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UK Space Agency International Partnerships Programme

Space for Forestry in Developing Countries

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The International Partnership Programme (IPP) is a five year, £152 million programme run by the UK Space Agency. IPP focuses strongly on using the UK space sector's research and innovation strengths to deliver a sustainable economic or societal benefit to emerging and developing economies around the world.

IPP is part of and is funded from the Department for Business, Energy and Industrial Strategy's Global Challenges Research Fund. This is a £1.5 billion fund announced by the UK government to support cutting-edge research and innovation on global issues affecting developing countries.

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Contents

Acknowledgments **4**

Background **6**

Executive summary **8**

The case for space **12**

- Space solutions support forestry challenges 12
- Space technology can support forestry in developing countries 14
- Space solutions for the forestry sector can be grouped into three thematic areas 18
- Forecasted impacts from IPP forestry projects 19
- Cost-effectiveness of space solutions for forestry 20
- Public domain evidence of the impact and cost effectiveness of space solutions for forestry 22

Seizing the opportunity **26**

- Space solutions 26
- Sustainability models 29
- Stakeholders and customers 32

Additional information and guidance **33**

- Characteristics of earth observation data 33
- Sourcing earth observation data 40
- Processing, storing and analysing earth observation data 40
- Sourcing earth observation expertise 45
- Additional reading and resources 48

Annex A: The value of forests **50**

Annex B: IPP forestry projects **52**

- CGI: PASSES (Peatland Assessment in SE Asia by Satellite) 52
- Ecometrica: Forests 2020 54
- Satellite Applications Catapult: Earth And Sea Observation System (EASOS) 56
- Stevenson Astrosat: Forestry Management And Protection (FMAP) 59
- Vivid Economics: Remote mapping and socio-economic valuation tools to support planning and implementation in land-use interventions in Peru 61
- Vivid Economics: Deforestation prevention with land-use monitoring and valuation in Côte d'Ivoire 64

Annex C: Methodology **67**

Annex D: Glossary **68**

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Background

This report is produced under the International Partnership Programme (IPP), a five-year, £152 million programme run by the UK Space Agency. IPP uses the UK space sector's research and innovation strengths to deliver a sustainable, economic and societal benefit to undeveloped nations and developing economies. Projects within IPP span themes including: improving agricultural development, enhancing disaster response, increasing resilience to climate change, reducing maritime pollution and illegal fishing, and reducing deforestation.

IPP is part of the Department for Business, Energy and Industrial Strategy's (BEIS) Global Challenges Research Fund (GCRF), a £1.5 billion Official Development Assistance (ODA) fund which supports cutting-edge research and innovation on global issues affecting developing countries. ODA-funded activity focuses on outcomes that promote long-term sustainable development and growth of developing countries on the OECD Development Assistance Committee (DAC) list. IPP is fully ODA compliant, being delivered in alignment with UK aid strategy and the United Nations' (UN) Sustainable Development Goals (SDGs).

The primary audience for this document is the development and forestry sectors, and it is written as an introductory primer on the role of space in forestry. This report outlines why and how the space industry has a critical role to play in addressing major challenges confronting the forestry sector in developing countries. It is part of a series of sector-focused reports, including **Space for Disaster Resilience in Developing Countries**[1] and **Space for Agriculture in Developing Countries**.[2] It sets out a view of how space can help, but it is recommended that the report is read alongside other relevant resources, some of which are listed in the section 'Additional information and guidance'.

Document structure

The document is structured as follows:

- **Executive summary**
- **The case for space:** why space solutions are an opportunity to help tackle the major global issues facing the forestry sector in developing countries
- **Seizing the opportunity:** existing space solutions, use cases and business models
- **Additional information and guidance:** next steps for accessing, processing and analysing satellite data, organisations to work with, and where to find further resources
- **Annex A:** The value of forests
- **Annex B:** Example IPP projects within the forestry sector
- **Annex C:** Methodology
- **Annex D:** Glossary

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[1] Caribou Space, for UK Space Agency. 'Space for Disaster Resilience in Developing Countries'. https://www.spacefordevelopment.org/library/space-for-disaster-resilience. Accessed November 2018.

[2] Caribou Space, for UK Space Agency. 'Space for Agriculture in Developing Countries'. https://www.spacefordevelopment.org/library/space-for-agriculture-in-developing-countries/. Accessed November 2018.

Audiences

Table 1: Audiences and messages

Audience	Why read this report?
Business, including: – high deforestation risk commodity consumers / producers – extractive industries – infrastructure developers – carbon project developers	– Comply with sustainability certification, corporate social responsibility (CSR) verification, and demonstrate adherence to environmental law – Reduce management costs through systems that improve forest monitoring, mapping and management – Identify how to use satellite data, what resources you need, and who to partner with
Government agencies involved in forestry and environmental management	– Ensure economic development and environmental conservation – Improve management efficiency and enhance operational capacity to monitor large areas cost-effectively through better decision support systems – Complement and enhance existing forest management systems
NGOs, investors, donors and research agencies in developing countries	– Find and access free data for forest monitoring – Understand what the latest space technologies achieve for forest conservation – Identify potential partners
Space sector	– Identify existing collaboration between the UK space sector and developing country partners – Understand which space technologies are currently being used in forestry – Assess the market opportunity for space for forestry in developing countries

Executive summary

The global forestry sector faces many challenges, many of which are more acute in developing countries. These nations have some of the most valuable forests in terms of timber and ecosystems, but their sustainability is increasingly under threat. Rapidly growing human populations require more land for agriculture, while increased exposure to international markets for commodities like timber, soy, and palm oil are driving deforestation and forest degradation. These processes are entirely legal but developing country forestry is also troubled by illegal deforestation.

These processes cause huge carbon emissions – around one-sixth of the emissions from all human sources – and are driving climate change. Additionally, the clearance of tropical forests is the largest driver of tropical biodiversity loss and also deprives forest-dependent communities of their livelihoods.

It is therefore crucial to monitor these processes. This is very challenging, or even impossible, using traditional ground-based methods. In some instances, such as for very high-resolution photography surveys, aircraft can be used. However, for consistent, accurate, high-frequency monitoring of forests at large scales, with automated data delivery, processing and analysis, space provides the only viable solution. This report outlines in detail why and how the space industry has a critical role to play in providing such solutions.

The major challenges facing the forestry sector in developing countries include:

- carbon emissions from deforestation and forest degradation
- loss of tax revenue from illegal logging and land use conversion
- risk to timber assets from disasters like fire
- the need to increase forest resilience to climate change
- loss of biodiversity and forest-dependent livelihoods through deforestation and forest degradation
- loss from deforestation and forest degradation
- balancing the need for economic development with the maintenance of natural ecosystems
- information deficits in the stock and change in forest assets

How do space solutions address forestry challenges affecting developing countries?

1. Improving the monitoring of deforestation and forest degradation

Deforestation[3] needs to be monitored to improve environmental management, but ground-based teams can only monitor small areas. By contrast, space solutions can map deforestation and forest degradation[4] at a national scale, consistently and with high frequency.

It is impossible to achieve the same results as space using ground teams. The only other comparable platform that can achieve such results is an aircraft, yet they are expensive to operate and provide very high resolution which may not be necessary for key monitoring requirements like REDD+. If the minimum mapping unit for monitoring is relatively large[5], then lower-resolution imagery is preferable as it is cheaper to acquire, process and analyse. Space solutions also provide the only solution for mapping in areas where it is dangerous to fly aircraft, such as conflict zones or very remote areas.

Space solutions are unique as a platform for data. So, space is critical for REDD+, and by extension, mitigating climate change. For instance, the European Space Agency's Sentinel satellites provide free 10 metre resolution optical and radar imagery around the world on a weekly basis. Radar can also penetrate through clouds, providing mapping in countries with lots of cloud cover like the tropics.

In addition, space solutions support early warning systems, such as fire alerts for forest managers, which enables emergency responses. They can enable decision support systems to allow management teams to target priority areas which can include suspected illegal logging sites and predicted high-risk deforestation hotspots. Space solutions also allow countries to report progress and outcomes of management activities and participate effectively in international climate change mitigation through REDD+.

2. Improved mapping and conservation of forest carbon and biodiversity

Policy makers, companies and NGOs wish to know how carbon and biodiversity are distributed across the landscape in order to inform planning and management. The standard tool for measuring these characteristics is the forest inventory plot. As with ground-based monitoring teams, it is only feasible to sample a very small area of forest using such plots. Space solutions can scale up these forest sample plot measurements providing mapping capacity across very large forest areas.

About 5% of all tropical forest grows on peat.[6] Peat deposits store a very large amount of carbon, up to 10 times more than the forest which grows upon it. However, the continued clearance of peat swamp forests for agriculture is causing huge carbon emissions, increasing fire risk and deteriorating local air quality.

Space solutions can:

- provide monitoring of peat condition and assess peat management performance by concessionaires
- detect fire hotspots, and support decisions on which areas to extinguish fires

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[3] Deforestation is typically defined as the permanent reduction in canopy cover below 10-30%. Thresholds for 'forest' are set nationally, within ranges of possible canopy cover, tree height, and minimum area given by the FAO. Deforestation is when an area that used to meet the national definition for forest is modified such that it no longer meets this definition.

[4] The removal of, for example, 10% of the trees in an area of forest.

[5] Hannes Böttcher and others, 2009.'An assessment of monitoring requirements and costs of 'Reduced Emissions from Deforestation and Degradation'. Carbon Balance and Management 4.1: 7.

[6] Greta C. Dargie and others, 2017. 'Age, extent and carbon storage of the central Congo Basin peatland complex'. Nature. https://www.nature.com/articles/nature21048. Accessed November 2018.

3. Improving commercial forest management and optimising land use planning

Commercial forest management (growing trees as crops) is undergoing a revolution. With a finite amount of cultivable land, there is increased demand to improve forest yields and sustainability. The increased use of modern tools and technology, such as remote sensing and GIS, to obtain as much information as possible is known as 'precision forestry'. Space solutions can support precision forestry activities by:

- mapping fire hotspots and fire risk, improving firefighting at a landscape scale
- enabling forest health monitoring
- monitoring conditions which affect tree growth rates
- mapping out storm damage to forests, such as blow-down
- classifying land use and the natural capital value of that land of forest

Space solutions for forestry are grouped into three thematic areas:

- active monitoring systems measure change in a forest over time and are able to support assessment of management performance across a country's forest estate
- mapping systems measure the state and properties, for example forest carbon at a point in time
- decision-support tools allow forestry managers to optimise management of their land, assess current and future land use, and quantify land and forest natural capital value to make intelligence-optimised decisions

Conclusion

While satellites capable of imaging forests have been in orbit for decades, the sector is undergoing a revolution. There is a profusion of satellites imaging the earth's surface with radar and optical sensors operating at a range of temporal and spatial resolutions, providing a huge increase in earth observation data.

Crucially, some of the new data is being provided free of charge, for example from the European Space Agency's (ESA) Sentinel satellites. The cost of medium and high resolution EO data is also decreasing. This improves the cost-effectiveness of space solutions in forestry compared to existing alternatives such as monitoring with ground teams or light aircraft. One IPP project calculates that between 2017 and 2023 their solution would cost just £62 per 'hectare of forest canopy cover saved', compared to £229 per hectare for additional ground and light aircraft patrols.

Furthermore, there is a parallel revolution in computing and data science, allowing for software to automatically process EO data to extract patterns and insights. A rapidly-growing ecosystem of space analytics companies (many featured in this report) are applying technologies such as artificial intelligence, machine learning and cloud computing to develop management solutions and decision tools for the forestry sector.

As costs fall and analytical products and platforms mature, space solutions will increasingly provide the opportunity to tackle some of the world's largest environmental problems while improving sustainability and margins in the forestry sector.

While there is a great deal of interest in achieving this in the public sector, there is also growing interest in the private sector. Automated and practical decision-support tools that support precision forestry and adhere to environmental legislation can reduce costs, assess and value land use, and improve bottom lines. This will improve commercial sustainability for technology providers and allow them to move away from historical dependence on the public sector for financial support.

The benefits of space are now rapidly becoming available to a huge new international audience in governments, NGOs and businesses helping to solve the global challenges facing the forestry sector.

The case for space

Space solutions support forestry challenges

At its broadest, earth observation (EO) is the gathering of information about the physical, chemical, and biological systems of the planet, including human activity, via remote-sensing (RS) technologies mounted on satellites and aerial vehicles. This has the aim of assessing and monitoring the status of and changes in the environment. RS technologies are usually integrated with in-situ earth-surveying techniques. There are three main types of EO data:

- ground-based, in-situ data collection such as from forest inventory plots
- remote sensing observations from sensors on aircraft or unmanned aerial vehicles (UAVs)
- remote sensing observations from sensors on satellites (see detail in 'Characteristics of earth observation data' section)

The unique benefit of EO is that it provides global, repeatable, accurate and scalable environmental data. The data delivers high value insights about how issues are impacting our planet and allows action to be taken to make a positive impact in many different areas.

There is a long history of space being used to support the forestry sector. NASA's Landsat mission was launched in 1972, providing half a century of EO data that has been used to monitor deforestation in developing countries. Some developing countries have their own satellites and forest monitoring systems, such as Brazil's CBERS satellites (produced jointly with China), which support the country's own monitoring system (PRODES). While these missions demonstrated the value of space for forestry, they were limited compared to what space solutions can offer today.

The space sector is undergoing a rapid transformation, with many new satellite platforms operating radar and optical sensors at a range of frequencies, and temporal and spatial resolution. This is being matched by the rapid development of technologies to analyse the data and distribute the derived products. Cloud computing, high-level data processing, data fusion, artificial intelligence and machine learning are all enabling the creation of new products. New platforms are being created to distribute this data, as high value actionable intelligence can support non-specialist users in decision-making. This greatly increases the number of users in the private and public sectors.

Crucially, huge volumes of high-quality EO data and tools for their analysis are now being provided free of charge. This includes NASA's ongoing Landsat mission, but most notably the European Space Agency's Copernicus programme. The programme's Sentinel-1 satellites provide free Synthetic Aperture Radar (SAR), while the Sentinel 2 satellites provide free optical data at up to 10-metre spatial resolution. The availability of high quality, high frequency data provided for free from the outset of a mission is unprecedented. In order to ensure sustainability of this revolution, and support the uptake of space solutions, ESA has committed to continue providing the free data until the 2030s. ESA has also committed to providing free software to allow users to process and analyse the data, as well as free online courses and documentation about how to use the software.

