Earth observation across the GEF project cycle.

Concept Development

Developing a GEF project concept requires compiling and analyzing a range of data to ensure an up-to-date understanding of the environmental conditions in the project's location. At this stage, published information and tools can be easily accessed to explore key issues, trends, and degradation processes and drivers to inform the proposed intervention.

The GEF **Project Information Form (PIF)** requires georeferenced data and a map showing the project's location. Systematic information on the location and impact of GEF interventions can improve decision-making, accountability, and transparency. However, like all types of data, geographic data needs to be managed to protect privacy and meet security requirements.

The benefits of collecting and sharing geographic information on GEF projects include:

- better understanding of the geographic context and spatial extent of GEF projects; currently, the GEF portal shows only the name of the country in which the project is located;
- accessible information on past and current GEF project locations can help users to identify synergies, avoid potential duplication of effort, and coordinate to maximize the impact of GEF investment;
- better monitoring of projects during the implementation phase, which could help projects to adapt to changing conditions; and
- robust and precise evaluation of project impacts.

Appendix 1 provides detailed guidance for GEF agencies to complete the PIF and provide an acceptable map. There are four approaches to using Earth observation data:

- **Do it yourself** – the Copernicus and NASA/USGS programs have unlocked a large amount of free, high quality and high-resolution Earth observation data. You can use in-house expertise, hardware, and software or cloud platforms such as Google Earth Engine, SentinelHub, NASA Worldview).
- **Use free, existing higher-level products** – requiring less expertise to utilize, thematic products provide quantitative data to develop a baseline, assess trends, and address GEF indicators. Examples include Copernicus Land Cover, Global Surface Water Explorer or above ground biomass from FAO WAPOR portal.
- **Use dedicated portals with more advanced visualization tools** - including Global Forest Watch or Trends.Earth (Box 10 below), or the Vital Signs Atlas used by the GEF Food Security Integrated Approach Pilot.
- **Work with specialized partners and consultants** –use external services for processing, image interpretation, and product development.

Earth observation can also contribute to the assessment of environmental and social risks and potential impacts associated with the proposed project or program, and identification of measures to address such risks and impacts. For example, the World Bank uses the Integrated Biodiversity Assessment Tool (IBAT) to assess the potential impacts of a project on biodiversity as part of its Environment and Social Safeguards screening process.

Project preparation

Once the project concept is approved, additional information is likely to be needed for CEO endorsement. For example, supplementary data analysis and quantitative information may be required to further delineate the project's boundaries, and to refine estimates of expected global environmental benefits. At **CEO Endorsement/Approval**, agencies provide additional information regarding the relevant environmental and social risks and impacts associated with the proposed project. The same data portals and tools used in concept development may provide the required information.

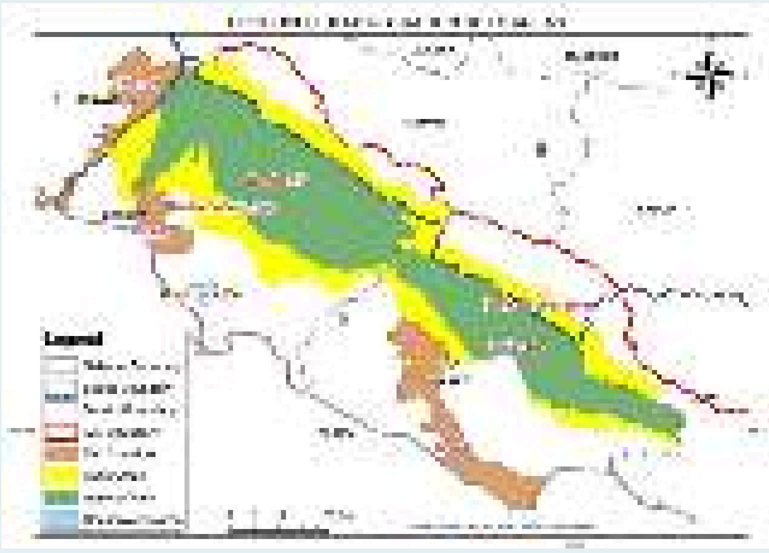
For example, the Integrated Landscape Management to Secure Nepal's Protected Areas and Critical Corridors project from WWF-US (see Box 5) used forest cover data derived from remote sensing images and spatial analysis to determine baseline information and to identify target areas for project interventions.

The project document can specify the Earth observation data and analysis that should be completed to support project implementation, for example what type of detailed mapping may be required or how Earth observation will be used to generate data for indicator reporting.

Box 5 – Using land cover and land use data for GEF project preparation in Nepal.

The Integrated Landscape Management to Secure Nepal's Protected Areas and Critical Corridors project (GEF ID 9437) aims to promote integrated landscape management to conserve globally significant forests and wildlife in Nepal. The focus of the project is in the biodiversity-rich corridors and protected area buffer zones of the Terai Arc Landscape (TAL). The project activities include multi-level inter-sectoral coordination, improved participatory planning for conservation, improved forest management practices, and management of the human-wildlife interface.

During project preparation, WWF and project partners required an understanding of recent and current baseline land cover and land use in the TAL. An existing widely used dataset for Nepal developed by International Centre for Integrated Mountain Development (ICIMOD) in 2010 provided historical context. To generate current land use and land cover conditions, WWF used Landsat images (30 m resolution) from 2016 and a supervised classification approach, followed by verification using field data.



The baseline area of degraded agricultural land was calculated using the land use and land cover map of 2010 and 2016 to identify agricultural land converted into barren land, sand exposed surfaces, or water bodies. The results were verified during field visits. Forest degradation and forest conversion to other land use was similarly assessed and validated in the field.

Other datasets were used to support planning, such as the Key Biodiversity Areas (KBA) provided by BirdLife International, and forest fires from a database of Active Fire Incidents in Nepal, managed by ICIMOD. Additional analysis included calculation of forest patch size to study connectivity of forest cover in targeted corridors.

The remote sensing data and analysis supported development of the results framework aligned with GEF-7 Core Indicators and baseline and target values for each GEF 7 Core Indicator.

Source: WWF.

Implementation and monitoring

Earth observation data and analysis can be used to support project implementation and monitor progress, including on performance indicators, building on data sources and information gathered for concept development and project preparation. The synoptic, consistent, and regular information that can be obtained from Earth observation can be used to review up-to-date environmental conditions and trends to support adaptive management. Earth observation data can inform proposals to modify the project design during, for example, the **Mid-term Review (MTR)**, at which time the implementing and executing agencies assess whether or not the project is on track to meet indicators set out in the project document and propose appropriate modifications, if necessary.

Evaluation

Earth observation is useful for evaluation of the project intervention and final reporting against project indicators for the **Terminal Evaluation (TR)**. When combined with other spatial information, Earth observation data can reveal new insights and geospatial analysis can help overcome some of the limitations that are encountered in evaluations on a regular basis, such as missing baseline information and information on the evolution of environmental conditions as a project progressed[37].

The GEF Independent Evaluation Office (IEO) is increasingly using Earth observation data and analysis to verify project outcomes in areas such as forest management, protected area management[38], and to assess impact and estimate value for money[39]. Building on this work and post completion evaluation assessments frameworks used by the World Bank and Japan International Cooperation Agency (JICA), the IEO has developed a methodological approach for consistent post-completion verification[40]. This integrates the use of satellite Earth observation data and geospatial analyses to generate and evaluate long-term data trends in environmental outcomes as well as to regenerate relevant key baseline data.

A pilot study for the Yellow Sea Region demonstrated that geospatial analyses of environmental indicators provide a valuable tool to gain insight to the impacts of GEF initiatives. Not only does satellite Earth observation allow for a pattern of observed time series data, but it also enables evaluators to understand the cumulative impact of GEF interventions, combined with other interventions, within a system or region to establish whether or not ecosystems are improving—a goal at the center of GEF environmental funding[40]. However, the method is useful only for those projects with environmental indicators that can be detected remotely (see Figure 3 above).

A goal of many GEF projects is to build capacity of in-country partners for environmental governance. An advantage of using Earth observation is that the development of the technical capacity of government partners and other local stakeholders to use open data and tools can contribute to enduring impacts beyond a project[41], for example to support long-term policy formulation, strategic planning, and growing the technical skills.

3.2 EARTH OBSERVATION APPLICATIONS

This section introduces the capabilities of satellite Earth observation data and products for GEF focal area projects and Impact programs, recognizing that the greatest benefits from Earth observation technology are usually achieved when it is used as a complementary tool with other scientific methods and data, including qualitative research.

3.2.1 Biodiversity

GEF-7 prioritizes integrated approaches to achieve the biodiversity conservation. Biodiversity is addressed in Impact Programs on Food Systems, Land Use and Restoration, Sustainable Cities, Sustainable Forest Management (SFM) and the International Waters Focal Area. GEF investments include: Biodiversity Mainstreaming in Priority Sectors; Global Wildlife Program; and Natural Capital Assessment and Accounting[1].

Spatial and land use planning is often a critical first step for biodiversity investments in production landscapes and seascapes. For example, the GEF Global Wildlife Program (GWP) strategy addresses spatial and land use planning in protected area management. Natural capital assessments are spatial assessments of stocks of natural capital and/or delivery of ecosystem services, which are often accompanied by assessing land cover and land use change under different scenarios with decision-makers and stakeholders[1].

Earth observation technology has a critical role in biodiversity conservation and is well suited to assess and monitor critical drivers of biodiversity change such as habitat change (loss, degradation, and fragmentation), particularly habitat loss driven by the expansion of agriculture and climate change. The Group on Earth Observations (GEO) Biodiversity Observation Network (BON) (a partner of the Convention on Biological Diversity (CBD)) supports systems for regional and global biodiversity assessment including defining the Essential Biodiversity Variables (EBVs), which are "derived measurements required to study, report, and manage biodiversity change"[42]. Effort is underway to apply remote sensing technology to assess the status and trend of EBVs. Table 1 summarizes candidate remote sensing EBVs (RS-EBVs). While EBVs are not formally part of GEF-7 results framework, projects can benefit from adopting RS-EBVs given their support within the Convention on Biological Diversity and research community.

Many geospatial databases for biodiversity (e.g. GBIF and NatureServe) complement data derived from Earth observation. Box 5 (above) illustrated how WWF used Earth observation data as part of planning a protected area management project in Nepal. Box 6 describes the United Nations (UN) Biodiversity Lab, which provides support to all GEF-eligible countries to revise their National Biodiversity Strategy and Action Plans (NBSAPs) and fulfill their national reporting obligations to the CBD. Box 7 illustrates a case study from the UN Development Programme (UNDP) of the use of remote sensing derived habitat information to assess ecosystem services provided by the habitat of the Jaguar (*Panthera onca*).

Table 1 Candidate remotely sensed essential biodiversity variables (RS-EBV).

Biodiversity theme	Candidate RS-EBV	Observational approach	Example product
Sustainable production and consumption	• Net primary and secondary productivity	• Measures of productivity derived from optical imagery	• NDVI • fAPAR2
Habitat loss, fragmentation and degradation; Protected areas	• Ecosystem extent and fragmentation	• Ecosystem extent and habitat mapping derived from optical and radar imagery • Fragmentation analysis	• Land cover • GFW tree cover
Sustainable exploitation of marine resources	• Net Primary Productivity	• Measures of productivity derived from optical imagery	• fAPAR • Ocean greenness
Sustainable management	• Habitat structure	• Land cover derived from optical images and forest canopy height derived from radar or lidar data	• Canopy height model
Pollution reduction	• Nutrient Retention	• Crop type maps and management practices derived from optical images • GIS modeling of nutrient retention on a watershed scale	• Crop cover • Land cover
Control of invasive alien species	• Species distribution	• Vegetation maps derived from optical images • Species distribution models	• Vegetation types
Coral reefs and other vulnerable ecosystems	• Ecosystem composition by functional type and/or habitat structure	• Functional type inferred from remote sensing • Forest habitat structure from airborne lidar • Bathymetry from lidar or sonar	• Canopy height model • Bathymetry • Coral reef, mangrove, and wetland extent
Ecosystem services safeguarded	• Ecosystem composition by functional type • Ecosystem extent and fragmentation	• Functional type inferred from remote sensing • Habitat structure from airborne lidar • GIS modeling of ecosystem services at landscape scale	• Land cover • Canopy height model
Ecosystem resilience enhanced	• Phenology and/or land cover change	• Land surface phenology optical imagery	• NDVI time series

Notes: Biodiversity theme is linked to Aichi target. fAPAR - fraction of absorbed photosynthetically active radiation (see Section 3.2.3)

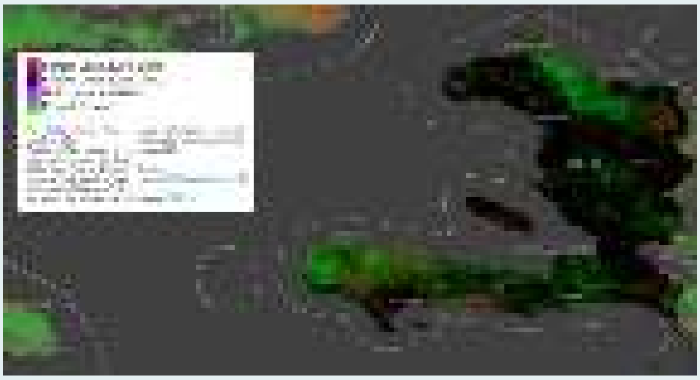
Source: Based on O'Conner et al. 2015[43]

Box 6 – UN Biodiversity Lab to build capacity of policymakers to use spatial data for conservation action.

During GEF-7 (2018 – 2021), enabling activity support is provided to all GEF-eligible countries to revise their NBSAPs and fulfill their national reporting obligations to the CBD. To build the capacity of GEF-eligible policymakers to use spatial data to implement their NBSAPs and the production of data-driven national reports, the United Nations Development Programme (UNDP), United Nations Environment Programme (UNEP), and the CBD Secretariat launched the UN Biodiversity Lab, with funding from the GEF and support from MapX, UNEP World Conservation Monitoring Centre (UNEP-WCMC), Global Resource Information Database - Geneva, and NASA. This free, open-source platform enables policymakers to access over 100 global data layers, upload their national datasets in private workspaces, and analyze these national and global data to produce key insights for conservation reporting and action.

For many countries spatial data is a powerful tool to improve baseline information and monitoring, which can provide a critical first step to support national reporting and NBSAP implementation. For example, in the Democratic Republic of Congo, the government has increased the protected area coverage from 9% (2000) to 13.8% (2019), and is drawing on spatial data from the UN Biodiversity Lab to map threatened species richness and guide establishment of new protected areas.

In Haiti, the use of spatial data from the platform has led to improved forestry management by supporting monitoring, reporting, and guiding decisions about where restoration efforts should be intensified.
In Viet Nam, UN Biodiversity Lab is being used to investigate, review, and map ecological regions with the purpose of identifying areas of high biodiversity value.



Use of UN Biodiversity Lab by GEF-eligible Parties increased the number of maps in the Sixth National Reports (6NRs) 150%, from 6.8 in the Fifth National reports to the 17 in the 6NR. For the Post-2020 Global Biodiversity Framework, the UN Biodiversity Lab can provide support to create scientifically rigorous targets, assess progress towards these targets at the global level, and support policymakers to identify where to take action based on their NBSAPs.

Source: UNDP

Box 7 – Ecosystem services provided by the habitat of the Jaguar (*Panthera onca*).

To assess the extent and value of ecosystem services within the jaguar range across Latin America, UNDP, King's College London, and Equilibrium Research used the Co$ting Nature tool and mapped other conservation-related factors including biodiversity, current human pressure on the land, and future threats. Biophysical ecosystem service production and value was calculated at the local, national and global scale. Many geospatial datasets contributed to the assessment, including vegetation information derived from MODIS and SPOT[b] satellite sensors and Landscan population data. Results identified the most important ecosystem services, which include carbon storage, natural hazard mitigation, non-timber forest products, water provisioning, culture-based tourism, and nature-based tourism. The information is used to raise awareness on the importance of jaguar landscapes for achieving sustainable development goals. It is also used to generate political will for greater investment and action in conserving Jaguar landscapes and corridors, in the context of government programs including GEF financed projects.

Source: UNDP

3.2.2 Climate Change Mitigation and Adaptation

Climate change is a priority for GEF-7 cutting across Focal Areas and Impact Programs with activities aligned with priorities identified in nationally determined contributions (NDCs). GEF-7's Climate Change focal area addresses renewable energy and other mitigation activities associated with Sustainable Cities, Food Systems, Land and Restoration, and Sustainable Forest Management Impact Programs. Several international initiatives provide important datasets for planning climate change action, including ESA's Climate Change Initiative, which provides systematic observation of climate based on the concept of the Essential Climate Variable (ECV) - a physical, chemical or biological variable or a group of linked variables that critically contributes to the characterization of Earth's climate.

Carbon accounting

Carbon accounting is crucial to addressing climate change, providing data on where emissions emanate and where they are absorbed. Decision-makers rely on the best information about the earth's changing sinks and sources as they seek to constrain global emissions[44]. Earth observation supports national inventory of sources and sinks of greenhouse gases (GHG), following good practice methodologies accepted by the Intergovernmental Panel on Climate Change (IPCC). The key applications are:

- **Land use and land cover mapping** – following the IPCC land categories for GHG inventory reporting: 1) Forest land; 2) Cropland; 3) Grassland; 4) Wetlands; 5) Settlements; and 6) Other land. These may be subdivided but the land cover classification system should be used consistently over time.

[b] Satellites Pour l'Observation de la Terre (SPOT) is a series of commercial medium resolution satellite sensors. Currently SPOT 6 & 7 provide optical data with a spatial resolution of 6 m.

- **Carbon stock assessment** – land use and land cover mapping capable of representing carbon stock changes and greenhouse gas emissions and removals. This is often achieved through national forest inventory data and stratification of land use and land cover data generated using remote sensing. In the future, the GEDI lidar mission (see Section 2.1) will provide canopy height, canopy form, leaf area index, and biomass estimates that can support carbon stock assessment. The GEF-financed Satellite Monitoring for Forest Management (SMFM) project developed a biomass estimation tool using ALOS PALSAR radar data (see Box 18 below).

Many GEF projects use the Ex-Ante Carbon-balance tool (EX-ACT) to estimate the potential carbon reduction benefits of project interventions. EX-ACT is a land-based accounting system that relates activity data from the agriculture, forestry and other land use (AFOLU) and the fishery sectors to:

1. Estimate values of the five carbon pools: above ground biomass, below ground biomass, dead wood, litter and soil organic carbon; and
2. Estimated coefficients of CO_2, CH_4, N_2O and selected other greenhouse gas emissions.

One of the inputs to the model is land use and land cover change, which can be obtained from remote sensing derived statistics of the target area[45]. This information is used by GEF projects to estimate the impact of projects on the total carbon-balance. Although easy to use and deploy, tools such as EX-ACT have certain limitations. It is not spatially explicit and does not account for the contextual factors driving land use and land cover change. A spatially explicit ecological forecasting approach, such Land Change Modeler in TerrSet can help address and complement appraisal systems such as EX-ACT[46].

Another important input for the land use module relates to fire activity, which is easily accessible through portals such as NASA's Fire Information for Resource Management System (FIRMS) (see Box 8) or ESA's World Fire Atlas.

Box 8 – NASA's Fire Information for Resource Management System.

For more than a decade, sensors aboard Earth observing satellites and NASA's FIRMS provide critical information about wildfires to anyone, anywhere in the world. FIRMS provides active fire data (including an approximate location of a detected hotspot) from NASA's MODIS and VIIRS instruments generally within three hours of a satellite overpass, with imagery available within four to five hours.

Global active fire detections can be viewed interactively using the FIRMS Fire Map application, and active fire data for the last 24 hours, 48 hours, or week can be downloaded in shapefile, KML, WMS, or text file formats (data older than seven days can be obtained using the FIRMS Archive Download Tool.

Along with government agencies, numerous non-governmental organizations also have developed systems or websites that use FIRMS data. These include the Firecast system developed by Conservation International (CI) and three websites run by the World Resources Institute (WRI) such as Global Forest Watch Fires.

FIRMS near real-time active fire data help land managers in the tropics monitor ecosystem threats, actively manage fires, strategize patrols of protected areas, and enforce land use policies.

The MODIS Fire and Thermal Anomalies Product (MCD14DL) is the foundation of FIRMS products. The VIIRS I-band (375 m) Active Fire product (VNP14IMGTDL_NRT) was added to the FIRMS collection in 2016. VIIRS, however, provides better response for smaller fires and provides improved mapping of large fire perimeters. In addition, the VIIRS 375 m product shows a better response in nighttime observations, when fire activity normally subsides.

FIRMS is part of NASA's Land, Atmosphere Near real-time Capability for EOS (LANCE) system. LANCE provides more than 100 near real-time products from instruments aboard Earth observing satellites. LANCE, in turn, is part of NASA's Earth Observing System Data and Information System (EOSDIS), which is responsible for NASA's Earth observing data collection.

Source: NASA EODIS[47]

Renewable energy

Earth observation and geospatial technologies play a key role in planning sustainable development of all forms of renewable energy, including bioenergy, geothermal, hydropower, solar and wind energy. For example, surface solar irradiance maps and offshore wind maps, derived from Earth observation, can support solar energy and wind energy planning, respectively.

The International Renewable Energy Association (IRENA) Global Atlas of Renewable Energy provides maps of renewable energy resources for locations across the world. It was developed for utility scale and off-grid applications using GIS-based spatial analysis method integrating data such as resource quality, transmission grid distance, population density, topography and protected areas. The Atlas identifies suitable zones for solar and wind energy development, and indicative estimates of the technical potential. Development of specific sites requires more detailed appraisal of environmental, economic, social, and resource potential data.

Climate resilience

Climate resilience is a key component of any healthy system, particularly in vulnerable countries that depend heavily on climate-sensitive natural resources and traditional agricultural practices for subsistence and livelihoods.

Climate-resilient decision-making requires good quality data and information, often lacking in many developing regions of the world. Up-to-date and accurate land cover and land use data provide a foundation for climate change adaption planning. Earth observation technology provides a critical input to weather forecasting and to climate data records, for example enabling the mapping and modelling of land surface temperatures, extreme precipitation, flooding, drought, and wildfires. At the landscape level, climate-smart agriculture requires integration of data on production systems, livelihoods, biodiversity, and ecosystem services.

Earth observation provides an important input into regional drought and water security monitoring services. For example, the FAO Agricultural Stress Index System (ASIS) provides a global overview of the impact of ongoing droughts on crops and pasture. Data from the METOP-AVHRR satellite are automatically processed every 10 days to map the extent, duration and severity of agricultural droughts[48]. ASIS can be fine-tuned and operated at local scale.

3.2.3 Land Degradation

Land degradation is any reduction or loss in the biological or economic productive capacity of the land resource base. Sustainable land management practices are required to achieve Land Degradation Neutrality (SDG Target 15.3), a state whereby the amount and quality of land resources, necessary to support ecosystem functions and services and enhance food security, remains stable or increases within specified temporal and spatial scales and ecosystems[49]. GEF-7 addresses the drivers of land degradation and ecosystem restoration in the Land Degradation focal area and the Food Systems, Land Use and Restoration (FOLUR), SFM, and Sustainable Cities Impact Programs[1].

The International Fund for Agricultural Development (IFAD) is a GEF partner focused on rural development, environmental sustainability and climate resilience. Earth observation and GIS are used within IFAD operations, across the project cycle and provides examples of a GEF agency and GEF financing acting as a catalyst for the adoption of consistent methods (see Box 9).