This approach represents a fundamental shift in the space sector, enabling the participation of countries and companies for whom the costs of data acquisition and processing has previously been prohibitive. With these rapid advances, the space sector is well-placed to transform information gathering and decision-making for users in the forestry sector. New and improved tools are certain to increasingly be part of the solution to forestry sector challenges.

In summary, the data and products derived from EO satellites have many advantages for forestry purposes, detailed below.

Coverage and quality: satellites have regular revisit times providing consistent observations, which make it possible to monitor forestry at project, regional, national and global scales in an accurate and repeatable way.

Range of data: the range of satellite sensors now available allows for the estimation and mapping of a variety of important forest properties including canopy cover, biomass (up to a certain threshold), forest health, and productivity. When time series data are used, deforestation (and to a lesser extent forest degradation) can be mapped.

Analysis-ready data: satellite data services organise and process data to defined industry standards and provide them in a form that allows immediate value-addition and analysis. An example is data as inputs to models like those being developed in some of the IPP projects.

Using increasingly standardised analytical tools, forest properties can be derived automatically from the data and presented as data compatible with geographic information systems (GIS), or as easy-to-use maps, spreadsheets and graphs. This provides intelligence for forestry management platforms or dashboards.

Remoteness and safety: data collection using satellites is significantly faster than on-ground data collection and is a safe and cost-effective way of working in remote areas or areas affected by conflict.

Speed of delivery: increasingly, analysis-ready EO data is available for use days or even hours after it is acquired, with data services enabling stakeholders to act quickly. This is particularly important where rapid management responses are required, such as to fires or illegal forest clearance in a national park.

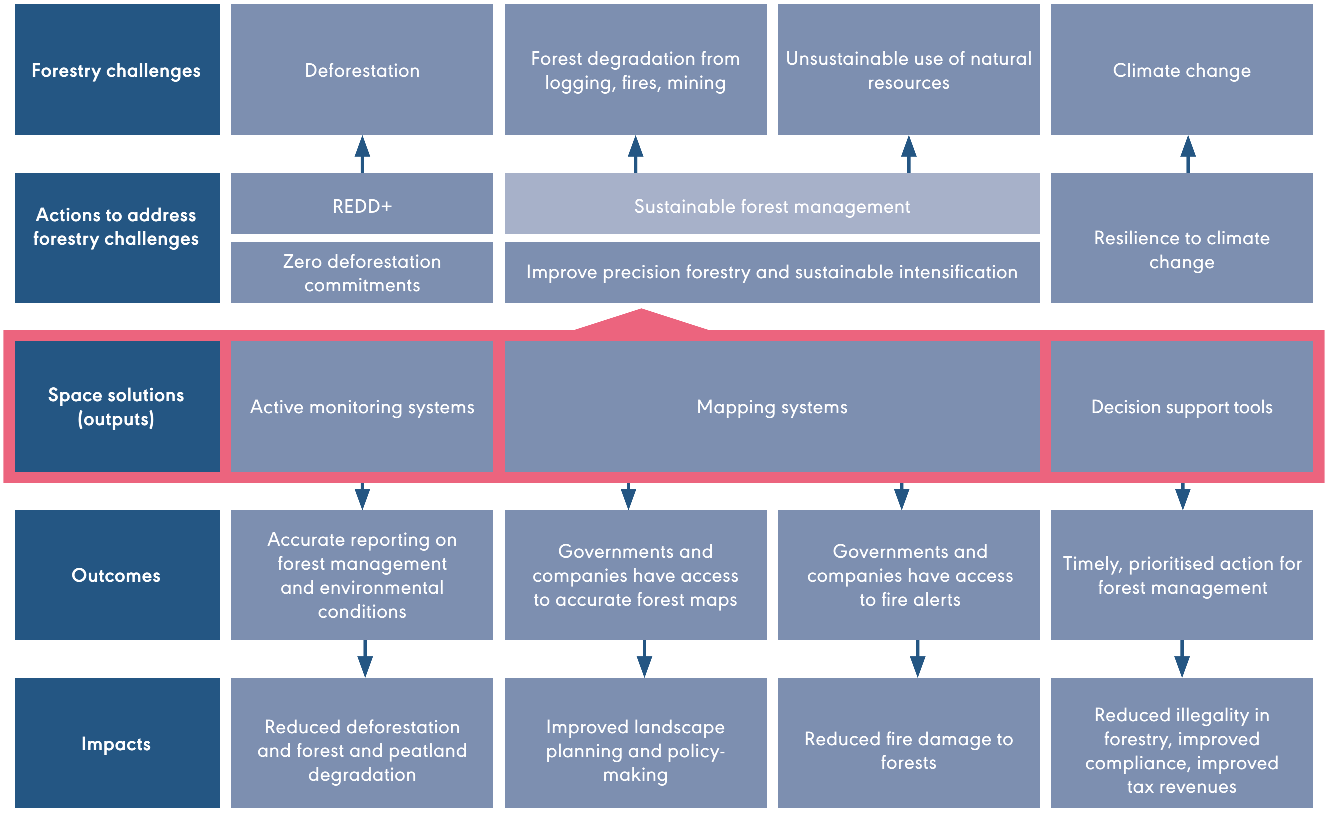
Space technology can support forestry in developing countries

There have been significant advances and impacts from using satellite technology in forestry in developed markets, and the opportunity to use space solutions in forestry in developing countries is increasingly recognised. For the space industry, these markets offer significant growth potential due to the sheer scale of the challenges. For example, billions of dollars of international finance are being committed to the climate change mitigation programme Reducing Emissions from Deforestation and Forest Degradation (REDD), and the sustainable management of forests and enhancement of forest carbon stocks (REDD+). Broadly, this involves richer governments paying developing countries to reduce their deforestation and forest degradation rates.

The only feasible way to monitor performance under REDD+ and across the vast areas involved is to use satellites. The private sector is also becoming involved in improved forest management and precision forestry. In particular, global commodities companies are pledging to cut deforestation from their supply chains by 2020, known collectively as zero deforestation commitments (ZDCs). As with REDD+ these commitments must be monitored and verified, requiring satellite data analysis. Finally, even where large budgets are not available, stakeholders in developing countries can now take advantage of access to free high-quality satellite data, free processing software, and information on how to use both.

Space solutions are well placed to provide solutions to forestry challenges affecting developing countries, with many positive outcomes and impacts.

Figure 1: Specific opportunities for space solutions to address forestry challenges in developing countries[7]



Forestry challenges	Deforestation	Forest degradation from logging, fires, mining	Unsustainable use of natural resources	Climate change
Actions to address forestry challenges	REDD+ Zero deforestation commitments	Sustainable forest management Improve precision forestry and sustainable intensification		Resilience to climate change
Space solutions (outputs)	Active monitoring systems	Mapping systems		Decision support tools
Outcomes	Accurate reporting on forest management and environmental conditions	Governments and companies have access to accurate forest maps	Governments and companies have access to fire alerts	Timely, prioritised action for forest management
Impacts	Reduced deforestation and forest and peatland degradation	Improved landscape planning and policy-making	Reduced fire damage to forests	Reduced illegality in forestry, improved compliance, improved tax revenues

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[7] Figure created for this report by Space Intelligence and Caribou Space. 2018.

1. Improving the monitoring of deforestation and forest degradation and predicting deforestation risk

Deforestation is typically defined as the permanent reduction in canopy cover below 10-30%.[8] Forest degradation is the removal of a smaller proportion of the trees in an area of forest (e.g. 15%), and the exact number depends on each government's definitions. These processes continue across developing countries[9] driven by a combination of factors.

The rapid expansion of agriculture is the driver for 80% of deforestation worldwide,[10] followed by extractive industries such as mining and logging. The production of commodities traded on global markets is central to this, including cattle and crops like soy and oil palm, which are collectively referred to as High Deforestation Risk Commodities (HDRCs). To produce these commodities, forest is cleared and converted into fields. Increases in agricultural land area are also being driven by increases in domestic demand for food crops. This is occurring even within protected areas where there is insufficient enforcement.[11] The low intensity of much of developing country agriculture means that domestic small-scale agriculture is often associated with forest degradation, rather than wholesale clearance of forest. Forest degradation probably affects a larger total area than deforestation. This is important, since forest degradation causes large carbon emissions and the remaining degraded forests experience an increased risk of fire and show lower levels of biodiversity.

Many forests in tropical countries grow on very thin soils, meaning that deforestation and forest degradation are followed by soil erosion, particularly in areas with steep terrain and heavy rainfall. This reduces the capacity of a forest to regenerate, or for land to be put to other use such as agriculture. The problem is exacerbated when the remaining vegetation is burned to clear the land, since fire can damage the seedbank and reduce climate resilience. These processes reduce biodiversity, release carbon and drive climate change, and further impoverish forest-dependent communities. These outcomes provide a clear rationale to monitor and reduce deforestation and forest degradation. Yet developing country forests are typically vast and remote, meaning that poorly-funded ground-based teams can often only patrol very small areas.

By contrast the new generation of space solutions provide the ability to map deforestation and forest degradation, repeatedly, at a landscape scale with relatively low cost. This allows users to direct management efforts. Early warning systems can flag deforestation hotspots to managers and enable emergency responses where deforestation is illegal or unplanned. With sufficient data, deforestation can be modelled to identify high-risk areas where more resources should be spent. Longer term reporting on forest management performance allows countries to participate in climate change mitigation programmes such as REDD+.

2. Improved mapping and conservation of forest carbon and biodiversity

The woody vegetation in tropical countries is highly carbon-rich and biologically diverse. Policy makers, companies, NGOs and civil society wish to know how these forests vary across the landscape and how they are changing.

They are also interested in mapping different forest types, and quantifying what carbon, biodiversity and other ecosystem services are present in the landscape. These maps need to be accurate and consistent. However, maps of forest type, biodiversity or carbon are typically out of date, of poor resolution, low accuracy, or do not exist at all in developing countries. The standard tool for quantifying such forest characteristics is the forest inventory plot, measured by ground teams. From these plots it is possible to differentiate forest types based on dominant tree species, and to estimate above ground biomass. Yet for logistical and financial reasons it is only possible

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[8] Thresholds for 'forest' are set nationally, within ranges of possible canopy cover, tree height, and minimum area, given by the FAO. Deforestation is when an area that used to meet the national definition for forest is modified such that it no longer meets this definition.

[9] Mathew Hansen and others, 2013. 'High-Resolution Global Maps of 21st-Century Forest Cover Change'. Science. http://science.sciencemag.org/content/342/6160/850. Accessed November 2018.

[10] Gabriel Kissinger, Martin Herold and Veronique De Sy, 'Drivers of Deforestation and Forest Degradation'. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/65505/6316-drivers-deforestation-report.pdf. Accessed November 2018.

[11] Murray B Collins and Edward T A Mitchard, 2017. Scientific Reports. https://www.nature.com/articles/srep41902. Accessed November 2018.

to sample a tiny proportion of any landscape with such plots. For instance it takes an experienced team a week to set up a single one-hectare plot in tropical forest.

However, these sample plots can be combined with satellite data to allow huge upscaling of surveys in a way previously not possible. This is because there are known relationships between forest patch size, forest connectivity, and biodiversity value. Space solutions can now provide maps of biodiversity and ecosystem type and provide data for models about how these could change under disturbance or climate change.[12]

While this report specifically concerns forestry, it is also important to mention peat forest. This is because it is now thought that there are over 500,000 square kilometres of peat forest in the tropics, which represents about 5% of all tropical forest.[13] Peat is partially-decomposed, water-logged remains of trees that can form in layers 10 to 15 metres deep, which can store up to 10 times the carbon as the forest which grows upon it. Relative to its area, peat is therefore disproportionately important for climate change mitigation, representing a vital carbon stock and sink. Since peat is waterlogged it has historically not been favoured for agriculture. Yet with increasing demand for crops like oil palm, and a finite amount of land, peat swamp forest is being cleared for agriculture.

In Southeast Asia in particular, much of this peat forest has been extensively cleared and drained in recent decades. Over half the forest existing in 1990 had been deforested or degraded by 2008.[14] This process requires digging networks of drainage canals to reduce the water table, drying the peat and making it suitable for growing crops. However, the drying causes the land to subside, accelerates carbon emissions, and dramatically increases fire risk. In low-lying coastal areas, this subsidence causes saltwater intrusion, where seawater seeps into the ground. Over the long term this renders the land unsuitable for agriculture. So, monitoring peat water tables is essential to ensure the land does not subside, and to support sustainable development.

When the forest has been cut down and the peat has been drained, fire is used to clear the remaining vegetation. These fires often spread, burning down neighbouring forests. In some cases, the peat also ignites. This causes huge carbon emissions as well as air pollution which is extremely hazardous for people living in the region. Fires need to be detected so that rapid response teams can extinguish them, and also to reduce the likelihood of further fires in the future. New space solutions, including those being developed under the IPP, can now be used to monitor peat forests, measure peat for subsidence, detect and predict fires, and support new sustainable peatland management.

3. Improving commercial forest management and optimising land use planning

Commercial forest management is changing rapidly. With a finite amount of cultivable land, there is increased demand to improve yields and sustainability, improve fire management, and reduce costs. Precision forestry has the opportunity to do this through modern electronics, computers, and sensors to support site-specific operational decision-making. In the context of a changing climate, fire risk monitoring is an increasingly important aspect of precision forestry. The consultancy company McKinsey reported that in 2017, 'one of South America's largest plantation forest owners lost 4% of its forest area due to fires' and that 'to reduce future losses, the owner is now investigating how to improve detection and control systems'.[15]

Multiple satellites systems can now map fire hotspots, and new solutions can rapidly deliver this data to forest managers. By integrating auxiliary data, space solutions can map out future fire risk. Managers are then far better placed to decide where to dedicate firefighting resources and how to plan future landscapes.

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[12] Urban and others, 2016. Science. https://doi.org/10.1126/science.aad8466. Accessed September 2018.