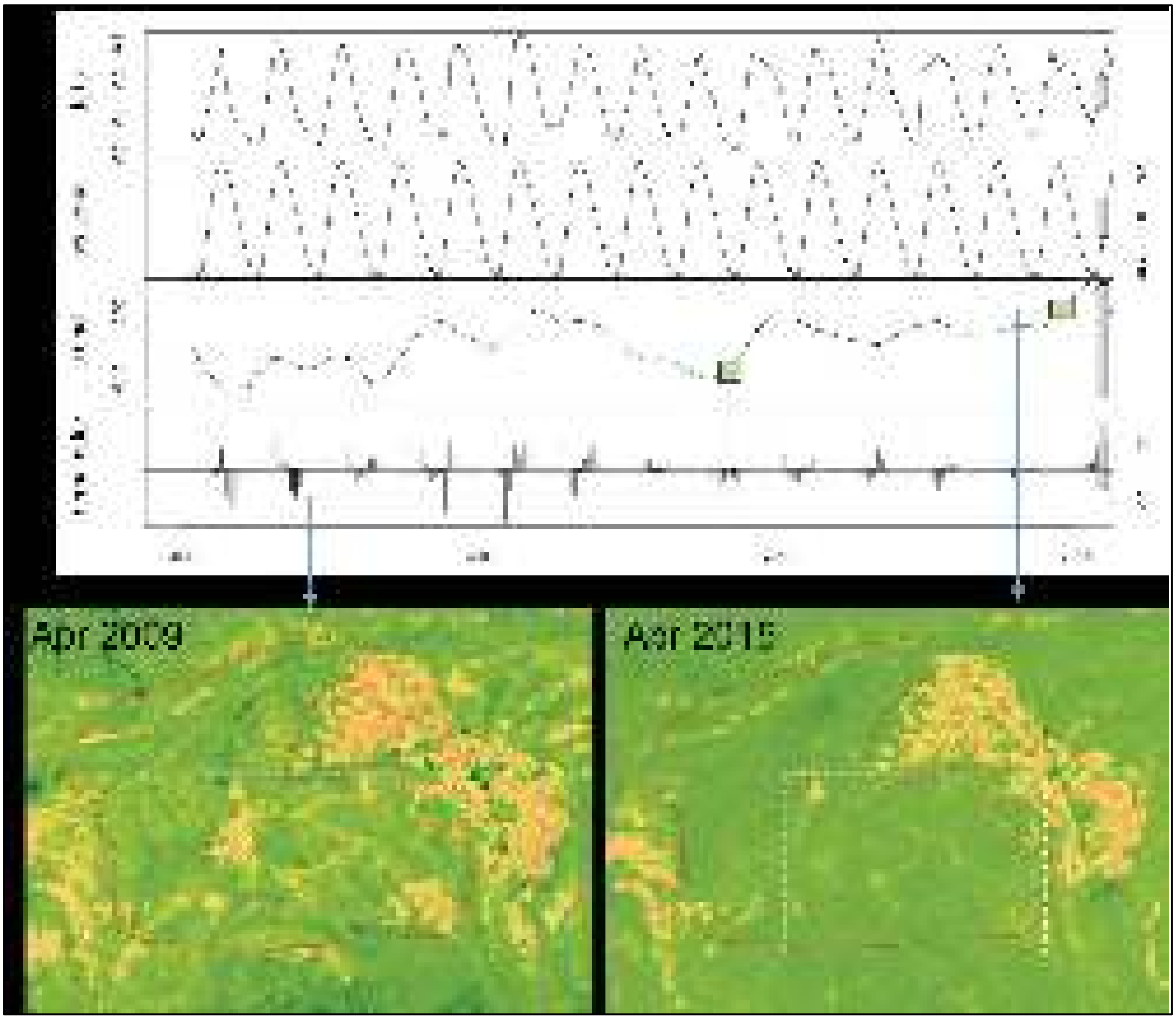
Earth observation data complement other data including field data, soils, topography, and rainfall data in a landscape approach to assess and monitor land degradation and restoration. For example, remote sensing derived land cover data contributes to the Land Degradation Surveillance Framework (LDSF)[50], a landscape level biophysical baseline, monitoring, and evaluation framework for assessing processes of land degradation and the effectiveness of rehabilitation measures.

For more information on Earth observation data for land degradation:

- Handbook and Database of Drought Indicators and Indices, Integrated Drought Management Programme.
- Products to assess land degradation and environmental conditions, EO4SD Agriculture and Rural Development Cluster

Trend analysis using remote sensing data in a time series is useful for assessing land degradation and restoration. Regular observations from Landsat-8, Sentinel-2, and MODIS provide opportunities to understand land degradation and improvements due to restoration activities. The GEF-supported Trends.Earth application (Box 10) provides tools for monitoring degradation or improvement in land conditions. The GEF IEO used time series analysis to assess the impact of GEF investments in ecosystem restoration (Figure 8)[51].

Figure 8 Time-series of vegetation productivity (upper panel) and before and after vegetation productivity maps (lower panel) for the Sustainable Land and Ecosystem Management Country Partnership Program in India.



Source: GEF IEO (2018)[52]

Direct measures of vegetation productivity and biomass are the best methods to monitor net primary productivity (NPP), but simple vegetation indexes such as NDVI are commonly used[53]. Earth observation variables such as leaf area index (LAI) or fAPAR are considered more robust tools for assessment of vegetation productivity but are more complex to estimate. Table 2 provides a summary of common remote sensing derived measures, including NDVI and fAPAR, and LAI.

Table 2 Remote sensing derived measure of net primary productivity for land degradation.

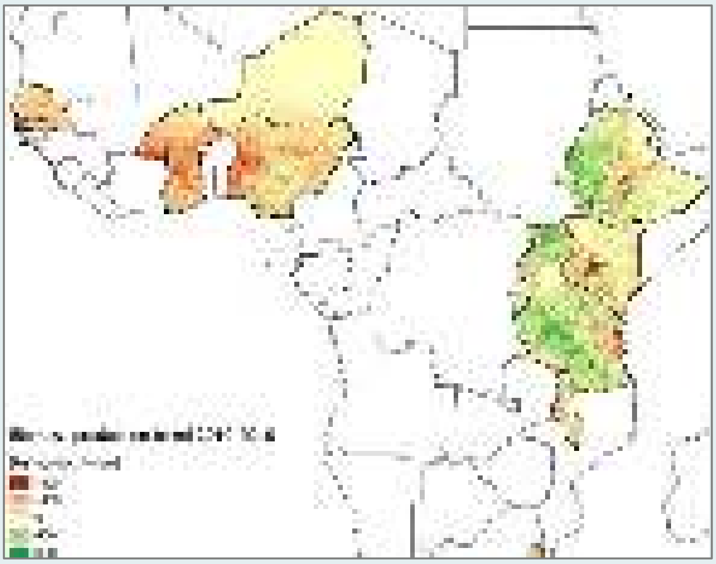
Metric	Description	Example Products	Spatial Resolution
NDVI	Ratio of the difference in the intensity of reflected light in the red and NIR band and the sum of these intensities	MODIS MOD13	250 m – 1 km
		Copernicus Global Land Service NDVI	300 m – 1 km
		Sentinel-2	10 m
		Landsat-8	30 m
SAVI	Soil-adjusted vegetation index (Huete 1988), A transformation technique is presented to minimize soil brightness influences from spectral vegetation indices involving red and near-infrared (NIR) wavelengths.	Sentinel-2	10 m
		Landsat-8	30 m
fAPAR	Fraction of the solar radiation absorbed by live leaves for the photosynthesis activity	MODIS MOD15	500 m
		Copernicus Global Land Service fAPAR	300 m – 1 km
LAI	Half the total area of green elements of the canopy per unit horizontal ground area. Practically, the LAI quantifies the thickness of the vegetation cover	MODIS MOD15	500 m
		Copernicus Global Land Service LAI	300 m – 1 km

Source: Copernicus Global Land Service[32] and USGS Earth Data Catalog[54].

Box 9 – IFAD's development and use of Earth observation

IFAD uses Earth observation technology and datasets to address information needs in climate and environment, crops, fisheries and aquaculture, and livestock and rangeland. In project design Earth observation derived maps and statistics inform the design teams, for example climate analysis and climate vulnerability assessment. During project implementation, GIS is used for monitoring and evaluation to map project interventions. Earth observation is an essential part of IFAD's project impact assessment.

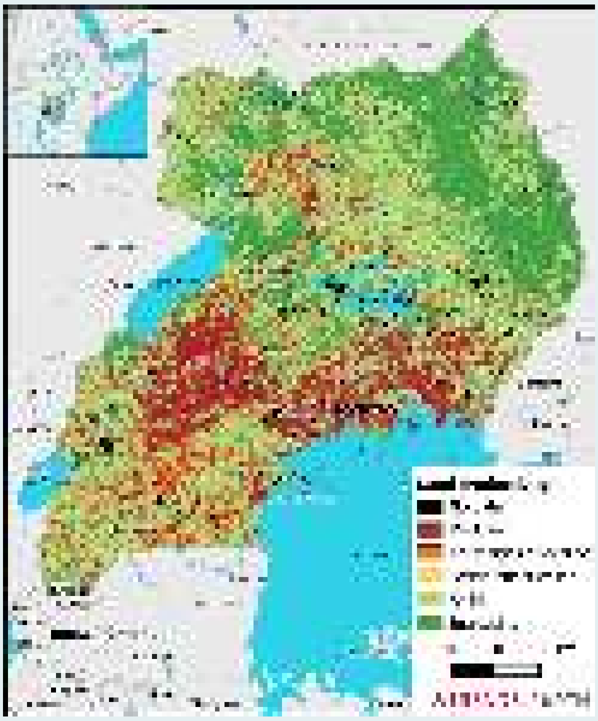
IFAD's Earth observation capacity is built in-house and via long term strategic partnerships (e.g. World Food Program, Conservation International, FAO, CGIAR, and ESA). A workshop in Ghana held in March 2019 under the GEF-financed Food Security Integrated A (Food-IAP) recognized the value of Earth observation for systematic monitoring of indicators on regional scale[55]. The Food-IAP Resilience Atlas developed by Conservation International provides satellite-based data on various indicators from the available and most recent datasets for all project sites and countries. This allows users to derive insights from large surveys and climate datasets by visualizing the factors that affect resilience to stressors and shocks like climate change. The ESA-funded Earth Observation for Sustainable Development (EO4SD) Agriculture Cluster contributed Earth observation-based information on biomass production, agricultural water productivity, water consumption and deficit and soil erosion potential from water, for monitoring sustainable and integrated land management and to inform the Program-Level Indicators[56].



Earth observation technology is well suited to support the implementation of the Food-IAP, providing independent and authoritative information to assess how investments are delivering global environmental benefits.

Image credit: EO4SD Agriculture cluster & FAO WaPOR database (eLEAF for ESA/IFAD, 2018)

Box 10 – Land degradation assessment and visualization using Trends.Earth



Trends.Earth is a free and open source tool for assessing land change, implemented using Quantum GIS (QGIS), a free and open source desktop GIS. Trends.Earth supports calculating, using standardized approaches, the three sub-indicators for monitoring achievement of Sustainable Development Goal (SDG) Target 15.3 (productivity, land cover, and soil organic carbon) as well as indicators useful in planning restoration projects, and the indicator for SDG Target 11.3 (sustainable urbanization).

Drawing on a range of Earth Observation data, Trends.Earth allows users to identify areas that may be hotspots of degradation or improvement, using either freely available global datasets (NDVI, Soil moisture, Precipitation, Land cover, and Soil carbon), or locally produced datasets when available.

Trends.Earth allows users to plot time series of key indicators of land change, to produce maps and other graphics that can support monitoring and reporting, and to track the impact of sustainable land management or other projects.

Trends.Earth was designed in order to address the needs of country representatives analyzing data for reporting to the United Nations Convention to Combat Desertification (UNCCD), as well to support the needs of GEF-funded projects tracking land degradation and improvement as a result of project activities. Trends.Earth was built to allow those with limited expertise working with geospatial data to be able to have access to the best available satellite-derived estimates of land change, while being flexible enough to support extensive analysis by advanced users. The tool was designed to have an easy to use and flexible interface that can work offline (in areas with limited connectivity) or in the cloud (where limited computing capacity is an issue).

The tool was developed and adapted in close collaboration with the UNCCD and other key stakeholders The user base is growing – over 2000 users from over 170 countries have already downloaded and used the tool to analyze EO data – and online training materials (tutorials, webinars, and forums) are available to assist new users in learning how to use the tool.