[13] Greta C Dargie and others, 2017. 'Age, extent and carbon storage of the central Congo Basin peatland complex'. Nature. https://www.nature.com/articles/nature21048. Accessed November 2018.

[14] Aljosja Hooijer and others, 2010. 'Current and future CO2 emissions from drained peatlands in Southeast Asia.' Biogeosciences. https://doi.org/10.5194%2Fbg-7-1505-2010. Accessed November 2018.

[15] Harsh Choudhry and Glen O'Kelly 2018. 'Precision forestry: A revolution in the woods'. McKinsey and Company. https://www.mckinsey.com/industries/paper-and-forest-products/our-insights/precision-forestry-a-revolution-in-the-woods?cid=other-eml-alt-mip-mck-oth-1806&hlkid=6df6e7a96eb143b49d8e145a78fbf02a&hctky=2299592&hdpid=0a048adc-3fff-4cb5-81ac-46ffd087bf21. Accessed November 2018.

In more standard management activities, tree crop harvesting often depends on a crop reaching a threshold height. Space solutions can now estimate forest height, and any changes in that height. This technology supports managers in scheduling spatially-explicit tree thinning and pruning operations. Maps that illustrate spatial variation in forest attributes, such as growing volume and grade, provide detail of the forest resource to support accurate harvest planning. Mapping out productivity with remote sensing data can support managers' decision making on planting over and above what is possible with field-level measurements.

Space solutions for the forestry sector can be grouped into three thematic areas

1. **Active monitoring systems:** These measure change over time and support assessment of management performance across a country's forest estate. This includes monitoring national parks and other state-managed forest assets, and ensuring that licenced forest concessionaires operate within permitted boundaries. In all of these contexts, stakeholders benefit from accurate and timely information on where and when deforestation and forest degradation are occurring.
2. **Mapping systems:** These measure the state and properties of a forested landscape at a point in time. Many developing countries struggle to quantify their own land use, particularly forest resources and values across often vast or remote areas. This lack of information prevents well-informed decision-making when planning for land use. Information is needed to understand the impacts of different policy choices on natural resources and sustainable economic development. Space solutions can improve spatially-explicit information on a country's resources and help countries to update and maintain maps over time in a cost-effective manner.
3. **Decision support tools:** Space solutions can underpin business intelligence systems that help decision-makers act. Such systems include early-warning alerts as to where fires are occurring, and where best to intervene to stop them spreading. They also include alerts as to where illegal deforestation is occurring and modelling of where deforestation is likely to occur in the future. Such modelling can support assessment of the impacts of land use scenarios, and the natural capital valuation of the land and forest. This will inform national reforestation and forest protection strategies. These tools help policy-makers understand the trade-offs between agricultural production and ecosystem conservation. The tools can help commercial forestry managers decide when and where to harvest and plant and respond to threats to forestry assets.

Figure 2: Deforestation occurs in remote locations, across large areas, which ground-based teams cannot monitor effectively

Forecasted impacts from IPP forestry projects

Forestry management is a major sector within the IPP portfolio with 6 projects receiving around £30 million of funding from IPP. Within these projects, there are roughly 30 UK space sector and academic institutions supporting around 40 international partners. Partners include government agencies, private companies, research agencies, academic institutions and NGOs. These projects are currently across five countries in Latin America, three in Asia and three in Africa.

Five of these projects launched in 2017, one in 2018 and all will conclude by March 2021. As such the final results are yet to emerge from the projects, however each project's monitoring and evaluation work stream forecasts its impacts. Projects in the IPP portfolio support interrelated actions to sustainably manage forests and contribute to the reduction of net deforestation through the following.

Improving the monitoring of deforestation and forest degradation and predicting deforestation risk

- IPP projects will help restore over 300 million hectares of forests by improving monitoring capacities in ten countries. Through faster and more accurate detection of forest change, in-country partners will be able to access more frequent, better quality data, and improve national forest monitoring systems.
- Four IPP projects are actively monitoring deforestation rates and degradation patterns in high-risk countries. These projects are identifying potential areas at risk for future deforestation (based on patterns and predictions) to enable government agencies to stop illegal deforestation before it happens. These projects aim to reduce net deforestation rates by 5% across IPP project areas.

Improved mapping and conservation of forest carbon and biodiversity

- All IPP forestry projects are using satellite data to improve the accuracy and frequency of forest mapping to support widespread forest governance and biodiversity conservation. By improving local partners' ability to map forests, they are better able to plan conservation activities and protect biodiversity.
- One IPP project is focused on monitoring and improving the management of over 1 million hectares of peatlands in Southeast Asia. Extensive clearance of peat forests and drainage of the peat is causing huge carbon emissions that drive climate change and worsen air pollution and biodiversity loss. This project will provide evidence of how improved monitoring improve the peat condition across the region.

Improving commercial forest management and optimising land use planning

- Two IPP projects focus on commercial forest management: monitoring the sustainable harvesting of trees, safeguarding and verifying supply chain interactions, and ensuring that landholders follow the law. Through digitisation of land concessions and electronic tagging of sustainably harvested trees, legal loggers can prove they are conforming to sustainability standards and managing their forest concessions responsibly.
- Two IPP projects in Africa and Latin America also focus on optimising land use planning by identifying priority areas for forest protection and reforestation activities. They also identify areas of forest that can be demarcated for non-forest activities (such as agriculture) to provide a legal source of income for people living in and near forested areas.

Cost-effectiveness of space solutions for forestry

Central to investment in space solutions for developing countries is the assumption that space solutions, including EO, offer the least costly method for achieving desired benefits within the forestry sector (specifically in developing countries).

To prove this assumption, a detailed cost effectiveness analysis (CEA) of all IPP projects, including the forestry projects, is currently being undertaken and UKSA will publish initial programme-level results of this analysis in 2019. This report will be updated in 2021 with CEA data from IPP forestry projects in Africa, South America and Asia.

The cost of EO-based space solutions is falling due to widespread industry trends. These include the access to low resolution optical and SAR data for all countries due to NASA's Landsat (28 metre resolution) and ESA's Sentinel satellites (10 metre resolution). This has driven the cost of low resolution EO data close to zero. Low resolution can be used for monitoring of forests over wide geographies and entire countries. There are also online tools such as Global Forest Watch – an open-source, freely accessible web application to monitor global forests loss and fire monitoring annually. Global Forest Watch also provides the GLAD rapid-alert system for forest management on a weekly basis over a subset of 22 countries at 30 metre resolution.

There are also commercial satellites collecting data at a far higher resolution, up to a maximum of 0.31 metre pixels for Worldview-3. The costs scaling is non-linear: Landsat and Sentinel data are provided for free, whereas Worldview and Rapideye are expensive to acquire commercially. SPOT6/7 medium resolution (1.5 metre) archive data is priced at $3.65 per square kilometre, and new tasking is $4.15 per square kilometre.[16] World View-2/3 high resolution (0.5 metre) archive data is priced at $17.50 per square kilometre and new tasking is $29 per square kilometre. Medium, high and very high resolution prices are also forecast to fall over next five years.

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[16] LANDinfo. 'Satellite Imagery Pricing'. http://www.landinfo.com/LAND_INFO_Satellite_Imagery_Pricing.pdf. Accessed November 2018.

Medium, high and very high resolution data is used for targeted, smaller regions of interest, for example where there is a suspicion of illegal logging activity.

While the costs of EO data are falling, this presents only one cost for space solutions for forestry. Other costs include:

- download
- storage
- processing
- analysis and delivery of results
- customer engagement
- software engineering
- capacity building and training
- ongoing operational support costs
- sales and business development etc.

The costs of data download, storage, processing, analysis, and delivery of results are also falling. Rapid developments in cloud processing mean that increasingly analysis-ready satellite data is hosted online. For example, the entire Sentinel archives are available through Google Earth Engine and Amazon Web Services, which removes the costs of data processing and storage. This efficient approach means that an algorithm for a new space solution can be brought rapidly to large amounts of data, with the user paying only for the CPU and storage that they require, rather than buying and maintaining servers in-house.

For users that do wish to download, process and analyse data on their own desktop computers and servers, the costs of bandwidth and data storage continue to fall. To process satellite data, the European Space Agency provides the Sentinel Application Platform (SNAP) toolbox for free in order to process data from ESA and other satellites. ESA provides free training sessions online on how to use this software, which can be automated using its command line tool. This reduces the costs from labour-intensive work and lowers the barriers to entry for analysts with less experience or formal training to begin using satellite data.

With respect to data analysis, the SNAP software also provides analytical tools. There is growing academic literature on how to analyse satellite data for forestry. The University of Leicester is producing a free public computer code repository for analysing Sentinel imagery, reducing the costs of analysis. Finally, the outputs of analytical processes such as deforestation mapping can be easily converted into GIS shapefiles ready for display for users on Google Earth, using free software like QGIS. These various systems can be integrated to allow further automation, using non-proprietary computer languages such as Python, for which satellite processing and analysis code libraries also exist.

The other factor that determines cost effectiveness is the scale and quality of the benefits and impacts provided by space-based assets (particularly EO) as they possess the following strengths relative to data collection from ground-based teams:[17]

- collection of data at regular frequency (high temporal resolution)
- data collection over large, remote, inaccessible areas (scale)
- fast turnaround of data (supporting in-year use)
- lower average data processing costs (through automated processes)
- consistency of data collected multiple times across a long time-series
- objectivity and lack of human error or bias in data collection
- re-use potential of the data for other applications

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[17] London Economics, 2018. 'Value of satellite-derived earth observation capabilities to the UK government'. https://londoneconomics.co.uk/wp-content/uploads/2018/07/LE-IUK-Value-of-EO-to-UK-Government-FINAL-forWeb.pdf. Accessed November 2018.

The comparison with UAV and aircraft-derived data is also clear. These platforms are assumed to be less cost-effective than space solutions because they:

- offer high-frequency observations, but depend upon on good weather to fly
- cover large areas, but not of the scale offered by space-based assets
- provide fast turnaround of data, but not through automated delivery services
- provide objective data, but with less consistent mission planning, and no planned repeat observations unless booked with the operator
- yield data with re-use potential for other applications, but hold less data in searchable databases

One of the IPP forestry projects has evaluated the cost effectiveness of their earth observation solution for detecting illegal logging and reducing deforestation compared to alternatives based on either increasing ground and light aircraft patrols for illegal logging or using a comparable satellite based solution deployed in Europe.

The impact indicator used in their analysis is 'hectare of forest canopy cover saved', and their analysis suggests that over the course of 2017 to 2023, their solution would cost £62 per hectare, compared to £229 per hectare for additional ground and light aircraft patrols. This is also in comparison to the £109 per hectare cost for the alternative space-based solution.

Public domain evidence of the impact and cost effectiveness of space solutions for forestry

In addition to the forecasted impacts from IPP forestry projects, there is public domain evidence of the impact of existing space solutions in forestry. Quantifying and communicating the impact and cost-effectiveness of space solutions within forestry is crucial to accelerating their adoption. For space solutions in forestry, the evidence supports the assessment that they deliver positive economic, social and environmental impact.

The evidence explores a broad range of space-based technologies, covering differing contexts, methodological approaches and outcomes of interest. While this evidence does not always explicitly explore impacts on forestry, it is helpful in establishing the efficacy of relevant approaches in the management and distribution of EO data.[18]

With respect to cost-effectiveness for space solutions developed under the IPP, given the brevity of the operational phases of the projects so far, it was not possible to make an empirical assessment from across the whole portfolio of relative costs to users against other solutions including the status quo. UKSA will publish initial programme-level CEA results in 2019. However, it is possible to draw on the literature to explore the cost-effectiveness of space solutions for forestry more generally.

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[18] Elisabeth Häggquist and Patrik Söderholm, 2015. 'The economic value of geological information: Synthesis and directions for future research'. Resources Policy Volume 43' (pages 91-100). March 2015. https://core.ac.uk/download/pdf/82368086.pdf. Accessed November 2018.

Table 2: Public domain evidence of the impact of space solution in disaster resilience

Space solution for forestry	Evidence of impact and cost-effectiveness in developing countries
Active monitoring systems	There have been satellites capable of imaging forests since at least 1972[19], and the impact of EO since then has increased due to awareness of developing country forestry challenges and rapid increase in availability of satellite data and free mapping products. High-resolution imagery available on Google Earth and global forest loss maps[20] have demonstrated to users the ability of EO to map forests and human impacts, and so its value. The Global Forest Watch platform offers free global forest loss and fire monitoring annually. This provides a world first in the availability of forest loss data at this scale. Global Forest Watch also provides the GLAD rapid-alert system for forest management on a weekly basis over a subset of 22 countries at 30 metre resolution. Even for charged services and products, despite apparently high costs, EO can be considerably more cost effective than in situ monitoring, depending upon the challenge faced.[21] For deforestation monitoring, 'satellites are the only efficient and realistic way to provide monitoring' at the national or international level[22] due to the vast land areas involved. It is not feasible to use ground-based personnel to do this. Developing countries creating National Forest Monitoring Systems to improve natural resource management and participate in climate change mitigation activities like REDD+ are discovering that the only feasible, cost-effective way to do this is by using satellite data.[23] However, for some national and regional problems, airborne solutions may be more viable than space, providing high spatial and radiometric quality data at a lower cost.[24] Space solutions will never replace the ground-based measurements required to calibrate EO data. With optical satellite data, weather conditions can limit the value of EO. Yet this simply means that EO provides huge benefits to scale up, rather than replace ground-based measurement.[25] Indeed, integrating[26] and tiered[27] UAV and EO analysis is increasingly common, with 'strong evidence that EO and geoinformatic techniques ... have valuable roles to play in an integrated approach, offering a more efficient and cost-effective means of surveillance for many habitats'.[28]

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[19] World Bank Group. 'Forests Sourcebook: Practical Guidance for sustaining forests in development co-operation'. https://siteresources.worldbank.org/EXTFORSOUBOOK/Resources/completeforestsourcebookapril2008.pdf. Accessed November 2018.

[20] Mathew C Hansen and others, 2013. 'High-resolution global maps of 21st-century forest cover change'. Science, 342(6160), pages 850-853.

[21] Cristina Secades and others, 2014. 'Earth observation for biodiversity monitoring: a review of current approaches and future opportunities for tracking progress towards the Aichi Biodiversity Targets'. https://www.cbd.int/doc/publications/cbd-ts-72-en.pdf. Accessed November 2018.

[22] Jim Lynch and others, 2013. 'Choose Satellites to monitor deforestation' Nature, 496: pages 293-294.

[23] Food and Agriculture Organisation of the United Nations. 'Voluntary guidelines on national forest monitoring'. http://www.fao.org/3/a-i6767e.pdf. Accessed November 2018.

[24] Sylvie Durrieu and Ross Nelson, 2013. 'Earth observation from space – The issue of environmental sustainability'. Space Policy, 29(4), pages 238-250.

[25] Barbara Koch, 2013. 'Remote Sensing supporting national forest inventories NFA', page 15. United Nations Food and Agriculture Organisation. http://www.fao.org/fileadmin/user_upload/national_forest_assessment/images/PDFs/English/KR2_EN__8_.pdf. Accessed November 2018.

[26] Murray Collins and Edward T A Mitchard, 2015. 'Integrated radar and lidar analysis reveals extensive loss of remaining intact forest on Sumatra 2007-2010'. Biogeosciences, 12(22), pages 6637-6653.

[27] Ray Purdy and others, 2017. 'Smarter Regulation of Waste in Europe'. https://www.researchgate.net/profile/David_Slater12/publication/320444901_Smarter_Regulation_of_Waste_in_Europe_LIFE13_ENV-UK-000549_LIFE_SMART_Waste_Project_Final_Report/links/59e5e874aca272390ee013aa/Smarter-Regulation-of-Waste-in-Europe-LIFE13-ENV-UK-000549-LIFE-SMART-Waste-Project-Final-Report.pdf. Accessed November 2018.

[28] Katie Metcalf and others, 2011. 'Making Earth Observation Work for UK Biodiversity Conservation—Phase 1'. JNCC Report, page 495. http://jncc.defra.gov.uk/PDF/Making_EO_work_for_UK_biodiv_PART_B_finala.pdf. Accessed November 2018.

Space solution for forestry	Evidence of impact and cost-effectiveness in developing countries
Active monitoring systems (continued)	Ultimately, cost-effectiveness depends on the data type and challenge. Very high resolution data (such as 30 centimetre resolution WorldView data) is not cost-effective for repeat national-level monitoring. However it is useful for the calibration and validation of assessments produced using free data, such as from ESA Sentinels. Low resolution data, such as that from MODIS, may not be cost effective where it lacks sufficient power to map the forest properties required. So: – Brazil uses its PRODES system to systematically map deforestation in the Amazon region on an annual basis with Landsat and CBERS satellites[29] – the government of Guyana's forest monitoring system uses high resolution (5 metre Rapid Eye) data to map deforestation and forest degradation as a condition of its bilateral REDD+ deal with the government of Norway[30]
Mapping systems	The UN Food and Agriculture Organisation (FAO) undertakes the Forest Resources Assessment (FRA) to gather essential information on the extent, condition, management and uses of forests worldwide. This is increasingly done with remote sensing surveys, with a portal to support FRA.[31] EO supports Social and Environmental Impact Assessments (SEIA) for development projects to map a project site more rapidly than ground teams. Since SEIA requires change detection, EO for SEIA tasks also falls into active monitoring systems. Two decades ago, EO was highlighted as cost-effective for low resolution environmental mapping.[32] Since then many new satellites have been launched, with data available free of charge, including most medium resolution satellites (around and under 15 metres) and the Sentinel 2 satellites at 10 metre resolution for some bands. Such freely-available data is most cost-effective for large-scale monitoring projects although free low-resolution data is most useful for visualisation.[33] Higher-resolution satellite, aircraft and UAV data has a cost of acquisition, which affects the cost-effectiveness for mapping. Broadly, costs vary directly with resolution, with Worldview-3 data (30 centimetre resolution) about ten times more expensive per hectare than RapidEye data (5 metre resolution). Very high resolution data like WorldView is typically only cost-effective for small-scale projects, validation of lower-resolution mapping products, or when very high accuracy or precision is required. This highlights the importance of revisiting the specific challenge faced to ensure a cost-effective solution from EO.

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[29] Maria T Borzacchiello and Massimo Craglia, 2011. 'Socio-Economic Benefits from the Use of Earth Observation'. http://ies-webarchive-ext.jrc.it/ies/uploads/SDI/publications/EOBenefitWS_JRCTechReport_final.pdf. Accessed November 2018.

[30] Indufor and The Guyana Forestry Commission. 'Guyana REDD+ Monitoring Reporting and Verification System (MRVS) Interim Measures Report'. https://www.regjeringen.no/globalassets/upload/md/2011/vedlegg/klima/klima_skogprosjektet/guyana/guyanamrvs_interimmeasuresreport_year2.pdf. Accessed November 2018.

[31] Food and Agriculture Organisation of the United Nations. 'FRA Remote Sensing Portal'. http://www.fao.org/forestry/fra/remotesensing/en/. Accessed November 2018.

[32] Peter J Mumby and others, 1999. 'The cost-effectiveness of remote sensing for tropical coastal resources assessment and management'. Journal of Environmental Management, 55(3), pages 157-166.

[33] As above

Space solution for forestry	Evidence of impact and cost-effectiveness in developing countries
Decision support tools	EO is used to support and improve decision-making in a range of contexts, including at the level of the individual, the firm and for society at large. EO is used to map out forest biomass and carbon, allowing decision-makers to plan plantation development to reduce climate impacts (High Carbon Stock Assessments).[34] EO data also supports mapping of High Conservation Value Forests (HCVF) for improved land use decision-making in developing countries. For example, the High Conservation Value Network's toolkit for Indonesia mandates the use of satellite data to monitor the distribution and quality of forest types, review the impacts of road development on forests, and review the impacts of external threats such as fire.[35] In Gabon, the plantation company Olam used EO to map vulnerable wetlands at risk from new oil palm development.[36] In Southeast Asia, forest clearance for plantations involves the use of fire, with negative economic, social and economic consequences. EO is now used to provide maps of fires and to help managers with limited budgets decide where to send resources to achieve maximum results in fire management.[37]

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[34] Technical Committee of High Carbon Stock. 'The High Carbon Stock Science Study'. https://www.tfa2020.org/en/publication/high-carbon-stock-science-study/. Accessed November 2018.

[35] Rainforest Alliance and Proforest, 2003. 'Identifying, Managing, and Monitoring High Conservation Value Forests in Indonesia: A Toolkit for Forest Managers and other Stakeholders'. https://www.hcvnetwork.org/resources/national-hcv-interpretations/hcvf-toolkit-for-indonesia-english.pdf. Accessed 9th November 2018.

[36] Ellen Brown and Michael Senior, 2014. A good practice guide for the adaptive management of HCVs. HCV Resource Network. https://www.hcvnetwork.org/resources/cg-management-and-monitoring-2014-english. Accessed November 2018.

[37] Global Forest Watch Fires. https://fires.globalforestwatch.org/home/. Accessed 9th November 2018.

Seizing the opportunity

There is a clear role and opportunity for space solutions to address some of the major challenges facing the forestry sector today. In order to take advantage of this opportunity, it is useful to understand some of the different solutions already available and their associated potential sustainability and business models. These are outlined in the following section.

Space solutions

The space solutions highlighted as outputs in Figure 1 are grouped into three thematic areas:

- active monitoring systems (measuring change in a system over time)
- mapping systems (mapping of state at a point in time)
- decision support tools (converting data into actionable intelligence)

Active monitoring systems

All of the projects listed take advantage of the SAR data from the European Space Agency's Sentinel-1 SAR satellite. The data is analysed using each of the project's proprietary algorithms. Broadly, they all take advantage of the dense time series of SAR data to examine radar backscatter[38] signals over time, with the exception of the PASSES project, which uses interferometry[39] to assess changes in the height of the peat surface.

The outputs of each of these analyses are then presented to users in different ways:

- **PASSES** provides information on changes in peat surface height, plus auxiliary data to users who decide whether to implement a new management plan and assess the performance of existing peat management interventions
- **Forests 2020** provides deforestation maps to users to monitor their areas of interest and report deforestation baselines
- **EASOS** flags areas of deforestation to users to prioritise interventions in forest clearings (this is also done by CUSAF, IMAGES and FMAP, which use dashboards to distribute information)

Mapping systems

Landscape classification

Landscape classification provides thematic maps of the landscape. This solution is used to provide a baseline of environmental conditions, perhaps at the inception of a project against which to measure future change. This is typically shaded into different colours, allowing the user to rapidly assess the types of different landscapes in their area of interest and how these are connected. At the broadest level there are two types of classification: supervised and unsupervised. A supervised classification involves using data collected from the field to train a machine learning algorithm to assess the properties of remote sensing data (such as radar backscatter per pixel) to determine the type of land cover in each pixel. A portion of the input data is retained and used to test the accuracy of the classification. An unsupervised classification uses an algorithm to distinguish between clusters within the dataset, without any field data to train or test the classification.

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[38] In a synthetic aperture radar system, microwave energy is emitted in a beam at the surface of the earth, and the energy which is reflected back by the land and vegetation structure is the 'backscatter'.

[39] Interferometric Synthetic Aperture Radar examines differences in the phase of a signal in multiple SAR images to generate maps of elevation and change, including subsidence, to very high degree of accuracy.

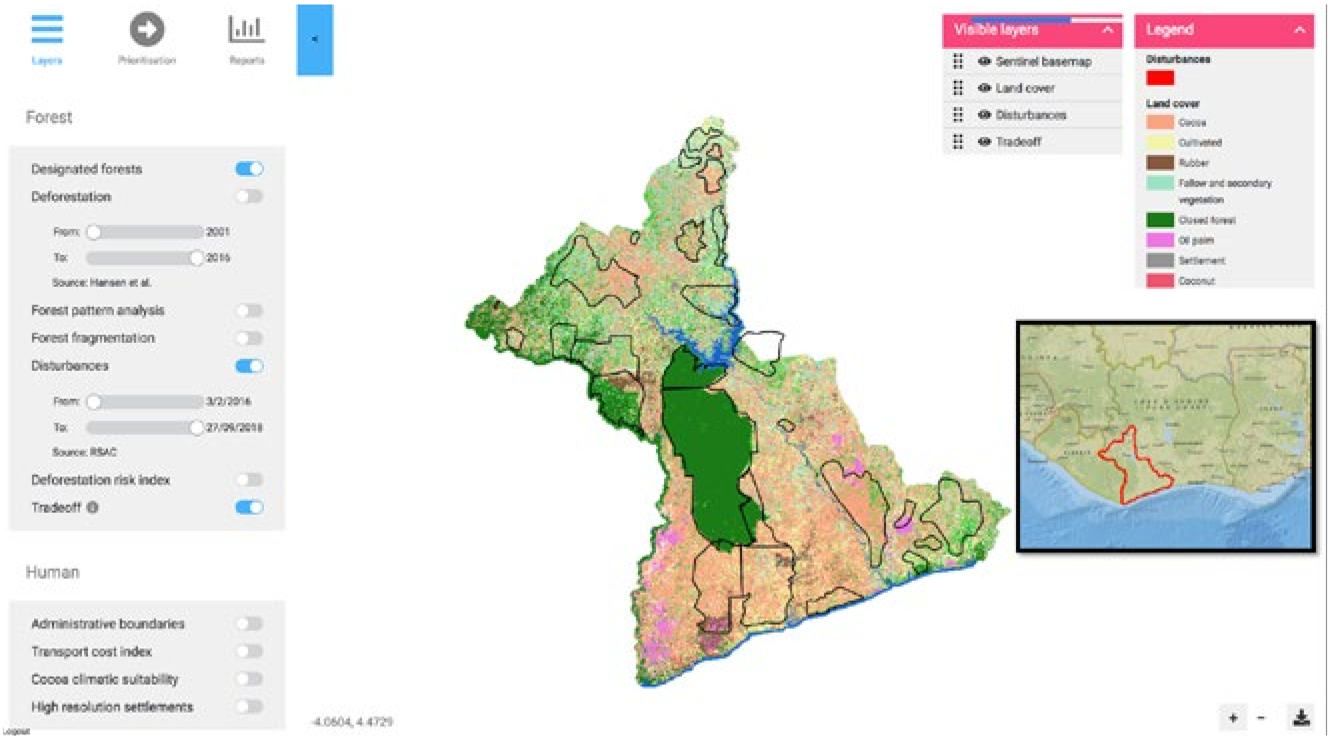
IPP projects providing active monitoring systems

- CGI – PASSES
- Ecometrica – Forests 2020
- Satellite Applications Catapult – EASOS
- Astrosat – FMAP
- Vivid Economics – IMAGES
- Vivid Economics – CUSAF

IPP projects providing mapping systems

- CGI – PASSES
- Ecometrica – Forests 2020

Figure 3: Land use mapping in Vivid Economics IMAGES[40]



Designated forests ●
Deforestation ○
From: 2001
To: 2016
Source: Hansen et al.
Forest pattern analysis ○
Forest fragmentation ○
Disturbances ●
From: 3/2/2016
To: 27/09/2018
Source: RSAC
Deforestation risk index ○
Tradeoff ●
Administrative boundaries ○
Transport cost index ○
Cocoa climatic suitability ○
High resolution settlements ○
-4.0604, 4.4729

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[40] Showing the thematic colours as set out in the key for Côte d'Ivoire under the IMAGES project (left panel) and an output from the land use valuation mapping product (right panel). The system models the trade-offs of different land use decisions, and examines the trade-offs between agriculture and natural ecosystem services, such as carbon storage, wood supply and biodiversity. The large area of dark green (reflecting closed canopy forest) in the left-hand image is displayed as dark blue (high values) in the valuation tool.