Trends.Earth was developed with GEF support by a partnership of Conservation International, Lund University, and NASA. Source: Trends.Earth

3.2.4 Coastal and Marine Spatial Planning

Ocean ecosystems are under pressures from climate change, acidification, habitat loss, pollution, fishing, shipping, and seabed mining[1]. Marine spatial planning (MSP) is the process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives[57] and is an effective approach for transparent, inclusive and sustainable oceans planning and management.

The GEF Large Marine Ecosystems MSP Toolkit[58] provides practical guidance and examples of tools and methods that are necessary for designing and carrying out the MSP process in large marine ecosystems. While the Toolkit focuses on the MSP process, mapping and integration of different datasets are critical components. Spatial data for all marine sectors such as tourism, extractive industries, renewable energy production, fisheries and aquaculture, coastal development, and marine transport are required for effective MSP. Information that can be derived from Earth observation to support the major MSP themes is summarized in Table 3.

The Atlas of Ocean Wealth led by The Nature Conservancy (TNC) integrates information about the economic, social and cultural values of coastal and marine habitats to visualize and simplify global, regional, and local ecosystem benefits for use in natural resource planning and policy decisions[59]. A new ESA EO4SD Marine and Coastal Resources initiative aims to deliver Earth observation information to international development stakeholders, including GEF projects and implementing agencies.

At a national scale, the Seychelles MSP Atlas (Box 11) shows how the integration of data, analysis, and mapping supports the MSP process. Box 12 illustrates how Earth observation technology can contribute to improved governance of resources, in this case the Skylight Platform to combat illegal fishing.

Table 3 Potential contribution of Earth observation products to marine spatial planning

Theme	Information from Earth observation	Description
Land and marine use	• Settlements • Aquaculture • Ports and industry	Interpretation of UHR/VHR optical images to identify land use and land use change.
Land cover & critical ecosystems	• Mangroves • Wetlands • Salt marshes • Sea grasses • Coral reefs	Classification of medium, high, or UHR/VHR optical and/or radar images to identify and characterize critical habitats.
Water quality	• Phytoplankton pigments especially chlorophyll • Suspended Particulate Matter • Colour Dissolved Organic Matter • Floating vegetation, e.g. Sargassum	Off-the-shelf products are available. See the International Ocean Colour Coordinating Group for more information. Specific Earth observation -based monitoring services are developed, e.g. Sargassum monitoring using medium resolution optical images.
Bathymetry	• Shallow water bathymetry	Processing of medium, high, or UHR/VHR optical images to derive bathymetry in coastal waters, depending on water properties.
Currents and winds	• Near-surface currents • Sea surface winds	Global scale data are derived from satellite-tracked drifting buoys and satellite radar.

Box 11 – Seychelles Marine Spatial Plan Initiative.

The GEF-supported Seychelles MSP Initiative is a process focused on planning for and management of the sustainable and long-term use and health of the Seychelles Exclusive Economic Zone (EEZ). To assist the MSP process, a Seychelles Marine Spatial Plan Atlas is being developed to create an opportunity for stakeholders to view spatial data and use the maps to provide input to the zoning design including information about missing data or information. The MSP Atlas will be useful for Ministries and stakeholders to support decisions for marine activities in Seychelles when the MSP is implemented.

- An integrated hierarchical classification scheme was developed, which attempted to harmonise previously used marine and terrestrial classification schemes. The integrated classification scheme was used to create a new base map for Seychelles, in which existing habitat datasets were combined where available and the gaps infilled using data from the freely available Landsat 8 data. The data in the Seychelles MSP Atlas pertains to the planning themes for the MSP: Marine biodiversity; Fisheries; Marine infrastructure; Shipping and transportation; Non-renewable resources; Renewable energy; and Tourism and recreation.
- The Preferred Biodiversity Protection Areas map below was developed using the MARXAN conservation planning tools[60].

Box 12 – Skylight Platform to combat illegal fishing.

Skylight is a software and service solution developed to provide transparency into maritime activity to combat environmental, economic, and geopolitical challenges, including illegal fishing. Built and managed by Vulcan Inc., Skylight uses advanced observation and remote sensing data to provide users with maritime information.

The Skylight Alerting Platform provides real-time detections of suspicious events and delivers those insights, along with dark vessel detection, from satellite imagery. Skylight also collaborates with partners to produce research using data, imagery, and analytics.

Skylight was used to analyze dark vessel activity in the South China Sea with the goal of leveraging previously underused technologies and data sources to analyze the size and behavior of fishing fleets in the Spratly Islands, South China Sea. The results tell a worrying story about the scale of unseen fishing activity in the region. Skylight leveraged a variety of satellite-based data sources including vessel Automatic Identification System (AIS), radar, and NASA's VIIRS instrument. In this case, no single Earth observation and positioning data source was able to provide a complete picture. By fusing all data sources, Skylight was able to identify vessel presence and assess fishing and non-fishing related activity. The analysis of maritime issues is best informed by leveraging a range of satellite-based technologies, rather than the use of any single source.

Image credit: SAR detections and correlated AIS signals in the Spratly Islands.
Source: Center for Strategic and International Studies for this publication.

3.2.5 Water Security

Freshwater ecosystems face daunting threats, including climate change, urbanization and increasing food demand. Increasing water scarcity in many regions along with pollution threatens human health and economic development[1].

Understanding water resources availability and use is important to balance competing demands and to adapt to the impact of climate change. Earth observation combined with other datasets and modeling is a valuable tool to understand basin water balance and rainfall-runoff. Information on average annual water produced by a watershed (water yield) and the relative contribution of land parcels or sub catchments to water yield can identify and inform how changes in the landscape will alter that contribution.

The GEF has supported numerous transboundary water management projects where Earth observation data play an important role in transparent, harmonized monitoring of watershed health. For example, remote sensing can contribute to a better understanding of the following:

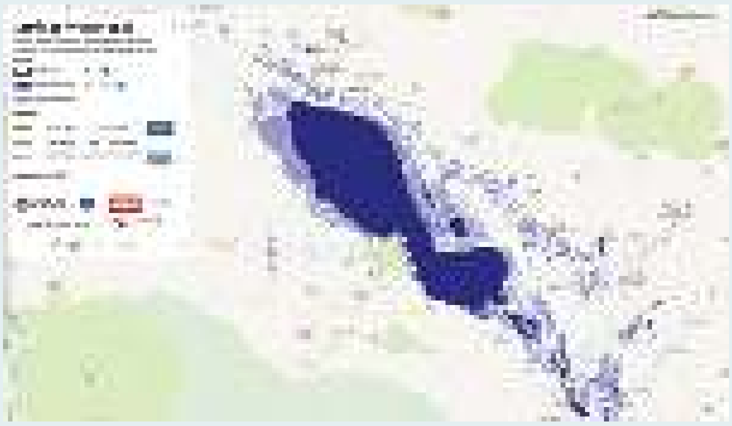
- water use demand – mapping the type and area of agriculture and aquaculture production, urban and industrial growth, wetlands, and natural and plantation forests;
- ecosystem services – sediment retention and estimating sediment loads from changing land use and land cover; and
- infrastructure development – contributing data for the assessment of hydropower, irrigation area, and other hard infrastructure.

Recognizing the important contribution that Earth observation can make to water resources management, international development and space agencies have collaborated to develop water monitoring methods, tools, and capacity. Box 13 summarizes three important initiatives involving USAID, NASA, ESA, and the Secretariat for the Convention on Wetlands (RAMSAR).

Box 13 – Water resources and wetland monitoring initiatives using Earth observation.

NASA, ESA, and the European Commission support important initiatives that apply Earth observation data for water resources and wetland assessment and monitoring:

- Global Surface Water Explorer – location and temporal distribution of water surfaces at the global scale over the past 35 years, including statistics on their extent and change to support better informed water-management decision-making.
- SERVIR – a joint development initiative between NASA, USAID and leading technical organizations around the world – created a Surface Water Mapping tool that leverages the archive of Landsat data in Google Earth Engine and Google's cloud processing to calculate past patterns of surface water extent from multiple layers of Landsat imagery. The tool consists of a Google Earth Engine application and a web interface which allows the user to specify the period evaluated and other calculation parameters that are then executed in a cloud service. Results are displayed on screen and can be downloaded for specified areas. SERVIR has also implemented a similar tool for monitoring ephemeral water bodies in arid parts of West Africa.



- EO4SD Water Resources Management – the ESA supported EO4SD Water Cluster developed and demonstrated a portfolio of Earth observation -based information services such as surface water extent, water quality, hydrological models, and crop water demand.
- GlobWetland Africa – RAMSAR and ESA supported the development and demonstration of an open source toolbox to support Earth observation-based wetland mapping and analysis, including wetland extent and wetland vegetation classification.

3.2.6 Food Systems and Land Use

The Impact Program on Food Systems and Land Use (FOLUR) addresses the underlying drivers of sustainable food systems and land use change through supporting countries to take a more holistic and system-wide approach[1]. Commodity sectors including palm oil, soybean, and beef have an important role in food security, energy supply, and economic development and livelihoods, but can also have negative environmental and social impacts. Demand for improved sustainability of food systems and deforestation-free agricultural commodity supply chains requires new tools and monitoring technology. Satellite Earth observation supports a landscape level approach and can enhance monitoring of land use and land use change, increase transparency and accountability, and enable adaptive management[1].

Data derived from remote sensing satellites are being used for monitoring agriculture commodity production and offer scientifically robust, objective, repeatable, information. Multi-spectral images from Sentinel-2 are acquired on a frequent basis, every five days, and are particularly suitable to support agriculture monitoring because of their high spatial resolution, frequent return period, and spectral bands. Commercial agriculture monitoring services also exist, using data from Planet and DigitalGlobe, and Airbus to name a few. This can be particularly useful in the context of smallholder agriculture to predict yields[14]. Using satellite remote sensing, mapping can be applied consistently over large, often remote areas to advance transparency and provide independent information. Earth observation information for sustainable food systems and commodity supply chains can include:

- infrastructure development, e.g. roads, irrigation;
- land use and extent of agriculture commodities;
- tree and forest cover change; and
- status of critical habitats, e.g. riparian areas, wetlands, natural grasslands.

Earth observation also supports agriculture production and farmers through crop production projections, weather forecasting, and early warning for food security. An area of rapid innovation, numerous services based on Earth observation data are being developed, tested, and providing real benefits to farmers. Precision agriculture uses data received from global positioning systems, satellite and aerial imagery, and sensors (for example, sensors for soil conditions, ground water levels, and precipitation detectors) to enable a range of precision agriculture applications[61].

For more information on agriculture and food security applications:

- NASA Harvest food security projects
- Sen2-Agri processing system for agricultural products
- EO4SD Agriculture and Rural Development commodity mapping products
- FEWSNET Famine Early Warning Systems Network
- GEOGLAM Impact Stories on Earth observation for agriculture and food security

The sustainability of agricultural production and potential impact on biodiversity and ecosystems is important to producers, consumers, and organizations such as the GEF (e.g. the UNDP Green Commodities Programme). In 2019, the World Resources Institute (WRI) announced that a coalition of ten major palm oil producers and buyers are collaborating to support and fund the development of a new, publicly available radar-based forest monitoring system known as Radar Alerts for Detecting Deforestation (RADD).

Much progress has been made through the Group on Earth Observations Global Agricultural Monitoring (GEOGLAM) Initiative. More recently, NASA Harvest led by the University of Maryland (UMD) commenced a multidisciplinary program to enhance the use of satellite data in decision making related to food security and agriculture. Focusing on the contribution of Sentinel-2 time series to agriculture monitoring, the Sen2-Agri project is designed to develop, demonstrate and facilitate an open source, operational standalone processing system generating agricultural products.

3.2.7 Sustainable Cities

Recognizing the critical role of cities for sustainable development, the Sustainable Cities Impact Program in GEF-7 supports sustainable integrated urban planning, building on the Sustainable Cities Integrated Approach Pilot program for GEF-6[1]. Integrated solutions in energy, buildings, transport, urban food systems, management of municipal solid waste and wastewater, and utilization of green space and infrastructure require a range of geospatial information that can be integrated and analyzed for urban planning.

GEF-7 explicitly recognizes evidence-based spatial planning at national, regional, and local scales. This includes enhancing spatial planning and investing in digital and data leadership. Given the role of cities in protecting and enhancing green infrastructure, planning often includes incorporating biodiversity conservation and nature-based solutions into the planning process.

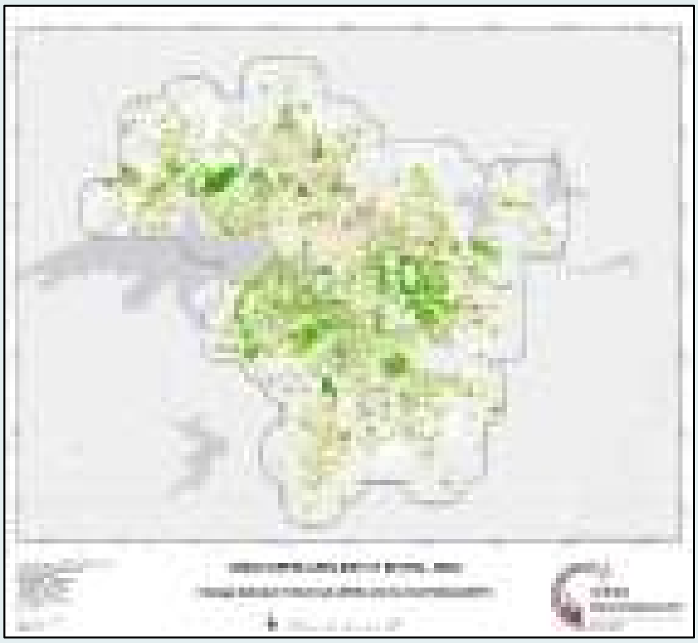
Urban planning requires the availability of consistent, accurate and up-to-date information on the status and development of the urban environment. A range of thematic information can be derived from Earth observation that supports urban planning. Box 14 summarizes the products that were defined by the EO4SD Urban Development Cluster, funded by ESA.

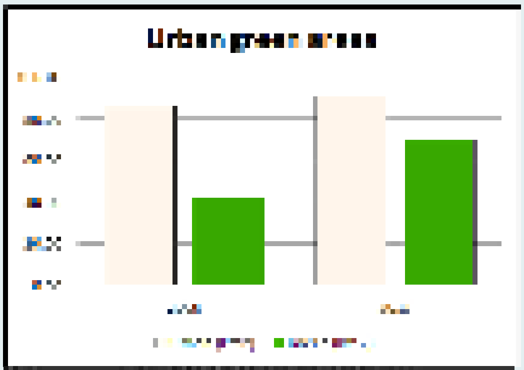
Box 14 – Global Platform for Sustainable Cities use of Earth observation for urban mapping.

The GEF-supported Global Platform for Sustainable Cities (GPSC) collaborated with the EO4SD Urban Development Cluster funded by ESA to provide geospatial data for sustainable urban planning in eight cities around the world: Bhopal and Vijayawada (India), Melaka (Malaysia), Abidjan (Ivory Coast), Dakar and Saint-Louis (Senegal), Campeche (Mexico) and Lima (Peru). The Earth observation derived products were specified and tested to support urban planning:

- Urban extent
- Urban green areas
- Extent and type of informal settlements
- Building footprints and types
- Transport infrastructure
- Peri-urban ecosystems
- Population density
- Waste sites
- Air quality, urban heat islands
- Building heights
- Flood history and flood risk
- Geohazards and subsidence

Using standard Earth observation derived urban geospatial data allowed comparative analyses between the cities regarding goals within the GEF program, e.g. tracking the sustainability status of urban areas and mapping and monitoring informal settlements. In Bhopal urban planners were able to map and quantify the change in urban green area.





Source: GAF AG and EO4SD Urban Development Cluster

3.2.8 Sustainable Forest Management

The GEF's approach to sustainable forest management encompasses broad landscapes that are managed for conservation, production, or multiple purposes at the local, national, regional and global levels. The Sustainable Forest Management (SFM) Impact Program focuses on three key biomes – the Amazon Basin, Congo Basin, and global dryland forests. The program aims to complement existing conservation and REDD+[c] initiatives and to operate at a large, ecosystem scale.

Earth Observation technology supports forestry operations, national forest inventories, and carbon stock assessment. Operational applications include Global Forest Watch (GFW; see Box 15) and Open Foris (see Box 4) and significant investments have been made by GEF implementing agencies in building capacity for national forest monitoring systems and implementation of REDD+. In other areas, new tools, methods, and research is ongoing to address challenges such as forest degradation assessment and biomass estimation (see Box 18 below on the GEF-financed Satellite Monitoring for Forest Management Project). Earth observation information and geospatial technology are key tools for identifying, analyzing, and monitoring changes in forest cover and condition and are indispensable for sustainable forest management. Developed in the framework of the Global Forest Observation Initiative (GFOI), the SERVIR-SilvaCarbon SAR Handbook also provides guidance to users on how to use radar data for forest monitoring. The topics covered in the SAR Handbook include the basics of processing radar data, the use and application of radar data for forest change detection, forest height estimation, biomass estimation, mangrove monitoring, and sampling design.

[c] Reduced Emissions from Deforestation and forest Degradation, which aims to foster conservation, sustainable management of forests, and enhancement of forest carbon stocks (Forest Carbon Parthership Facility 2018)

Box 15 – Global Forest Watch for global forest cover monitoring.

GFW is an online platform that provides data and tools for the global monitoring of forests. Led by WRI, a large group of partners contribute data, technology, and funding that enables users to access information about where and how forests are changing around the world at a variety of spatial and temporal scales.

Earth observation data and information are a critical part of the GFW platform, which include: UMD global tree cover change data based on Landsat satellite images; NASA Active Fires (see Box 8 above); and Terra-i near real-time monitoring system that detects land cover changes in the tropics using MODIS vegetation indices. Global Forest Watch provides an Open Data Portal.

Powerful, cloud computing infrastructure supports the generation of datasets and enables GFW to provide reliable access via the platform. Building on the datasets and platform, numerous apps have been developed for specific user requirements and user communities, which include:

- GFW Map - view and analyze data on the GFW Interactive Map.
- GFW Dashboards - view global, country, and subnational forest statistics and information.
- Forest Watcher Mobile App - access the dynamic forest monitoring and alert systems of Global Forest Watch on mobile devices, including offline.
- GFW Climate - track carbon emissions and removals in forest landscapes.
- GFW Fires - track fires and haze, view the latest data on fire locations and air quality.
- GFW Pro - An application to securely manage deforestation risks in commodity supply chains.

Source: WRI and UMD

Amazon Sustainable Landscapes program

The Amazon Sustainable Landscapes (ASL) II Impact Program aims to generate scalable results in reducing deforestation and the loss and fragmentation of natural habitats as well as preventing the extinction of threatened species and improving their conservation status.

Scientists have used satellite Earth observation data to track deforestation in the Amazon biome for several decades, particularly the Brazilian National Institute of Space Research (INPE) which began to publish annual data beginning in 2002. Most GEF interventions require the use of Earth observation data and can build on these existing national and international Earth observation programs (Box 16). Key GEF interventions under the Amazon Sustainable Landscape (ASL) 2 Impact Program are: protected areas management; integrated landscape management; freshwater ecosystems management; and productive landscape management to address the drivers of deforestation.

Box 16 – Satellite-based environmental monitoring in the Amazon biome.

Satellite monitoring programs led by INPE produce systematic data on deforestation and forest degradation in the Brazilian Amazon region. These data are the main source of information for decision making related to policies to combat deforestation in the Amazon. The release of this information has been recognized as an important factor in reducing deforestation in Brazil.

INPE's monitoring of forest coverage in the Amazon via Earth observation includes:

- PRODES – performs satellite monitoring of clear-cut deforestation in the Legal Amazon and since 1988 has produced annual deforestation rates in the region, which are used by the Brazilian government to establish public policies. PRODES historically used Landsat 5 images, but now also incorporates imagery from Landsat 7 and 8, CBERS-2, CBERS-2B, Resourcesat-1, and UK2-DMC to minimize the problem of excessive cloud cover and ensure interoperability.
- DETER – identifies and maps, in near real time, deforestation and other changes in forest cover with a minimum area close to 1 ha. DETER makes use of daily observations of deforestation, fire, and vegetation health from MODIS on NASA's Terra and Aqua satellites.

INPE also developed the TerraAmazon open source software designed to be a multi-user editor of vector geographic data, which supports users to edit and attribute data on forest change that may have been detected using Earth observation data.

Mapbiomas (the Brazilian Annual Land Use and Land Cover Mapping Project) is another collaborative initiative that uses Google Earth Engine and automated classifiers to generate Brazil's annual land use and land cover time series.

Recently, attention has again focused on Amazon deforestation given the increase in the rate of deforestation. Scientists using MODIS data to track fire activity detected an increase in the number and intensity of fires in the Brazilian Amazon in 2019, making it the most active fire year in that region since 2010.Image: year of forest loss using PRODES data.

Source: NASA Earth Observatory[62]

Congo Basin Sustainable Landscapes

The Congo Basin Sustainable Landscapes (CBSL) Impact Program incorporates environmental management principles in forest management through landscape approaches at local, national, and transboundary levels. Innovative mechanisms and partnerships will improve law enforcement against illegal logging and poaching of global important biodiversity[1].

The CBSL Impact Program builds on a history of support for the Congo Basin. This includes the Central Africa Regional Program for the Environment (CARPE), a long-term initiative of the United States Government to promote sustainable forest management, biodiversity conservation, and climate change mitigation in the Congo Basin through increased local, national, and regional natural resource management capacity. The CBSL Impact Program benefits from CARPE's involvement in the development and use of remote sensing tools in the region (Box 17).

Box 17 – Forest Monitoring and the Central Africa Regional Program for the Environment (CARPE).

In support of CARPE, NASA, UMD, and the Observatoire Satellital des Forêts d'Afrique Centrale (OSFAC) created a system to measure, track and verify deforestation through satellite remote sensing. Due to the large scale of the Congo Basin, satellite-based regional forest cover mapping is the best way to effectively monitor forest cover change, a critical parameter in evaluating CARPE's progress towards achieving sustainable management of targeted forested landscapes.

The World Resources Group has developed online Forest Atlases to help countries better manage their forest resources by combining government data with the latest forest monitoring technology. The Forest Atlases include interactive mapping and database tools that forest managers can use to visualize, analyze and download data to make better-informed decisions. The Forest Atlases offer two types of near real-time alerts to quickly pinpoint changes in the land: (1) Weekly deforestation alerts from the University of Maryland; and (2) Daily VIIRS fire alerts from NASA to identify where fires have occurred

Source: CARPE and WRI Forest Atlases

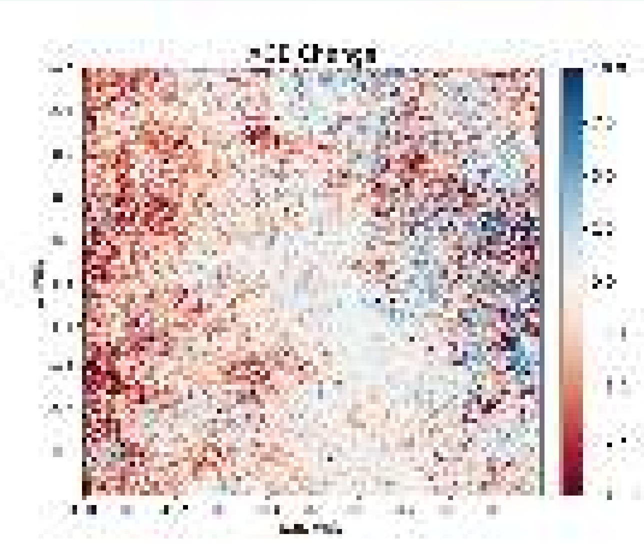
Dryland Forests

The GEF Dryland Sustainable Landscapes Impact Program aims to avoid, reduce, and reverse further degradation, desertification, and deforestation of land and ecosystems in drylands through the sustainable management of production landscapes, addressing the complex nexus of local livelihoods, land degradation, climate change, and environmental security. Tropical dryland forests are subject to some of the highest rates of deforestation and degradation around the world[63]. These ecosystems are particularly at risk due their fragility and the high demand for forest goods and services, which are required to support the livelihoods of large numbers of the world's poorest people.