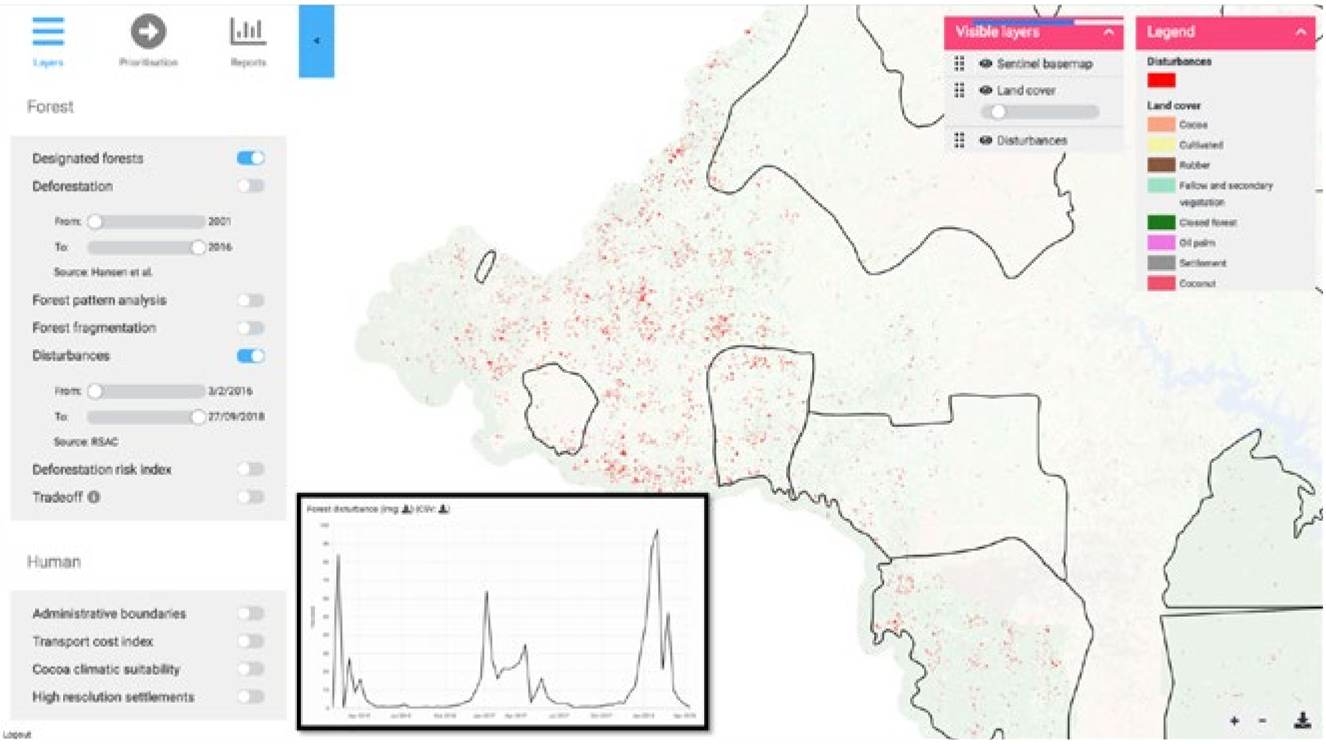
Deforestation risk modelling

Both Vivid Economics and Ecometrica provide deforestation risk modelling tools which take input data from previous deforestation patterns. They use this, and auxiliary input data, to estimate (using a statistical model) where deforestation is most likely to occur in the future. Further, by altering the inputs into the model, these products can estimate deforestation under different scenarios. An example of such scenario modelling would be when creating a road near to remaining areas of forest. From historic deforestation data, analysts will be able to estimate the impact on deforestation caused by the proximity of a parcel of forest to a road. This can then be extrapolated to estimate the impact on deforestation of a planned road.

IPP projects providing decision support tools

- Satellite Applications Catapult – EASOS
- Vivid Economics – IMAGES
- Vivid Economics – CUSAF
- CGI – PASSES
- Ecometrica – Forests 2020

Figure 4: Deforestation mapping and risk modelling in Cote D'Ivoire, under the IMAGES project



Designated forests ●
Deforestation ○
From: 2001
To: 2016
Source: Hansen et al.
Forest pattern analysis ○
Forest fragmentation ○
Disturbances ●
From: 3/2/2016
To: 27/09/2018
Source: RSAC
Deforestation risk index ○
Tradeoff ○
Administrative boundaries ○
Transport cost index ○
Cocoa climatic suitability ○
High resolution settlements ○

Decision support tools

Decision support tools take a series of input datasets and integrate them in context to allow users to make better informed decisions. These decisions could be which management interventions to take, and when to take them, to improve natural resource management. More broadly, such tools can help policy makers create policies that balance environmental management with economic growth.

Both the EASOS and PASSES projects provide decision support systems. The PASSES system provides users with information on:

- where peat swamp is subsiding as a result of agricultural activity
- which information is also integrated with fire detection alerts
- phenological data which allows the assessment of the quality of the vegetation in the locations where subsidence is occurring

This integrated data allows users to decide where companies need to stop draining the swamps, restoring the water table. The system also provides monitoring of the impact of such peat restoration activities. It allows users to make decisions about which interventions are effective and decide the future of concessions that are not managing peat areas well.

EASOS provides forest monitoring data that highlights where plantation companies are exploiting forests outside of the boundaries of their concessions, and so where government agencies need to intervene to deal with them. The IMAGES and CUSAF projects provide landscape-level deforestation risk modelling, land classification and land valuation. This provides government agencies with tools to decide where to plan future development activity and to plan future policy by assessing the impacts of different development pathways.

Sustainability models

Space solutions in the forestry sector require a sustainability model that will ensure continuity of the project beyond the initial funding to establish the project (for example a grant from UKSA IPP). Stakeholders need to identify sufficient revenue streams to cover operational costs in the long term to ensuring the solution and the positive impact to the country continue.

There are different sustainability models being pursued by the companies which are recipients of IPP support. These range from an ambitious transfer of IPR to the domestic partners who will host and run a new space-based service domestically, through to ongoing service provision on a commercial basis from the UK. In between these two extremes there exists a sliding scale with more or less developing country ownership of the IPR and production of products and services.

From conversations with the project leaders, the key determinants of the sustainability model appear to be a combination of the below.

- **Driver and source of demand for the services offered.** For instance, the willingness of private sector clients to pay provides the rationale for a commercial model, whereas an inability of a public sector customer to fund a project means that donor agency funding may be appropriate.
- **Capacity of the developing country partner.** Lower technical and human resource capacity in-country reduces the ease and probability of Intellectual Property Rights (IPR) transfer. This includes the partners' critical skills level in computer programming and the retention of staff once they have developed these valuable skills. Partner organisations are often reluctant to take on technologies that they can't use in-house.
- **Ownership of intellectual property rights (IPR).** The owners of the background IPR that is brought to the projects are key to determining the model, since if the IPR is a core company asset, there is no incentive to transfer it to a developing country customer.

Source of funding

During the course of the IPP projects, customers are insulated from the commercial costs of services being provided. However, at the end of IPP funding, a central concern among all projects was the risk that there would be no budget for the developing country customers to pay for ongoing costs of service provision or business overheads. This is in addition to direct project costs such as staff time, data purchase, storage, processing, delivery, portal development and maintenance, as well as development and maintenance of core products such as satellite data analysis algorithms. A range of funding sources are possible including commercial revenues, government investment, and donor funding.

Commercial revenue: Organisations including commercial foresters (buyers, growers, input companies) and large forestry groups in developing countries are increasingly using EO data to map forest resources, for instance under High Carbon Stock and High Conservation Value Forest assessments. Finding users in this group provides one potential route to sustainability.

Government revenue: Large scale forest monitoring is typically the domain of the public sector, so many IPP projects are working directly with government institutions and exploring B2G models to ensure sustainability. This involves developing spend-to-save models to demonstrate value of the space solution to government agencies with very limited budgets. In this scenario, the revenue required by the UK consortium would come from government paying a fee for access to the solution (such as deforestation monitoring) or purchasing the solution and taking over the management. In other cases, government bodies can provide the necessary seed funding to enable the solution to be developed, tested and launched in the market before alternative revenue streams are identified later.

A 'freemium' sustainability model allows UK providers to offer some elements of the service for free while other elements are charged at a premium. An example is where government agencies pay for the solution directly, but then fund this by charging the companies which need data to support forest management. For example, donor funding could be used to fund core services that are freely available, based on free low-to-medium resolution satellite data from ESA or NASA. Additional services would be available to companies and government agencies with the willingness to pay, using higher resolution commercial data ordered and analysed on demand for specific cases.

Donor funding: Many space solutions developed for forestry in developing countries require initial funding from donors. In some cases, donor funding will continue to be the main source of income to cover development and operational costs of the solution. Forestry mapping solutions are particularly important for the development of REDD+, specifically for National Forest Management Systems (NFMS). This suggests that donor funding will be a key source of revenue for some projects.

As the space sector continues to advance and increase its influence in developing countries, some trends and alternative business models are emerging.

Drivers of demand and industry trends

There is increasing awareness around the world of the role of human activity in driving accelerated climate change. As such, governments of tropical forest countries are responding with a suite of hard legislation and policies to reduce human impacts on the environment generally and on forests and peatlands specifically.

UN REDD+ development

There is growing global investment in forestry as a means to mitigate climate change. In the public sphere, the governments of Norway, the UK, Germany and Japan have committed $1 billion per year to reduce emissions from deforestation and forest degradation (REDD+). These projects require monitoring, reporting and verification (MRV), which is only feasible across the vast areas concerned by using space solutions. Any country that is required to submit Forest Reference Emission Levels to the UNFCCC will be required to have a satellite monitoring system in place.

The development of NFMS requires private sector expertise and large budgets. For instance, in 2017 the Brazilian government announced that it would outsource monitoring of the Amazon river, with a $25 million contract.[41]

Where IPP projects produce information pertinent to UNFCCC reporting mechanisms (such as CGI PASSES in Indonesia) the long-term sustainability of the solution will depend on the government of Indonesia's relationship with the REDD+ donor organisations. For peatland monitoring, there is demand for monitoring companies' plantations on peatland. These companies need to report on peat water tables, domestic environmental legislation and internal corporate social responsibility (CSR) requirements. In this case, the private sector may offer a more sustainable solution than donor funding.

Voluntary carbon market

There are voluntary carbon market projects around the world involving conservation or forest restoration. The purchasers of the resulting carbon credits want to be assured that the credits produced are real. This is typically undertaken by a third-party company who measure deforestation and forest carbon stocks, using satellite data to assess rates of forest change and field data to assess carbon stocks. Such companies follow (or develop their own) methodologies under particular carbon standards, such as the Verified Carbon Standard, Gold Standard, or Plan Vivo. The project's adherence to these standards, and the analyses done for them by specialist consulting companies, are then validated and verified by independent and approved validation and verification bodies.[42]

Supply chain management

In the private sector, consumer goods companies such as Unilever are under pressure to take responsibility for impacts of their purchasing High Deforestation Risk Commodities (HDRCs), such as tropical hardwoods, soy and palm oil. As a consequence of such pressure, over 500 of the world's largest companies have made zero deforestation commitments (ZDC). Stakeholders in forest management want to know that these commitments are being adhered to, requiring accurate data on forests and changes over time. Satellites provide the only realistic way to provide such verification.

Tropical peatland monitoring

The clearance and burning of peat swamp forest is a major environmental challenge, driving environmental and health problems such as the haze crisis that affected Southeast Asia in 2015. In response to international pressure and the deal with Norway REDD+, the government of Indonesia now obliges companies operating on peatland to report on water tables in their concession areas and monitor the condition of the peat. The only cost-effective way to monitor huge areas of peatland is with satellite data, driving demand for services such as PASSES.

Developing country capacity

A crucial dimension of the sustainability question is the level of developing country capacity. This determines the degree to which a developing country is able to adopt a technology. There are two main forms of adoption, either as a principal, which adopts the means of production under a full technology transfer agreement, or as a service buyer, that adopts the results of a technical analysis into a decision-making process or chain. The first option is the least probable sustainability strategy across the IPP programmes, due not only to low developing country capacity, but also the incentives of the companies which own the intellectual property rights to earn revenues.

Cost of EO data

Global trends around open data and making EO data freely accessible, such as from the ESA's Sentinel satellites, are influencing business models. Forestry organisations interested in the opportunity for space solutions will benefit from open data policies in forestry and EO, making the solutions more affordable for developing countries. Furthermore, open EO data can trigger innovation and tool development within developing countries, increasing the number of home-grown space solutions. See detail above in 'Cost-effectiveness of space solutions for forestry'.

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[41] Erik Stokstad, 2017. 'In controversial move, Brazil may outsource Amazon deforestation monitoring'. http://www.sciencemag.org/news/2017/05/controversial-move-brazil-may-outsource-amazon-deforestation-monitoring. Accessed 9th August 2018.

[42] VERRA. 'Validation and Verification'. http://verra.org/project/vcs-program/validation-verification/. Accessed September 2018.

Stakeholders and customers

Across the projects involved in IPP there are typically a wide range of stakeholders in both the UK and developing country. These include:

- prime supplier – a co-ordinating project principal that has the capacity and vision to develop the solution, such as Ecometrica
- technical partner that has developed a core technology or algorithm, such as GeoSpatial Ventures Ltd within the CGI PASSES collaboration
- UK universities who have been central to the development of the IPP projects by providing technical expertise, in-depth knowledge of the use-cases for solutions, the current state of technology, and networks with access to users in the developing countries, such as the University of Edinburgh in Forests 2020
- developing country government users – for example, the Ministry of the Environment in Indonesia
- developing country commercial users – commercial users under IPP see a benefit from the use of space solutions to improve forestry management and decision-support systems, and also to validate their adherence to environmental legislation
- developing country NGOs for local understanding and networks within forestry, such as ARCAS in Astrosat's FMAP project
- UK universities who have been central to the development of the IPP projects by providing technical expertise, in-depth knowledge of the use-cases for solutions, the current state of technology, and networks with access to users in the developing countries, such as the University of Edinburgh in Forests 2020
- sales agent or organisation in-country in order to ensure sustainability of the projects in the partner country, and to have good permanent contacts there to disseminate products and services and develop long-term strategies

Additional information and guidance

Overview

The preceding chapters of this report have highlighted the opportunity for space solutions to bring benefits to forestry, as well as the different business models being tested.

This chapter provides guidance for development and forestry practitioners as to how they can use space solutions. In order to realise the opportunity for using satellite data in forestry, it is necessary to partner with organisations that have the required expertise, skill and infrastructure. Here we provide guidance on:

- characteristics of EO data
- sourcing EO data
- processing and analysing EO data
- sourcing EO expertise
- additional reading and resources

Characteristics of earth observation data

EO data comes from a variety of sensors. Satellite sensors are commonly divided into active and passive, each offering different benefits and constraints. A sensor can often be referred to using other names including camera, instrument and payload. The exact terminology depends on the sensor type.

Passive sensors receive emitted or reflected energy, typically from the earth's surface (land, ice or ocean). Examples of passive sensor include instruments and cameras that can detect visible wavelengths, infrared and thermal (for surface temperatures), and microwave wavelengths (for surface roughness, soil moisture and salinity).

Active sensors both emit and receive signals and include radar systems such as synthetic aperture radar (SAR), radar scatterometers, radar altimeters, weather radar and laser range-finding (light detection and ranging, LiDAR). EO usually refers to remote sensing with satellite-based sensors, but also includes platforms such as aerial. The sensors used on other platforms are often the same as for satellites and in many cases, sensors are tested on aerial platforms before being used on satellites.

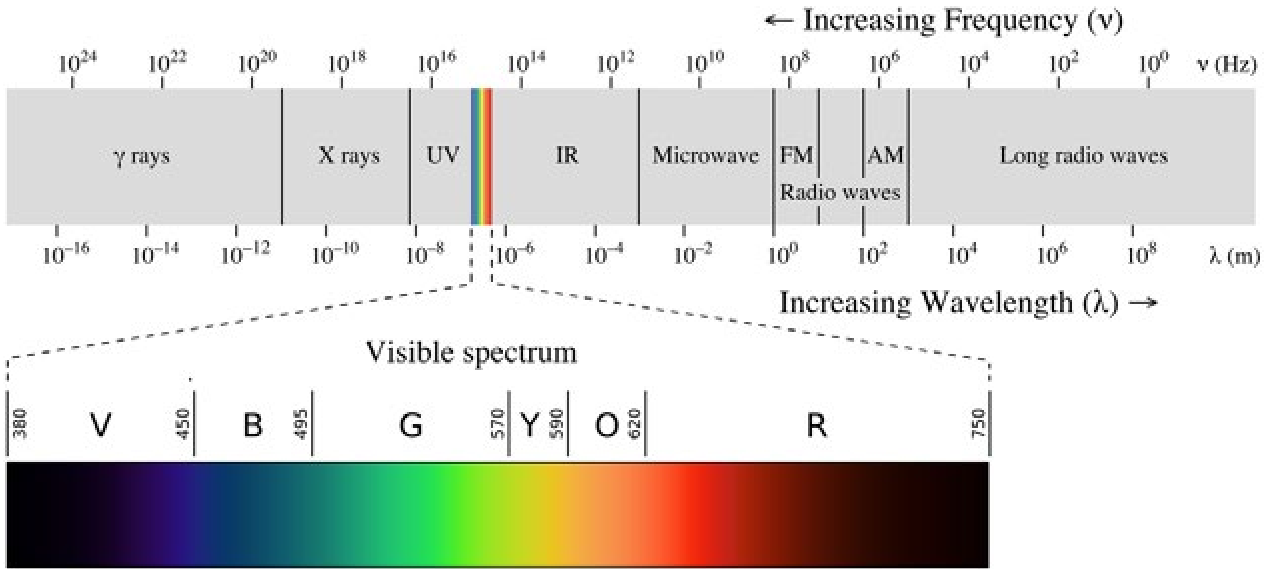
EO solutions are dependent on the satellite input data used, other data they are combined with, and the processing and analysis techniques applied. EO data varies from sensor to sensor in terms of the parameters that are measured and the spectral, spatial and temporal resolution of the products.

There are three main types of EO data: optical, radar and LIDAR. Each has different characteristics, strengths and weaknesses, and all three are discussed. It is important when choosing sources of satellite data to consider the characteristics of the features to be examined.

Spectral resolution

EO sensors use the electromagnetic spectrum to 'see' the earth. Spectral resolution refers to the number of colours or discrete spectral samples that are recorded for each image pixel. Typically, the presence of more spectral wavebands increases the ability of the imagery to discriminate between different features, such as land cover as there is more information and therefore more discriminating power in the image.

Figure 5: The electromagnetic spectrum



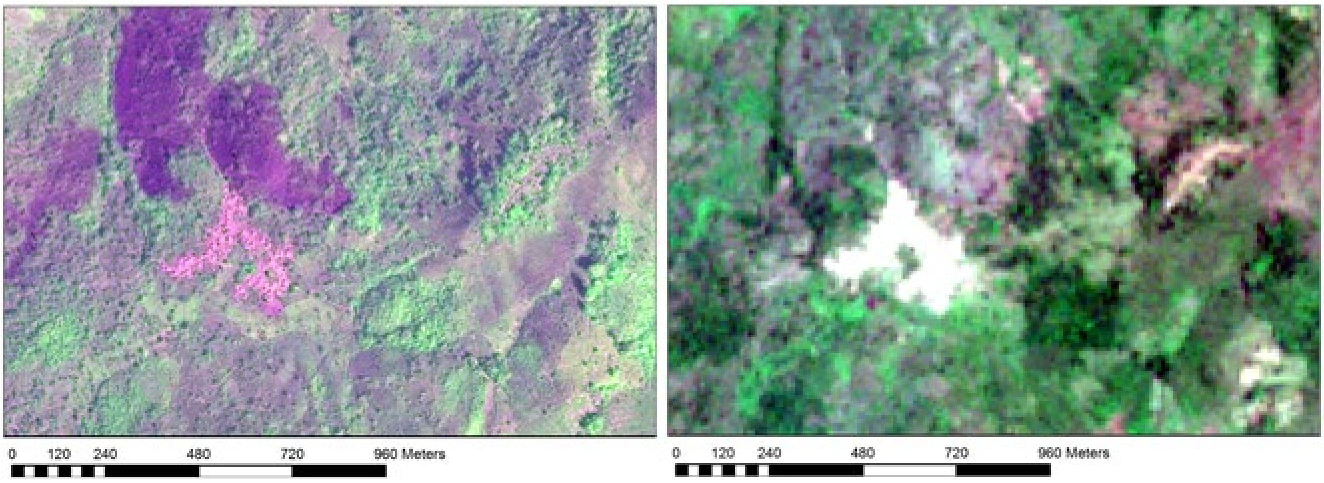
Spatial resolution

Spatial resolution refers to the pixel size of an image. The higher the spatial resolution, the greater the ability to identify and 'see' more detail in an image (see Figure 6). Typically, a higher spatial resolution means a smaller area observed per image, although a sufficient budget could allow multiple images to be acquired and mosaicked together. Beyond this, the limitation of high-resolution imagery is its low temporal frequency. When discussing the resolution of imagery in this report, the following terminology is used as set out in the table below.

Table 3: Resolution definitions

Abbreviation	Image resolution (metres)
LR (low resolution)	20+
MR (medium resolution)	10-20
HR (high resolution)	5-10
VHR (very high resolution)	0.5-5
AP (aerial photography)	0.3-0.5

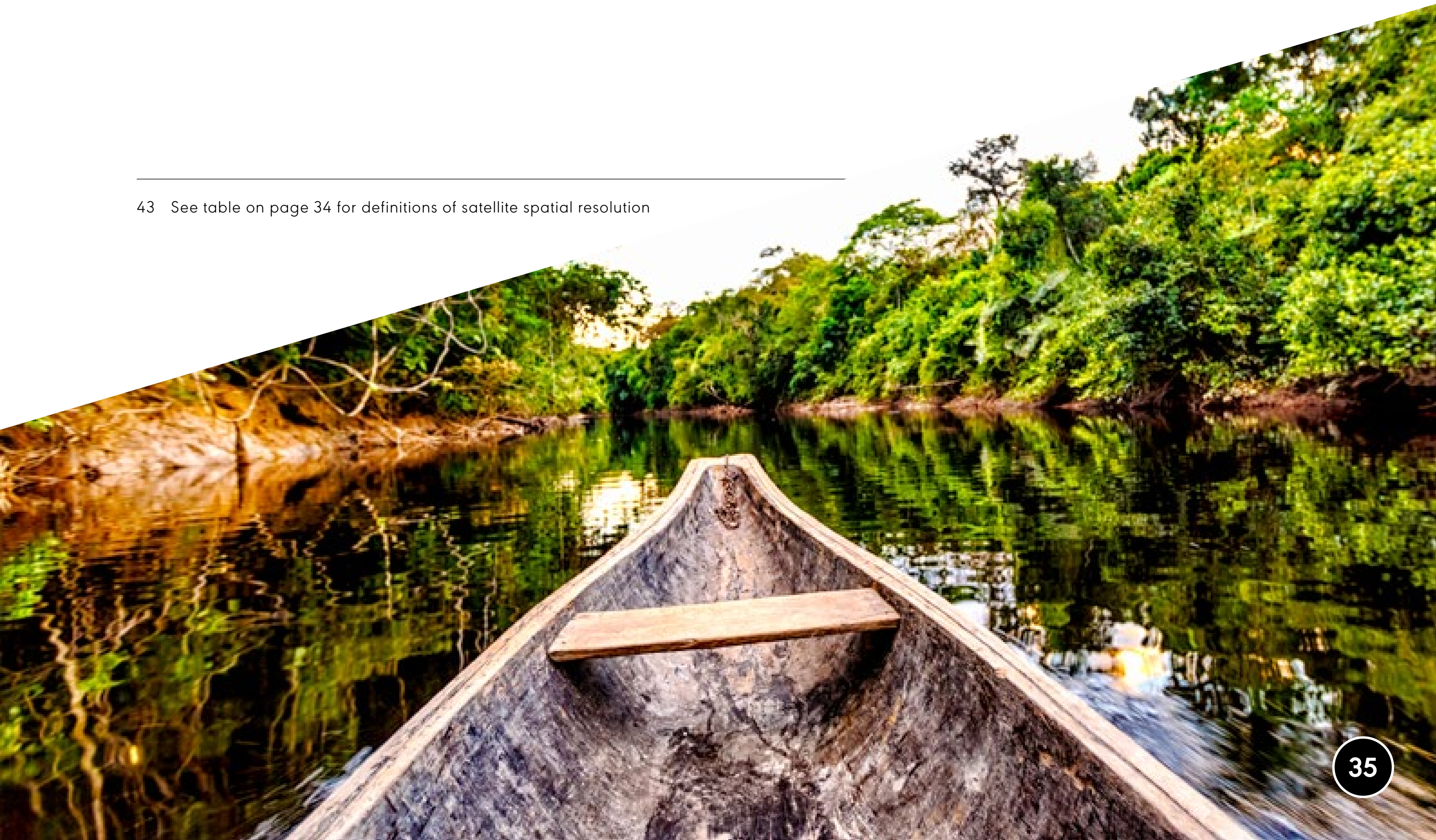
Figure 6: Forest visible at very high resolution (left) and as viewed at medium resolution (right)[43]



Temporal resolution

Temporal resolution is related to the repeat frequency with which a system can acquire images of the same location. For satellite EO, this is mainly determined by the revisit time of a satellite over the same location, which is a function of the satellite orbit. However, with optical satellites, environmental factors such as cloud cover have an overriding impact on the availability of suitable images.

One of the current trends in EO is to maximise the use of time series that new EO constellations provide to give ultra-high tempo data as the basis for analytics. One example is the weather-independent availability that Sentinel-1 SAR provides.



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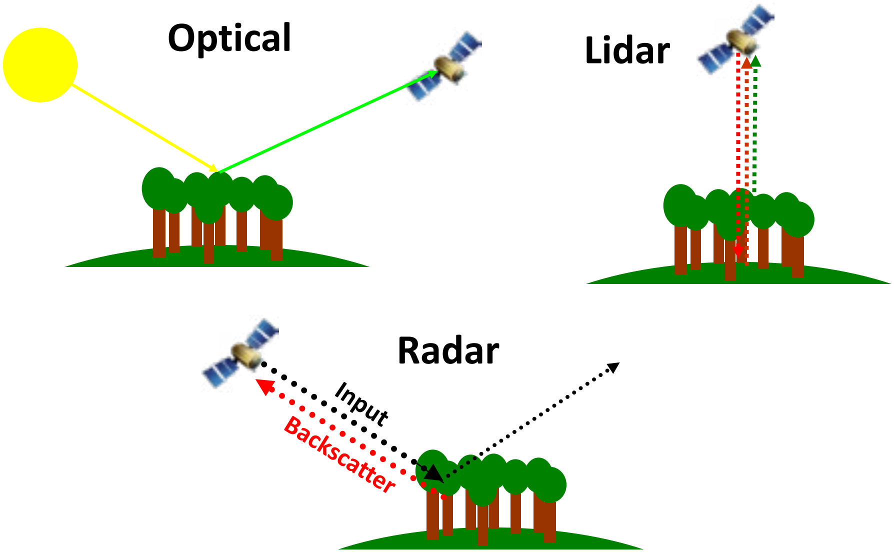
[43] See table on page 34 for definitions of satellite spatial resolution

Types of EO data

There are three main types of EO data: optical, radar and LIDAR. Each has different characteristics, strengths and weaknesses, and all three are discussed.

Figure 7: Understanding optical, radar and LIDAR sensing



Optical sensors

Multi-spectral satellites are common in EO (often collectively referred to as optical satellites). They provide images of the earth's surface and atmosphere captured in the visible and infrared portion of the electromagnetic spectrum. Optical data is relatively easy to process and understand, so is therefore a more easily transferable technology.

In forestry, optical data views the top of the canopy, and can be used to assess canopy cover and potentially estimate the density and health of leaves and trees. It has traditionally been the main tool used to map deforestation and has been used with limited success to detect forest degradation, though this requires data with very high temporal and spatial resolution.