Forest monitoring in tropical dryland regions presents unique challenges and existing satellite Earth observation analysis methods often fail to produce acceptable results due to marked vegetation seasonality, low vegetation density, and low biomass gradients in land cover class-to-class transitions. The GEF-financed SMFM project described in Box 18 was designed to address these challenges.

Box 18 – Satellite Monitoring for Forest Management (SMFM) in dryland forest regions.

The objective of the World Bank's GEF-financed SMFM project was to develop satellite Earth observation methods and global knowledge to address challenges related to monitoring tropical dry forest ecosystems and forest degradation assessment.



The project involved development and testing of new and improved methods to process and analyze optical and radar satellite Earth observation datasets, particularly to take advantage of the new technical capabilities provided by the Copernicus Sentinel-1 and Sentinel-2 satellites, in complement with other data sets such as Landsat and ALOS PALSAR.

Several open sources tools were developed and tested in Zambia and Mozambique:

1. Sen2mosaic – semi-automated pre-processing of Sentinel-2 data for land use land cover classification, suitable for use on a cloud-based platform. Generates wall-to-wall mosaics at regional to national scales using composite images from multiple satellite overpasses to create season-specific cloud-free images suitable for land cover classification.

2. Sen1mosaic – semi-automated pre-processing of Sentinel-1 data for land use land cover classification, suitable for use on a cloud-based platform.

3. Biota – above-ground biomass estimation and annual forest biomass change and degradation mapping using free ALOS PALSAR Mosaics.

4. Deforestation and Degradation Mapping – utilizing dense time-series of Sentinel-2 for continuous change monitoring and proxies of forest change.

Image: above ground biomass (AGB) change created using the Biota tool. Source: SMFM Project.

3.3 PRAGMATIC APPROACH TO USING EARTH OBSERVATION INFORMATION

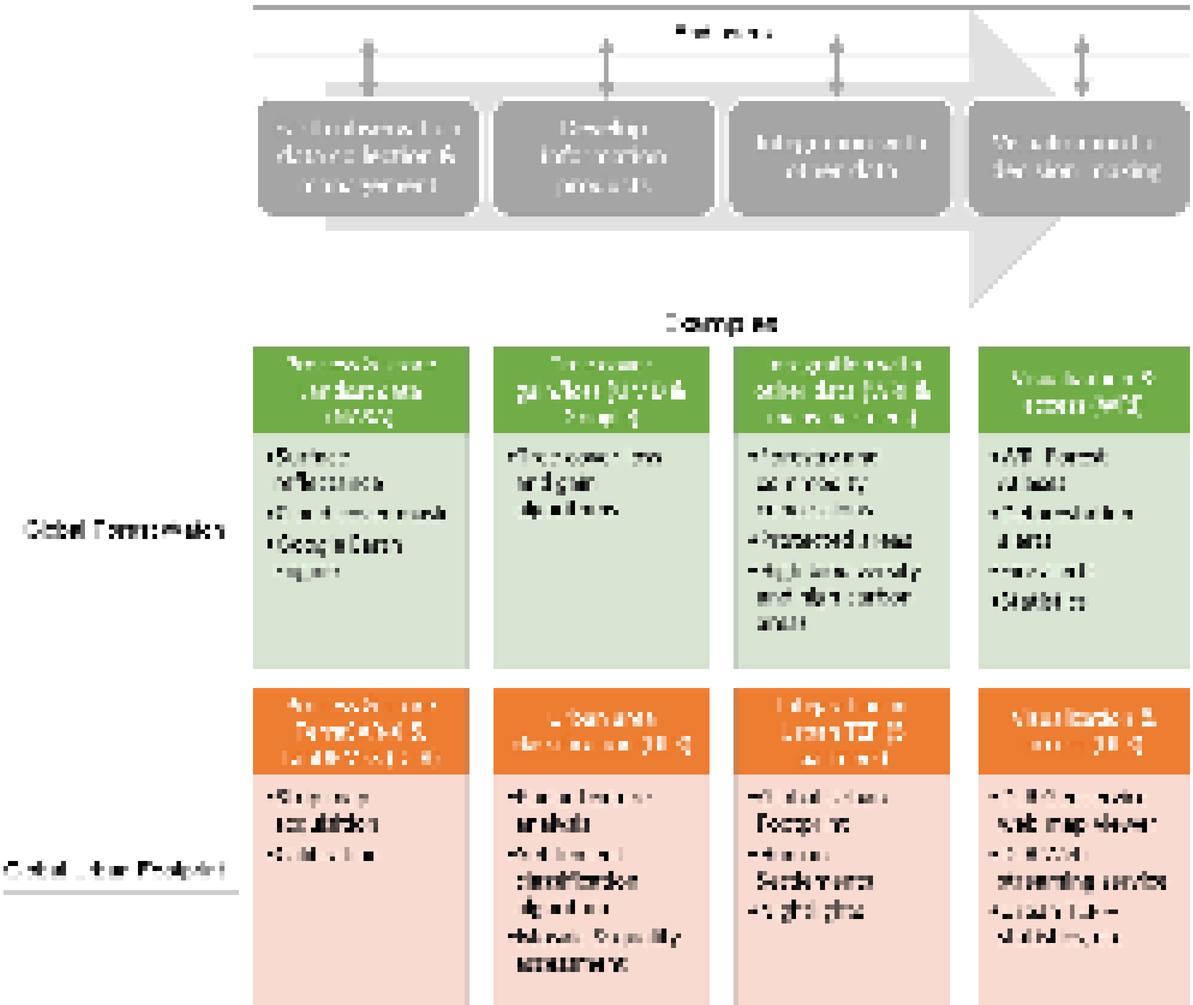
Earth observation is a large, complex scientific and technological discipline that is applied across numerous fields of physical, environmental, and socio-economic science. Like many other disciplines, Earth observation increasingly leverages developments in computer and data science, particularly cloud computing and analytical methods. To maximize its benefit for GEF projects and programs, it is useful to follow a pragmatic approach to applying Earth observation technology.

3.3.1 Earth Observation Value Chain

To play a role in decision-making, the use of Earth observation data must be driven by the requirements of decision-makers rather than the capabilities of the Earth observation technology or analysts processing the data. Within the GEF's mandate, the information required, and presentation or visualization formats can vary considerably.

For Earth observation data to be useful for decision-makers, it typically must be processed and combined with other geo-referenced socio-demographic, economic, and environmental data to make indicators and analyses more relevant and targeted. This processing and integration can be considered as a value chain. Earth observation data are one of several 'fundamental' datasets and value is added through processing and integration in response to user requirements. Progress along the value chain involves integration of data and a reduction in the complexity, size and number of the data being handled, so that the information presented to decision-makers is understandable without technical expertise. Collaboration and engagement with end users is fundamental to develop the value-chain. The ultimate objective is to support decision-making and positive development outcomes. Global Forest Watch (see Box 15) provides an example of the value chain to provide decision makers in government, private companies, and other organizations with forest change information.

Figure 9 Earth observation value chain to support decision making.



Note: DLR = German Aerospace Center. Source: Hatfield Consultants

3.3.2 Evaluating Requirements and Existing Earth Observation Capabilities

Since the establishment of the GEF, the capabilities of Earth observation technology have advanced dramatically along with capacity to process, analyze, and integrate data to support decision-making. Awareness and knowledge of Earth observation by GEF agencies has improved, but some may lack the most up-to-date knowledge of scientific and technological developments.

When evaluating whether Earth observation can support a GEF project or program, it is useful to first define the information requirements and then assess how Earth observation technology can address those requirements, in conjunction with other data sources and methods:

Define project information requirements

- What is the challenge to be addressed?
- What biophysical information is required?
- What is the size of area?
- What is most important: spatial detail, large area, high frequency of observation, or long timeframe?
- How will Earth observation data be integrated with other data?

Assess how Earth observation can address the requirements

- Do existing Earth observation information products or services exist?
- Consult with Earth observation experts from research institutions, specialist agencies, or companies.
- Evaluate trade-offs such as costs of data, processing and storage, and skills and expertise.
- Recognize the benefits and limitations of Earth observation technology for particular phases of the GEF project cycle.

An additional resource regarding defining user requirements is the SERVIR Service Planning Toolkit[64], developed based on SERVIR's experience implementing demand-driven geospatial services in five regions of the world.

Where possible, agencies should use existing, off-the-shelf, freely available information products to fulfill information requirements. Government agencies, research scientists, international organizations, and private companies have developed numerous methods to process Earth observation data into products, such as land cover classes, soil moisture, and biomass (see Section 3.3.3 providing a selection of available products). Using off-the-shelf products provides several benefits:

- cost and time efficiency – multiple users don't have to repeat the same processing to obtain a product;
- standardization – supports comparability among different studies; and
- precision and accuracy – published products have typically undergone rigorous calibration and validation and have known quality and levels of uncertainty.

Existing products may not meet exact requirements (e.g. the spatial resolution may be too coarse, or they may lack some important information) and the information may need to be tailored to the individual context of the project, whereby standard products are not fully sufficient to meet the project-specific needs. In this case, it is good practice to supplement existing products with custom products, while still applying scientifically accepted methods that are repeatable.

3.3.3 Earth Observation Products, Platforms, and Tools

Numerous web portals and services exist to enable discovery, access, and use of Earth observation data and derived information products. Users have a broad range of expertise and experience with Earth observation data. Applying the value chain concept (Section 3.3.1), some users want access to Earth observation data to complete processing, integration, and analysis, whereas other users are interested in high level derived information. Portals exist to support different users and they can be classified into three broad functions, with some crossover:

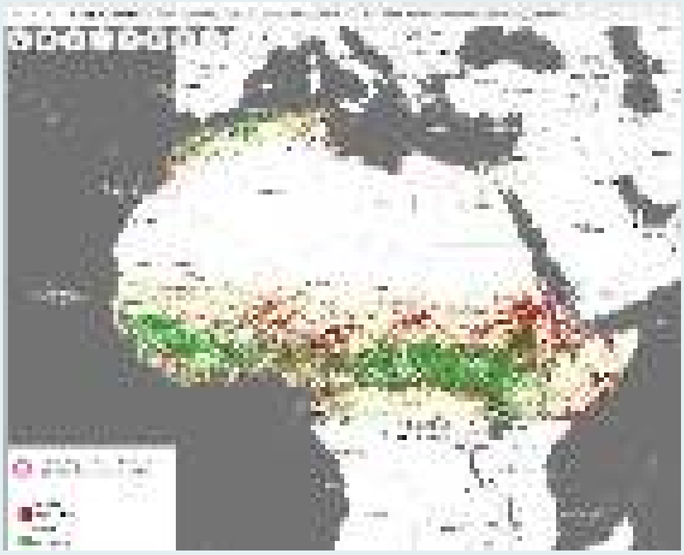
- **Earth observation data portals** – users can identify and download satellite images based on criteria such as acquisition date, sensor, and product. Many portals exist for specific groups of sensors (see Table 5). For Landsat, the most common download location is the USGS EarthExplorer and for the Sentinel missions the Copernicus Open Access Hub. Both Landsat and Sentinel-2 optical data provide access to new data that are calibrated (see Section 2.2.6). Landsat and Sentinel optical data are also available from other services as well, such as Google Cloud and AWS, but these are aimed at advanced users, particularly for bulk downloading large collections of imagery. Landsat and Sentinel-2 data is available to view alongside PlanetScope data through Planet Explorer.
- **Earth observation derived information products and services** – users can directly access derived products, which range from simple re-computed spectral indices such as NDVI to products resulting from advanced and complex algorithms such as global tree cover change or ocean water quality (see Table 5). Several portals and applications compile and curate a range of geospatial datasets (e.g. Spatial Agent, OpenDRI portals, World Environment Situation Room (WESR; Box 19), while others offer integration and analytics functions (e.g. Trends.Earth, Global Forest Watch).
- **Earth observation processing and visualization platforms** – cloud computing platforms for Earth observation data allow users to access, store, and analyze large volumes of EO data when they have limited Internet bandwidth and local computing infrastructure. Earth observation platforms "bring the user to the data and tools" and users access the data, tools, and resources required, as opposed to downloading, replicating, and exploiting data 'at home'[9]. A user community may be developed in the platform to enable collaboration. Perhaps the most well-known platform is Google Earth Engine, but several others have developed including those focused on specific themes (see Table 7). Many platforms are currently free and tools and processes developed on one platform may be transportable to another platform with reasonable levels of ease, which limits the risk of being 'locked in' to a specific platform.

Commercial and open source software tools are available to process, integrate, analyze, and visualize Earth observation data, which can be used locally and in cloud computing environments. Table 7 summarizes commercial and open source software tools. Several open source tools are well-developed in terms of their capabilities, documentation, and user communities. Many commercial software tools are available with discounts for non-profits and environmental projects.

Box 19 – World Environment Situation Room and MapX.

The World Environment Situation Room (WESR) is the future United Nations Environment Programme (UNEP) on-line data and knowledge platform that will enable users to visualize, interrogate, access, link and download, data, information and knowledge products regarding the World environment.

This platform will be at the heart of UNEP's processes for assessments, foresights, monitoring, communications, support to UN country team and related Common Country Analysis (CCA), for following progresses made regarding the Sustainable Development Goals (SDGs) for which UNEP is custodian and for near real time monitoring.



MapX provides the WESR geospatial functionality and allows to visualize, interrogate, and access hundreds of geospatial datasets on different topics such as biodiversity, chemicals, disaster risk reduction, mercury, extractives, renewable energy and environmental security. Several of these datasets were derived from Earth Observation data.

Image: Land degradation in North-Africa from the original SDG 15.3.1 Land Degradation global dataset. Original dataset generated using Trends.Earth.

Sources: http://wesr.unep.org/wesr/ and http://www.mapx.org.

Table 4 Selected Earth observation data portals applicable to GEF programming.

Portal	Provider	Program	Satellites/Sensors
Copernicus Open Access Hub	ESA/European Commission	Copernicus	Sentinel-1, Sentinel-2, Sentinel-3
Earth Explorer	NASA/USGS	EOS	Landsat-8, MODIS, etc.
Earth Data	NASA	EOS	Landsat-8, MODIS, etc.
Worldview	NASA	EOS	Over 900 imagery layers, US sources
National Centers for Environmental Information	NOAA	JPSS, GOES, POES	AVHRR
Data Distribution Service	Japan/JAXA	ALOS	PALSAR-1, PALSAR-2
Earth Observation Data Management System*	Canada	Radarsat	RCM
Bhuvan	India	IRS	CARTOSAT
Catálogo de Imagens	China/Brazil	CBERS	CBERS-4
Discover	Maxar	-	WorldView, GeoEye
GeoStore	Airbus	-	SPOT-6/7, Pleiades, TerraSAR-X
Planet Explorer	Planet	-	PlanetScope, SkySat, RapidEye, Landsat-8, Sentinel-2
GPM Data	NASA/JAXA	-	GPM

Acronyms: Earth Observing System (EOS); Joint Polar Satellite System (JPSS); Geostationary Operational Environmental Satellite Program (GOES); Polar Operational Environmental Satellite Program (POES); Indian Remote Sensing Missions (IRS); RADARSAT Constellation Mission (RCM); China–Brazil Earth Resources Satellite (CBERS); Global Precipitation Mission (GPM).

*Registration and access method to be confirmed.

Table 5 Selected Earth observation thematic products and services applicable to the GEF.

	Primary Themes							
Portal/Product Name	**Biodiversity**	**Climate change**	**Land Degradation**	**Int. Water**	**SFM**	**Description**	**Spatial scale**	**Temporal coverage**
ESA CCI Land Cover		■	■		■	Land cover	300 m	1992-2015
GFW Tree Cover		■	■		■	Provides access to UMD tree cover gain and loss	30 m	2001-present
GFW Fire		■	■		■	Provides access to FIRMS active fire and other data	375-1000 m	Present
NASA FIRMS		■	■		■	Active fire data within 3 hours of satellite overpass from MODIS and VIIRS	375-1000 m	2000-present
ECMWF		■				Gridded Climate Datasets	varied	varied
NOAA PSD		■				Gridded Climate Datasets	varied	varied
IPCC		■				GCM Climate Change Scenarios	varied	1961 to 2099
UMD Global Forest Change		■	■		■	Global forest change	30 m	2000-present
GPW			■			Gridded Population of the World v4	1 km	1995-2015
Trends.Earth			■			Provides access to global data suitable for land degradation assessment	varied	varied
Protected Planet	■					Provides access to the World Database on Protected Areas (WDPA)	varied	present
JRC Global Water				■		Spatial and temporal distribution of surface water	30 m	1984-2015
DLR Global Urban Footprint			■			Mapping of global settlement areas	12 m	present
FAO WaPOR			■	■		African continent above ground biomass, evapotranspiration, etc.	30-250 m	2009-present
Coral Reef Watch	■			■		SST, SST Anomaly, Coral Bleaching Hotspot, etc.	5 km	2014-present
Allen Coral Atlas	■			■		World coral reefs	3.7 m	present
Global Mangrove Watch via UNEP Ocean Data Viewer	■				■	Mangrove extent, gain, and loss	0.8 arcsec	1996 - 2015, and 2016
Digital Observatory for Protected Areas	■					JRC database of protected areas	varied	present
Global Biodiversity Information Facility	■					Species occurrences in space and time	varied	Historical - present
UN Biodiversity Lab	■					Information on the Aichi Biodiversity Targets and nature-based SDGs	varied	present
Ocean Biogeographic Information System	■			■		Marine biodiversity	varied	present
Map of Life	■					Biodiversity analysis and indicators	varied	present

Table 6 Selected Earth observation data processing platforms applicable to GEF programming.

Platform Name/Owner	Description	Access	Business Model
Google Earth Engine/ Google	Platform hosting archive of Landsat, Copernicus, and other public Earth observation data. Provides APIs and other tools to enable the analysis of large datasets.	Google account registration	Free, commercial licensing expected
SEPAL/ FAO	Platform providing Earth observation data processing tools. Infrastructure leverages Google Earth Engine and AWS for data access and processing.	Restricted	Free
Sentinel Hub Playground/ Sinergise	Platform to browse and explore Sentinel-2, Landsat 8, DEM and MODIS imagery. Easy to use web-interface with tools to explore band combinations, spectral indexes, and other image effects.	Registration required	Free and commercial licensing
Thematic Exploitation Platforms/ ESA	Platforms to provide access to Earth observation data and thematic tools required to process data and generate products. Several TEPs are hosted in a DIAS, which provides data access and infrastructure.	Registration required	Free and commercial licensing
Copernicus Data Information Access Services (DIAS)/ European Commission	Multiple DIAS established with different private and public sector partners. Provides access to Copernicus and Landsat data and provides infrastructure to establish processing applications. Each DIAS provides some tools to enable users to process Earth observation data.	Registration required	Limited free access with commercial licensing
Amazon Web Services/ Amazon	Makes available open Earth observation data and provides infrastructure to establish processing applications. No specific Earth observation tools are provided.	AWS account registration	Free data access, commercial infrastructure
Google Cloud/ Google	Makes available open Earth observation data and provides infrastructure to establish processing applications. No specific Earth observation tools are provided.	Google account registration	Free data access, commercial infrastructure
Azure/ Microsoft	Makes available open Earth observation data and provides infrastructure to establish processing applications. No specific Earth observation tools are provided.	Microsoft Azure registration	Free data access, commercial infrastructure

Table 7 Selected remote sensing and GIS software.

Name	Publisher	Main purpose	License	Cost	Complexity
ArcGIS	Esri	GIS analysis and cartography	C	$$$	■■
ENVI	Harris Geospatial	Image processing for most types of remote sensing data	C	$$$	■■
ERDAS	Hexagon Geospatial	Image processing for most types of remote sensing data	C	$$$	■■
Geomatica	PCI Geomatics	Image processing for most types of remote sensing data	C	$$$	■■
GRASS	OSGeo	GIS and image analysis and visualization	OS	N	■■
TerrSet	Clark Labs	GIS and image analysis and cartography	C	$$	■
ILWIS	52°North open source software initiative	GIS and remote sensing analysis	OS	N	■■
Manifold	Manifold	GIS analysis and cartography	C	$	■
Open Foris	FAO	Land cover and land user data collection	OS	N	■
Orfeo Toolbox	CNES	Image processing for most types of remote sensing data	OS	N	■■
QGIS	QGIS	GIS analysis and cartography	OS	N	■■
Sentinel Toolboxes	ESA	Toolboxes for the scientific exploitation of Sentinel missions	OS	N	■■■

OS = open source; C = commercial. Cost rating: $$$ > $5 000; $$ ≤ $5 000; N = none/free. Complexity rating: ■ = beginner user, training manuals; ■■ = expert user, good documentation; ■■■ = expert user. List of software is not exhaustive and not an endorsement. Source: adapted from Aguilar-Manjarrez et al. 2018[65]

4.0 CONCLUSIONS

Earth observation is not new, but recent investments in satellite capabilities such as the Copernicus Programme, open and free access to data and tools, and advances in algorithms and data processing have enabled the widespread use of this information at scale, and beyond the specialized scientific community.

This document aims to provide GEF implementing agencies and their partners with information to support informed use of EO data and technology during this period of rapid innovation in acquisition platforms, sensors, data processing infrastructure, and products. Currently, Earth observation application by the GEF implementing agencies tends to be "one-off" and project-specific, with a variety of approaches taken to address similar environmental assessment and monitoring challenges. This is changing as some Agencies as several GEF Agencies are making greater use of geospatial data and general and many now have a centralized system that systematically captures and stores project information. The IEO has recommended that the GEF make greater use of spatially explicit data for projects addressing protected areas[38], biodiversity[66], land degradation[39], and more precision in recording and reporting project location for monitoring and evaluation of progress and results and sustainability[67]. This work recently led to the development of a methodological approach for consistent post-completion verification that exploits Earth observation and complementary geospatial data[40].

While Earth observation is recognized as an important source of information, the greatest value is typically derived when it is integrated with complementary data and observations obtained using other methods, including qualitative research and information contributed through citizen science. The value chain concept helps to ensure that information is integrated and presented to be meaningful for decision-making.

Several GEF agencies already use geospatial information and Earth observation technology in their projects and have a designated lead person for geospatial technology, providing opportunities for sharing experience and practices. Expanding the use of Earth observation data and products within GEF programming requires further awareness raising and capacity building to promote consistent and appropriate applications. Readers are encouraged to follow the provided external references for more information and to share Earth observation science and tools to provide opportunities for others to benefit from successes.