However, optical data has two major problems:

- it cannot see through clouds, which cover much of the tropics most of the time, limiting observations
- it cannot see through the top of the forest canopy, meaning low-level degradation that doesn't involve canopy trees will be invisible

Multispectral sensors generally capture information from around 3 to 10 bands. Hyperspectral sensors can capture hundreds or thousands of bands, each representing a much narrower wavelength of the electromagnetic spectrum. Having a higher level of spectral detail in hyperspectral images improves the ability to observe the characteristics of the land surface that the human eye cannot. However, having so many bands increases the complexity of handling the data. In addition, the cost of acquiring hyperspectral images (airborne) is relatively high and is therefore better suited to smaller scale, targeted surveys.

Optical remote sensing data is the most widely available of the three types of sensor, with over a hundred satellites collecting data regularly. There are a number of options for free optical satellite data, with the most widely used being NASA's Landsat and ESA's Sentinel-2. The Landsat series of satellites started collecting data in 1972, with the data now freely distributed for any use by the United States Geological Survey (USGS), at 30 metre resolution. The Sentinel 2A satellite was launched in 2015, with a second satellite 2B launched in 2017. This orbiting pair provide data globally at up to a 10 m spatial resolution, and the data is free of charge.

There are also commercial satellites collecting data at a far higher resolution, up to a maximum of 0.31 metre pixels for Worldview-3. The satellite operator Planet runs a constellation of Dove satellites which from 2017 have been able to image the entire earth every day (at 3.5m resolution in Visible Near Infrared). This means the likelihood for a cloud-free mosaic product at a monthly cadence is quite high, even in tropical regions.

Optical data can also be collected from UAVs or manned aircraft, allowing centimetre-scale resolution from which it is possible to map individual trees, their relative heights (if stereo data is collected), and characteristics such as drought stress or species type. Yet again, this data is very expensive, and hence typically only used to observe small areas.

Synthetic aperture radar (SAR)

These are active sensors that transmit beams of microwave energy at the earth, and record the energy reflected back, independently of light and heat, unlike the optical systems above that rely on reflected light from the sun.

As a result, SAR can provide day-and-night imagery of the earth. The microwave frequency used for EO penetrates clouds.[44] This is of prime importance for monitoring tropical forest, since clouds cover half of the tropics 95% of the time.

Radar energy also penetrates through the forest canopy to obtain information on forest structure. Therefore, radar satellites have been used to map deforestation and above ground biomass. Rather than being considered as a choice between sensors, SAR complements optical data, measuring different vegetation properties.

Radar can also be used to accurately estimate surface and canopy height through a process called interferometry, involving looking at the same area twice from a slightly different angle and studying the phase difference in the waves. This has great potential for mapping forest degradation through studying changes in these canopy height models through time, but it does not allow for the direct estimation of tree height unless an accurate model of the elevation of the ground is available. However, such Digital Elevation Models (DEMs) are not currently available in most developing countries.

While satellite radar data has previously seen little uptake, its use in forestry is now rapidly increasing for several reasons. Firstly, it can penetrate cloud and forest canopies. Moreover, ESA's Sentinel 1 satellites are now providing high frequency data globally, with around 20 metre spatial resolution, as well as radar processing and analysis tools, all free of charge. Simultaneously, the academic community has produced work demonstrating how radar time series can be used for forest mapping in developing countries using radar technology.[45] [46]

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[44] European Space Agency. 'Synthetic Aperture Radar Missions'. http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/SAR_missions. Accessed November 2018.

[45] Murray Collins. and Edward T A Mitchard, 2015. 'Integrated radar and lidar analysis reveals extensive loss of remaining intact forest on Sumatra 2007–2010'. Biogeosciences, 12(22), pages 6637-6653.

[46] Johannes Reiche and others, 2018. 'Improving near-real time deforestation monitoring in tropical dry forests by combining dense Sentinel-1 time series with Landsat and ALOS-2 PALSAR-2' Remote Sensing of Environment. 204: 147-161.

Light detection and ranging (LIDAR)

This is a surveying method that measures distance to a target by illuminating that target with a pulsed laser light and measuring the reflected pulses with a sensor. Differences in laser return times and wavelengths are then be used to make digital 3D models of the target, such as a forest. LIDAR can be used with rough terrain and can penetrate forest canopies, which means it can provide complex information on forest structure. It can overcome some issues of cloud cover, but not as completely as radar. UAV or aircraft-based LIDAR data can build a forest model with height, stem density and canopy cover all estimated. The direct mapping of stem density requires accurate segmentation of tree crowns, but if this is done, repeat surveys can show up the removal of individual trees, giving better opportunities to detect forest degradation. There are also space-borne LIDAR sensors, carried on IceSAT in the 2000s[47], with IceSat II having been launched and GEDI[48] about to be sent to the International Space Station (at time of publication). These provide very valuable detail on the structure of forests and are very useful for upscaling in forest mapping projects. However, the limitations of these space-based LIDAR technologies are that:

- the surveys are not systematically repeated
- the products have coarse resolution, as the LIDAR beam divergence increases with distance (the footprint of an airborne LIDAR sensor is typically less than 1 centimetre for UAV and less than 30 centimetres for plane, whereas the footprint of a satellite-borne sensor is over 100 metres)
- the results provide point sampling across the landscape rather than wall to wall mapping – so this data is useful for integration with satellite imagery that maps the entire landscape, and for upscaling of parameters like forest height

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[47] NASA. 'ICESat:GLAS Instrument'. https://icesat.gsfc.nasa.gov/icesat/glas.php. Accessed November 2018.

[48] GEDI ECOSYSTEM LIDAR. https://gedi.umd.edu/. Accessed November 2018.

Figure 8: LIDAR data from a helicopter over Gabon, showing houses and trees, with colours representing height

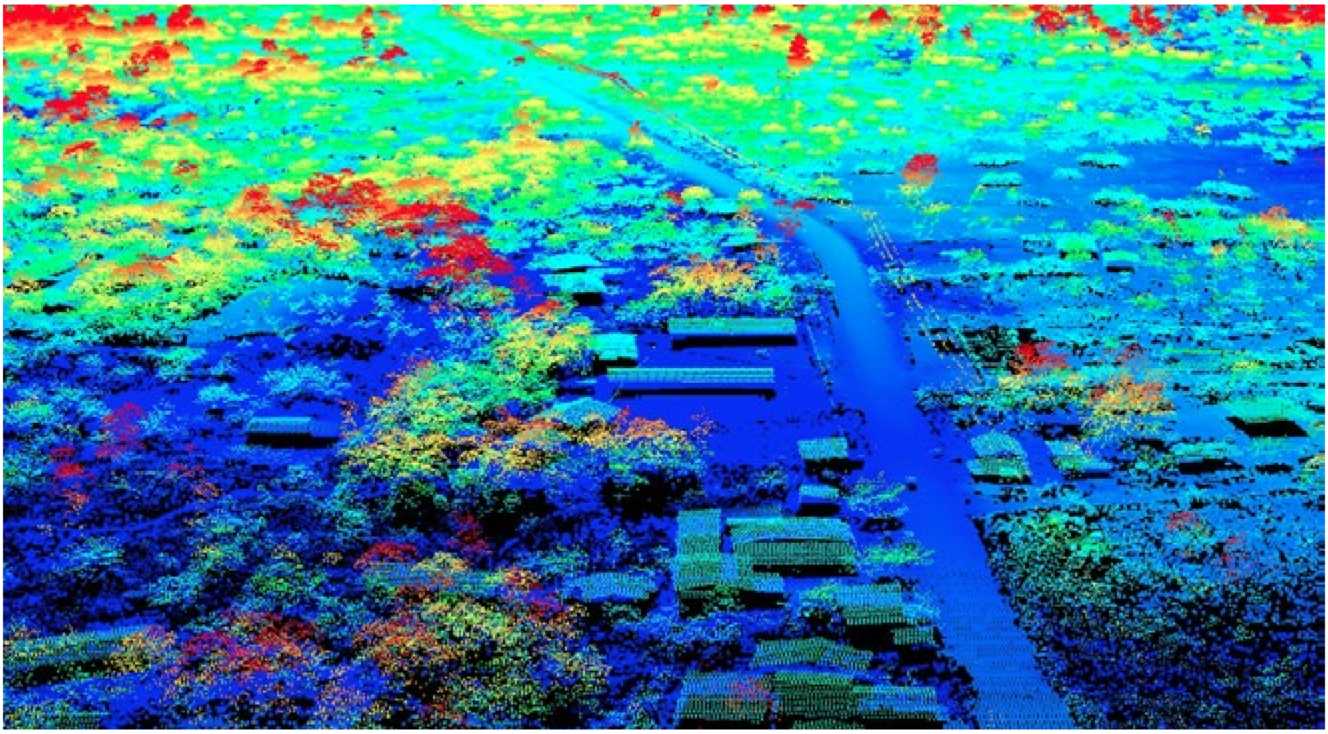


Figure 9: Map of % annual cloud cover

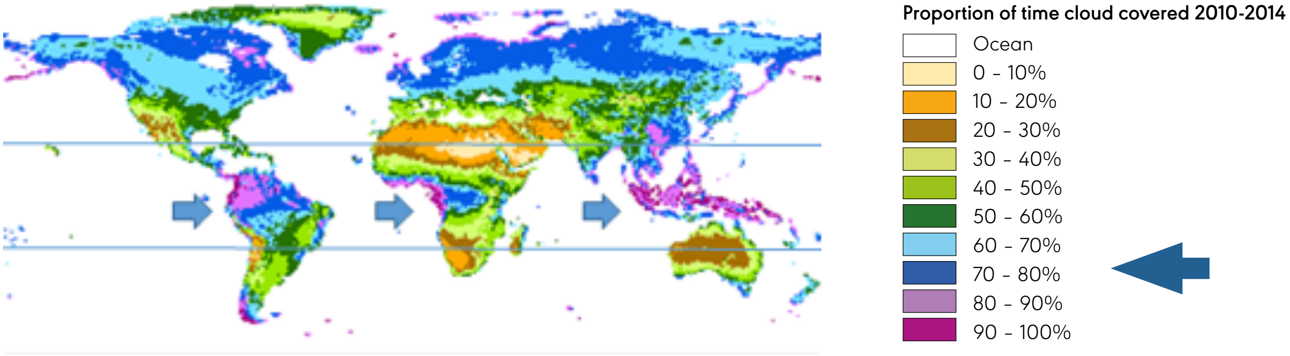
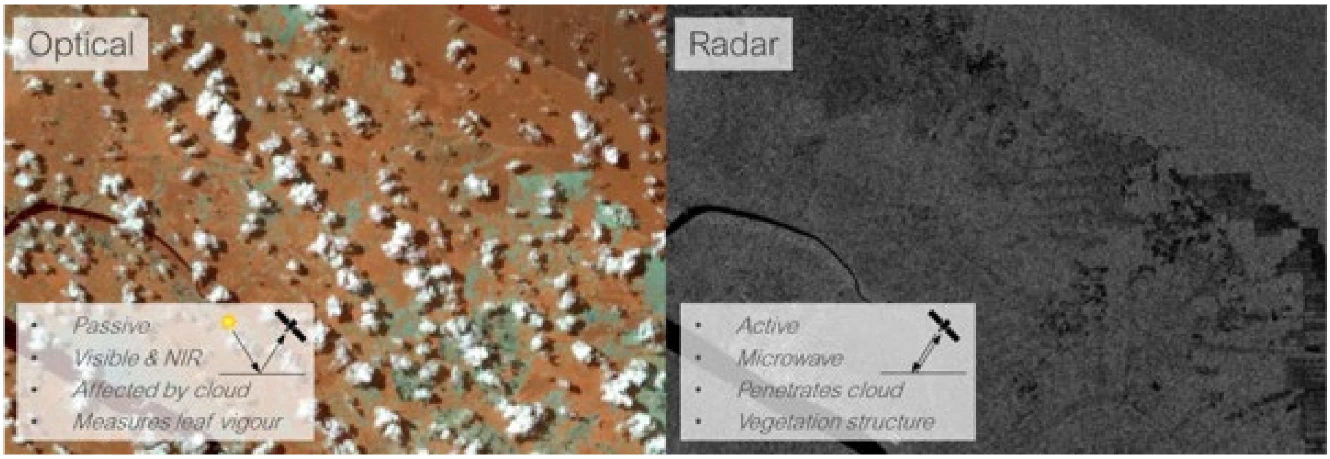


Figure 10: The differences between optical and radar satellites



Sourcing earth observation data

Satellites are one of the most numerous platforms for remote sensing. As of 2016 there were over 400 EO satellites in orbit, and at least 400 more are expected to be launched by 2025.[49] There are numerous sources of EO data that can be accessed for use in forestry.

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[49] The Parliamentary Office of Science and Technology. 'Environmental Earth Observation'. http://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-PN-0566. Number 566 November 2017. Accessed November 2018.