5.0 LIST OF ACRONYMS

AFOLU	Agriculture, Forestry and Other Land Use
AIS	Automatic Identification System
ARD	Analysis Ready Data
ASIS	Agricultural Stress Index System
ASL	Amazon Sustainable Landscapes
AWS	Amazon Web Service
BON	Biodiversity Observation Network
C	Commercial
CARPE	Central Africa Regional Program for the Environment
CBD	Convention on Biological Diversity
CBERS	China-Brazil Earth Resources Satellite
CBSL	Congo Basin Sustainable Landscapes
CI	Conservation International
DLR	German Aerospace Center
EBV	Essential Biodiversity Variable
ECV	Essential Climate Variable
EEZ	Exclusive Economic Zone
EOS	Earth Observing System
EOSDIS	Earth Observing System Data and Information System
EO4SD	Earth Observation for Sustainable Development
EX-ACT	Ex-Ante Carbon-balance Tool
FAO	Food and Agriculture Organization
fAPAR	fraction of Absorbed Photosynthetically Active Radiation
FIRMS	Fire Information for Resource Management System
FOLUR	Food systems, Land Use and Restoration
Food-IAP	Food Security Integrated Program
GBIF	Global Biodiversity Information Facility
GEDI	Global Ecosystem Dynamics Investigation
GEF	Global Environment Facility
GEO	Group on Earth Observations
GFOI	Global Forest Observation Initiative
GHG	GreenHouse Gases
GIS	Geographic Information System
GOES	Geostationary Operational Environmental Satellite Program
GPM	Global Precipitation Mission
GPSC	Global Platform for Sustainable Cities
ICIMOD	International Centre for Integrated Mountain Development
IEO	[GEF] Independent Evaluation Office
IFAD	International Fund for Agricultural Development
INPE	Institute of Space Research
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Association
IRS	Indian Remote Sensing
JICA	Japan International Cooperation Agency
JPSS	Joint Polar Satellite System
KBA	Key Biodiversity Areas

LAI	Leaf Area Index
LANCE	Land, Atmosphere Near real-time Capability for EOS
LDSF	Land Degradation Surveillance Framework
Lidar	Light detection and ranging
MSP	Marine Spatial Planning
MTR	Mid-Term Review
NBSAP	National Biodiversity Strategy and Action Plan
NDC	Nationally Determined Contribution
NDVI	Normalized Difference Vegetation Index
NGO	Non-Governmental Organization
NIR	Near-InfraRed
NPP	Net Primary Productivity
ODC	Open Data Cube
OS	Open Source
OSFAC	Observatoire Satellital des Forêts d'Afrique Centrale
PIF	Project Identification Form
POES	Polar Operational Environmental Satellite Program
QGIS	Quantum GIS
Radar	Radio detection and ranging
RADD	Radar Alerts for Detecting Deforestation
RAMSAR	Convention on Wetlands
RCM	RADARSAT Constellation Mission
REDD+	Reduced Emissions from Deforestation and Forest Degradation
SFM	Sustainable Forest Management
SMFM	Satellite Monitoring for Forest Management
SWIR	ShortWave InfraRed
SDG	Sustainable Development Goal
STAP	Scientific and Technical Advisory Panel
TAL	Terai Arc Landscape
TNC	The Nature Conservancy
TR	Terminal Evaluation
TSM	Total Suspended Matter
UAV	Unmanned Aerial Vehicle
UHR	Ultra High Resolution
UMD	University of Maryland
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNEP-WCMC	United Nations Environment Programme World Conservation Monitoring Centre
USGS	United States Geological Survey
VHR	Very High Resolution
WMO	World Meteorological Organization
WRI	World Resources Institute

6.0 GLOSSARY OF KEY EARTH OBSERVATION AND RELATED TERMS

Accuracy assessment – The comparison of the classified image to another data source or ground truth data that is considered to be accurate.

Adaptive management - Structured, iterative process of robust decision making in the face of uncertainty, with an aim to reducing uncertainty over time via system monitoring.

Aerial photography – The action of taking photographs from an aircraft or other flying object. Also referred to as airborne imagery.

Artificial intelligence – The simulation of human intelligence processes by machines, especially computer systems.

Atmospheric scattering and absorption – Interaction of electromagnetic radiation with particles and gases in the atmosphere that can affect the amount and wavelength of energy reaching the surface or sensor.

Backscatter - The reflection of waves, particles, or signals back to the direction from which they came.

Big Earth Data – the science related to acquisition, management, analysis, and systematic extraction of information from Earth sciences data sets that are too large or complex to be dealt with by traditional data-processing application software. Especially but not limited to Earth observation data.

Change detection - Process that measures how the attributes of an area have changed between two or more observations, performed comparing images of the area taken at different times.

Citizen science - The collection and analysis of data relating to the natural world by members of the general public, typically as part of a collaborative project with professional scientists.

Cloud computing - The on-demand availability of computer system resources, especially data storage and computing power, without direct active management by the user.

Cloud platform - Suite of cloud computing services running on the same infrastructure a provider uses internally for its end-user products.

Confidence interval - Type of estimate computed from the statistics of the observed data proposing a range of plausible values for an unknown parameter.

Crowdsourcing - The practice of obtaining information or input into a task or project by enlisting the services of a large number of people, either paid or unpaid, typically via the Internet.

Data cube - a common analytical framework composed of a series of data structures and tools which facilitate the organization and analysis of large gridded data collections.

Data portal - Web-based interface designed to facilitate the localization of re-usable information.

Data triangulation - The application and combination of several research methods in the study of the same phenomenon.

Data validation - Process of ensuring data have undergone data cleansing to ensure they have data quality, that is, that they are both correct and useful.

Earth observation - The gathering of information about the physical, chemical, and biological systems of the planet, including remote-sensing technologies, in-situ sensors, GPS technology, and citizen science.

Ecosystem - Community of living organisms in conjunction with the nonliving components of their environment, interacting as a system.

Electromagnetic spectrum - Range of frequencies of electromagnetic radiation and respective wavelengths and photon energies.

Environmental change - Change or disturbance of the environment most often caused by human influences and natural ecological processes.

Fraction of absorbed photosynthetic active radiation - The fraction of the incoming solar radiation in the Photosynthetically Active Radiation spectral region that is absorbed by a photosynthetic organism, typically describing the light absorption across an integrated plant canopy.

Geographic Information System - Software designed to capture, store, manipulate, analyze, manage, and present all types of geographical data.

Geometric correction - Process to ensure image coordinates match their true positions in ground coordinates (e.g. latitude, longitude).

Geospatial technology – Collection of hardware, software, data, and standards that enable the collection, storage, analysis, visualization, and sharing of geographical data.

Geostationary orbit - Circular orbit 35,786 kilometres above Earth's equator and following the direction of Earth's rotation. Also referred to as a geosynchronous equatorial orbit.

Image processing - The use of a digital computer to process digital images.

***In-situ* measurement** - Measurement taken in the same place the phenomenon is occurring without isolating it from other systems or altering the original conditions of the test. Also referred to as field observation.

Internet of Things - The interconnection via the Internet of computing devices embedded in everyday objects, enabling them to send and receive data.

Leaf area index - Dimensionless quantity that characterizes plant canopies defined as the one-sided green leaf area per unit ground surface area in broadleaf canopies.

Lidar –Light Detection and Ranging, a remote sensing method that uses light in the form of a pulsed laser to measure range (distance) to the Earth surface features.

Machine learning - The use of algorithms and statistical models by computer systems to perform a specific task without using explicit instructions, relying on patterns and inference.

Microsatellites - Satellite with a wet mass approximately between 10 and 100 kg, sometimes working together or in a formation. The generic terms "small satellite", "smallsat", and "satlet" are also sometimes used.

Net primary productivity - The rate at which all the autotrophs in an ecosystem produce net useful chemical energy.

Normalized Difference Vegetation Index - ratio of the difference in the intensity of reflected light in the red and NIR band and the sum of these intensities. Used to assess whether the target being observed contains live green vegetation or not.

Off-the-shelf product - Packaged solution adapted to satisfy the needs of the purchasing organization, rather than the commissioning of a custom-made solution.

Open data - The idea that some data should be freely available to everyone to use and republish as they wish, without restrictions from copyright, patents or other mechanisms of control.

Orbit cycle - Time a satellite takes to complete one orbit around the Earth.

Orthophoto - Aerial photograph or satellite image that have been processed to correct distortions from the sensor system, sensor view angle, and ground terrain.

Polar orbit – Orbit in which a satellite passes above or nearly above both Earth poles on each revolution.

Polarization – An important property when for radar/microwave energy propagation and scattering, related to the orientation of the electromagnetic wave.

Precision agriculture - Farming management concept using data received from global positioning systems, satellite and aerial imagery, and sensors to enable a range of agriculture.

Radar - Radio Detection and Ranging. A system that transmits a microwave (radio) signal towards the target and detects the backscattered portion of the signal. The strength of the backscattered signal is measured to discriminate between different targets and the time delay between the transmitted and reflected signals determines the distance (or range) to the target.

Radar altimeter – Sensor measuring altitude above the terrain beneath an aircraft or satellite by timing how long it takes a beam of radio waves to travel to ground, reflect, and return.

Radiometric calibration - A process whereby different calibrations are applied to bring the digital numbers that comprise an image to a comparable scale.

Remote sensing - 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.

Revisit period - Time elapsed between observations of the same point on Earth by a satellite.

Satellite constellation - Group of satellites working together as a system and providing permanent global or near-global coverage, such that at any time everywhere on Earth at least one satellite is visible.

Spatial resolution - Measure of the smallest object that can be resolved by the sensor, or the ground area imaged for the instantaneous field of view (IFOV) of the sensor, or the linear dimension on the ground represented by each pixel.

Spectral signature - Distinct properties or responses of an object or feature to electromagnetic radiation across the electromagnetic spectrum.

Sun-synchronous orbit - Nearly polar orbit around a planet, in which the satellite passes over the Earth's surface at the same local mean solar time.

Swath - The area imaged on the surface of the Earth.

Synoptic coverage - The unique ability of remote sensing satellites to provide comprehensive and multi-temporal coverage of large areas at regular intervals.

Time series - Series of data (including images) indexed, listed, or graphed in time order.

Vintage – The age of an image or set of images or data relative to the present date.

Water yield - The average amount of fresh water that runs off in an unregulated watershed.

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A1.0 PROJECT IDENTIFICATION FORM: GEOREFERENCED INFORMATION AND PROJECT MAP

The GEF's current guidance on providing geo-referenced information and a map in PIFs recommends using geonames.org to provide geolocation ID numbers to standardize the format in which data are provided. Alternatively, latitude and longitude of one point in the project area is requested. All GEF agencies systematically collect information on projects that can be geo-referenced. Some agencies go further and collect GeoNames or coordinates of a bounding box (a pair of longitude and latitude coordinates that define a box that covers the project area).

To ensure that implementing agencies provide consistent and high-quality project geo-location, the following harmonized approach to fulfilling the guidance should be followed, which addresses recommendations by the IEO.

A1.1 GEOREFERENCED INFORMATION

Global projects:

a. *Specify the project is global, no GeoNames required.*

Multi-country projects:

a. Whole countries are the project area:
   - *specify country names and GeoNames ids*

b. Sub-areas of countries are the project area:
   - *specify country names and GeoNames ids*
   - *specify* province/state names and GeoNames ids

Example:
A multi country project in Vietnam and Lao PDR focused on the River Ma Transboundary Basin and Coastal Areas. The country and province GeoName ids are provided.
- Countries: Vietnam (1562822) and Lao PDR (1655842)
- Provinces: Thanh Hóa Province (1566166), etc. so that all provinces with activities are listed.

Single country projects:

a. Whole country is the project area:
   - *specify country name and GeoNames id*

b. Sub-area(s) within country are the project area:
   - *specify country name and GeoNames id*
   - *specify province/state names and GeoNames ids*

Example:
A single country project in Brazil addressing Sustainable Forest Management in the states of Amazonas and Rondonia. The country and province GeoName ids are provided.
- Countries: Brazil (3469034)
- States: Amazonas (3665361), Rondonia (3924825)

For any project in a **sub-area** of country or multi-countries (e.g. a protected area), provide the bounding box in decimal degrees.

Example:
A project in Brazil addressing Sustainable Forest Management in the states of Amazonas and Rondonia. The latitude and longitude of the bounding box are provided in decimal degrees.

Upper left -74.03502, 2.340589
Bottom right -56.047211, -13.72352

A1.2 PROJECT MAP

A project map should be provided in the PIF with the following elements:

- Title.
- Description of intervention, to correlate the expected impact and activities that will be completed.
- Scale bar (using the International System of Units); Coordinate System and datum.
- North arrow.
- Graticule (a latitude, longitude grid overlay).
- Inset map showing context of project location in country/region.
- Legend, including identification of project sites as needed.

All elements must be readable, and maps are recommended to have minimum 150 dots per inch and minimum 10-point font for text.

Two example maps of acceptable standard are:

- Strengthening the integral and sustainable management of biodiversity and forests by indigenous peoples and local communities in fragile ecosystems of the dry forests of the Bolivia Chaco (GEF ID10393); and
- Securing Luangwa's water resources for shared socioeconomic and environmental benefits through integrated catchment management (GEF ID10412)