Table 4: Sources of free EO data

Source	Brief description	Link to access data
DETER (produced by INPE)	Produced for Brazil at a 250 metre resolution, using MODIS. Produced first in 2004, on a monthly basis, with a maximum 4-month delay.	http://www.obt.inpe.br/deter/indexdeter
European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)	EUMETSAT delivers agreed data, products and support services to its member states and users worldwide – both from their own programmes as well as third-party programmes. EUMETSAT provides datasets on key indicators of interest, including: faPAR, fractional vegetation cover, LAI, land surface albedo, surface soil moisture, active re-monitoring product, daily evapotranspiration, fire risk map, LST, and burnt area products.	https://www.eumetsat.int/website/home/Data/index.html
FORest Monitoring for Action (FORMA)	Produced for the humid tropics, at 500 metre resolution using MODIS for the years 2006 to 2015, with a frequency of around 16 days. Maximum lag is around 1 month. No data has been released since mid-2015.	http://www.wri.org/blog/2014/03/forma-near-real-time-alert-system-tropical-forest-loss
Global Forest Watch	The World Resources Institutes (WRI) hosts what is probably the most widely-used map of forest loss, Global Forest Watch (GFW). The underlying product is a global forest loss map led by the University of Maryland, and produced in partnership with Google, using their Earth Engine platform.	Also see Global Forest Watch for forest monitoring, but not data download. https://www.globalforestwatch.org/ https://earthenginepartners.appspot.com/science-2013-global-forest http://data.globalforestwatch.org/datasets/glad-alerts-footprint
Global Forest Watch Pro	The World Resources Institute is in the process of developing a commercial service called Global Forest Watch Pro. This is being created to provide for the increasing need for monitoring forest conservation and management commitments such as those being made under zero deforestation commitments.	http://pro.globalforestwatch.org/
Hansen / University of Maryland / Google / USGS/ NASA (UMD)	Underlying product for the GFW product, provided at a 30 metre resolution from Landsat.	https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.1.html

Source	Brief description	Link to access data
PRODES (produced by INPE, Brazil's National Institute for Space Research)	Produced for the Brazilian Amazon at 60 metre resolution, using Landsat TM/OLI, CBERS, LISS-3, and DMC-2. Began in 1975, with data online from 2000. Annual resolution, with a 3-month timer lag.	http://data.globalforestwatch.org/datasets/prodes-deforestation
Radiant Earth Foundation	Radiant Earth Foundation provides open access to geospatial data, with analytical tools for global development practitioners. Radiant Earth Foundation exposes imagery across the globe, date and spectrum. It provides technology and tools to analyse geospatial data, thereby improving the usage of data for greater impact. It works with the community to create new, open standards and focuses thought leadership, market analytics and capacity development programs.	https://www.radiant.earth
SEPAL	System for earth observations, data access, processing and analysis for land monitoring.	https://sepal.io/
Terra-i	Latin America deforestation monitoring data using MODIS+ TRMM rainfall data, at a 250 metre resolution. First produced in 2004, with a 16-day resolution and maximum time lag of 2 months.	http://www.terra-i.org/terra-i.html
Copernicus Open Access Hub	The Copernicus Open Access Hub (previously known as Sentinels Scientific Data Hub) provides complete, free and open access to Sentinel-1, Sentinel-2 and Sentinel-3 user products.	https://scihub.copernicus.eu/
Earth Explorer	Earth Explorer is an online search, discovery, and ordering tool developed by the United States Geological Survey that supports the searching of satellite, aircraft, and other remote sensing inventories through interactive and textual-based query capabilities. Through the interface, users can identify search areas, datasets, and display metadata, browse and integrated visual services.	https://earthexplorer.usgs.gov/distribution

There are various EO data portals that provide commercial data (optical or SAR) useful for forest mapping and monitoring.

The following list is not exhaustive but provides examples of what is currently available from the companies in the IPP.

Table 5: List of remote sensing portals, tools, data and products available for a fee.

Company	Description (from websites)	Resolution	Refresh rate
Airbus Defence and Space[50]	Based on a constellation of EO satellites, Airbus Defence and Space's Geo-Intelligence offer a sophisticated portfolio. It ranges from pure satellite imagery to value-added products, efficient data management solutions and leading-edge software.	0.25 metres Range of satellites and resolution available	Daily
Deimos Imaging[51]	Deimos Imaging, one of the world-leading satellite imagery provider, owns and operates the DEIMOS-1 and DEIMOS-2 satellites. DEIMOS Imagery is used to provide deforestation mapping services in IPP projects.	22 metres, 0.75 metres	Every 3 days
DMCi[52]	The DMC is a unique EO satellite constellation that delivers high-frequency imaging anywhere on the globe from a long established and growing collection of satellites.	2.5 metres, 5 metres, 22 metres, 32 metres	Daily
Telespazio Vega UK[53]	Telespazio is one of the major global suppliers of geospatial application solutions and services. Telespazio VEGA is active in all areas relating to the EO market, from acquiring and processing satellite data to developing and selling software and products. Telespazio's Cosmo SkyMED satellite provides high resolution SAR data that is used in IPP projects to map deforestation and forest degradation.	1 metre	Multiple

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[50] Airbus. 'Geo-Intelligence Services and Products'. http://www.intelligence-airbusds.com/en/11-products-services. Accessed November 2018.

[51] deimos imaging. 'deimos imaging - satellite imagery with top-quality service'. http://www.deimos-imaging.com. Accessed November 2018.

[52] dmc International Imaging. 'DMC Constellation'. http://www.dmcii.com/?page_id=9275. Accessed November 2018.

[53] Telespazio. 'Geoinformation Services'. http://telespazio-vega.com/solutions-services/geoinformation-services. Accessed November 2018.

Processing, storing and analysing earth observation data

The software tools for processing, analysing and displaying satellite data include image processing software and geographical information systems (GIS). This software includes specialised tools that correct and adjust images to improve location accuracy and provide the ability to identify features on the imagery. One example of free software is ESA's Sentinel Application Platform (SNAP) which can process data from multiple satellite sensors.[54] To automate these processes, these systems use algorithms and functions to extract information. There are four phases to extract information from imagery.

1. **Acquisition of raw data:** This is either from archive imagery, recently captured imagery or tasking bespoke requests. Each of these will vary in their complexity, cost and value to different applications. Things to consider include location and date of the features of interest.
2. **Conversion of raw data into analysis-ready format:** This process can include, but is not limited to, orthorectification, georeferencing and radiometric or atmospheric correction. For radar data it includes TOPSAR processing, Single Look Complex (SLC) processing and interferometric processing. It is important to consider the types of analysis that will be conducted during the next stage and availability of storage space and computing power.
3. **Analysis of the data:** This is a diverse phase that can include manual human interpretation of the imagery through to automated interpretation. Automation uses algorithms to quantitatively analyse the features of interest and delineate their spatial location and extent. In some cases, algorithms extract ancillary information about the objects. This stage also provides visualisation of the data and communication of uncertainty, which are important components for decision makers. EO big data and cloud computing can benefit greatly from artificial intelligence, and more specifically machine learning algorithms. This allows analysis of terabytes of data to discover hidden patterns and trends over time in environmental parameters. The predictions from these programmes become more accurate as more observation and validation data is fed to the algorithm. Things to consider here include forest properties or features to be mapped, the extent to map, and the availability of technology and skills.
4. **Validation of the outputs:** This involves assessing the validity of the results either by comparing with known values or using reference data (such as field observations to compare with the outputs from the image analysis). Things to consider include the expertise to understand expected values, the logistics and costs involved when collecting reference data, and scaling issues between EO data and validation data.

International organisations within the space sector are working to reduce the barriers that individuals face when accessing, processing and analysing EO data. While there is a vast amount of EO data available for free, when it comes to downloading and storing the data, there are many logistical challenges. ESA recently launched the Copernicus Data and Information Access Services (DIAS) to make the process of accessing data and information easier and to avoid issues associated with downloading and storing data. DIAS will provide a cloud-based one-stop shop for all Copernicus satellite data and imagery, as well as information from the six Copernicus services, and will also provide access to sophisticated processing tools and resources.

Given the problems of accessing, downloading, analysing and storing data, cloud service providers are increasingly making EO data and processing available in powerful online storage and computing platforms. One example of this is NOAA's Big Data Project, produced in collaboration with several cloud service providers. Another notable example is the Google Earth Engine which hosts the entire Landsat archive, and more recently hosting Sentinel-1 and 2 data, in addition to providing methods to analyse the data.

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[54] ESA. 'SNAP. https://step.esa.int/main/toolboxes/snap/. Accessed November 2018.

Sourcing earth observation expertise

Currently, the use of EO in forestry is complex and requires significant skill, capability and computing infrastructure. To convert the EO data into valuable products that inform decision support systems, considerable skill is required in software engineering, geographic information systems, machine learning and user interface design. Computing infrastructure expertise is also required including significant data storage capacity, internet bandwidth and processing power. Therefore, forestry stakeholders will need to source specialist expertise to support them to apply EO to their specific challenge.

Table 6: Organisations that are part of the IPP, with the required skills and experience working with EO in forestry (this list is not intended to be exhaustive)

Company	Description
Astrosat (Stephenson Astrosat Ltd)	Edinburgh-based company specialising in the analysis of satellite data for forest, agriculture and disaster monitoring.
Carbomap Ltd	Edinburgh-based specialists in the use of LIDAR deployed on unmanned aerial vehicles (drones) to map forests.
CEH	The Centre for Ecology and Hydrology is a world-class research organisation focusing on land and freshwater ecosystems and their interaction with the atmosphere.
CGI	IT firm leading the PASSES project. CGI can provide satellite data, processing and analysis, such as processing land use classifications.
Ecometrica Ltd	A company that describes itself as the 'Netflix of environmental data'. Ecometrica's platforms provide easy access to deforestation mapping, deforestation risk modelling, and deforestation monitoring.
Elecnor Deimos	Deimos offers full turn-key EO systems based on several platforms, with different spatial resolution performances.
eOsphere	eOsphere was established in 2001 and is strongly focused on solving real remote sensing problems for a range of customers and end users.
Satellite Applications Catapult	A world-leading technology and innovation company, helping the UK realise the potential from satellite applications and space data.
Telespazio Vega	Telespazio provides the British corporate and institutional market with innovative solutions and services in space engineering and operations, EO, navigation, and satellite communications. They provide a forest monitoring service and can separate large scale illegal operations from licenced and permitted removal.
University of Edinburgh	Expertise in EO data processing, analysis, research and development.
University of Leicester	Expertise in EO data processing, analysis, research and development.
Vivid Economics	Leverage a suite of proprietary analytic tools, with broad expertise in macro and sector level modelling, econometrics, spatial modelling, market surveys, game theory, and behavioural economics.

Table 7: International organisations supporting space solutions for forestry

Company	Description
Committee on Earth Observation Satellites[55]	CEOS has several working groups[56] that address topics such as calibration and validation, data portals, capacity building, climate, and common data processing standards. CEOS also has data and tools[57] available on their website.
European Space Agency[58]	The largest environmental monitoring programme in the world. It provides a unified system through which data is fed into a range of thematic information services designed to benefit the environment, the way we live, and humanitarian needs, and to support effective policy-making for a more sustainable future. Copernicus data is free and open to all worldwide.
Group on Earth Observations (GEO)[59]	An intergovernmental organisation working to improve the availability, access and use of earth observations for the benefit of society.
SERVIR[60]	A joint development initiative of NASA and the United States Agency for International Development. SERVIR works in partnership with leading regional organisations worldwide to help developing countries use information provided by EO satellites and geospatial technologies for managing climate risks and land use.
UNITAR's Operational Satellite Applications Programme (UNOSAT)[61]	Provides timely and high-quality geo-spatial information to UN decision makers, member states, international organisations and non-governmental organisations. UNOSAT develops solutions on integrating field collected data with remote sensing imagery and GIS data through web-mapping and information sharing mechanisms, remote monitoring of development projects and sharing of geographic data using web services.
United Nations Food and Agriculture Organisation (UNFAO)	The UNFAO conducts the Forest Resource Assessment (FRA), which provides information for understanding the extent of forest resources, their condition, management and uses. Since 1990, FRA complements the information collected through the country reporting process with global and regional analysis of the world's forest resources using remote sensing. With better access to a growing archive of satellite imagery and availability of new tools, remote sensing is becoming an important tool for assessment of status and changes in tree cover and land use.
Global Forest Observation Initiative	Through the work of its partners, GFOI supports REDD+ countries to develop their national forest monitoring systems and associated emissions measurement, reporting and verification procedures.
UNOOSA[62]	The United Nations Office for Outer Space Affairs is the UN office responsible for promoting international co-operation in the peaceful uses of outer space. Included in UNOOSA's areas of work are environmental monitoring and natural resource management, and biodiversity and ecosystems management.

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[55] Committee on Earth Observation Satellites. 'Overview'. http://ceos.org/about-ceos/overview/. Accessed November 2018.

[56] Committee on Earth Observation Satellites. 'Working Groups'. http://ceos.org/ourwork/workinggroups/. Accessed November 2018.

[57] Committee on Earth Observation Satellites. 'Data and Tools'. http://ceos.org/data-tools/. Accessed November 2018.

[58] European Space Agency. 'Disaster Relief and Emergency Management'. http://www.esa.int/Our_Activities/Preparing_for_the_Future/Space_for_Earth/Space_for_health/Disaster_Relief_and_Emergency_Management. Accessed November 2018.

[59] Group on Earth Observations. 'Earth Observations for the Benefit of Humankind'. http://earthobservations.org/index2.php. Accessed November 2018.

[60] SERVIR. 'About SERVIR'. https://servirglobal.net/#aboutservir. Accessed November 2018.

[61] UNITAR. 'UNITAR's Operational Satellite Applications Programme – UNOSAT'. https://unitar.org/unosat/. Accessed November 2018.

[62] UNOOSA. http://www.unoosa.org/oosa/index.html. Accessed November 2018.

Company	Description
World Food Programme (WFP)[63]	The WFP Seasonal Monitor examines satellite imagery of rainfall and vegetation to assess the development of the growing season and how conditions impact the lives and livelihoods of the resident populations. Real time satellite data streams and seasonal forecasts are analysed to highlight potential developments that may be of humanitarian concern. WFP is implementing a pilot project on crop type and crop status mapping in food insecure regions, in particular those with restricted or difficult access or in countries where deficient agricultural statistics systems deliver poor quality or no information.
World Resources Institute (WRI)	WRI is a global research organisation that spans more than 50 countries. Work focuses on six critical issues at the intersection of environment and development: climate, energy, food, forests, water, and cities and transport. The WRI provides the international community with the Global Forest Watch product.

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[63] World Food Programme. 'Seasonal Monitor'. https://www.wfp.org/content/seasonal-monitor. Accessed November 2018

Additional reading and resources

Committee on Earth Observation Satellites (CEOS) and European Space Agency (ESA). 'Satellite Earth Observations In Support Of The Sustainable Development Goals. The CEOS Earth Observation Handbook Special 2018 Edition'. Available at http://eohandbook.com/sdg/.

Global Forest Observation Initiative. 'GFOI Overview'. Available at http://www.gfoi.org/wp-content/uploads/2016/08/GFOI-factsheet-final-web-version.pdf.

Global Forest Observation Initiative. 'Space Data Services Strategy'. Available at http://www.gfoi.org/wp-content/uploads/2015/03/SDCG_Element-2-Space-Data-Services-Strategy_Apr2014.pdf.

Global Forest Observation Initiative. 'Integrating remote-sensing and ground-based observations for estimation of emissions and removals of greenhouse gases in forests'. Available at http://www.gfoi.org/wp-content/uploads/2015/03/MGD_copyedited06082014.pdf.

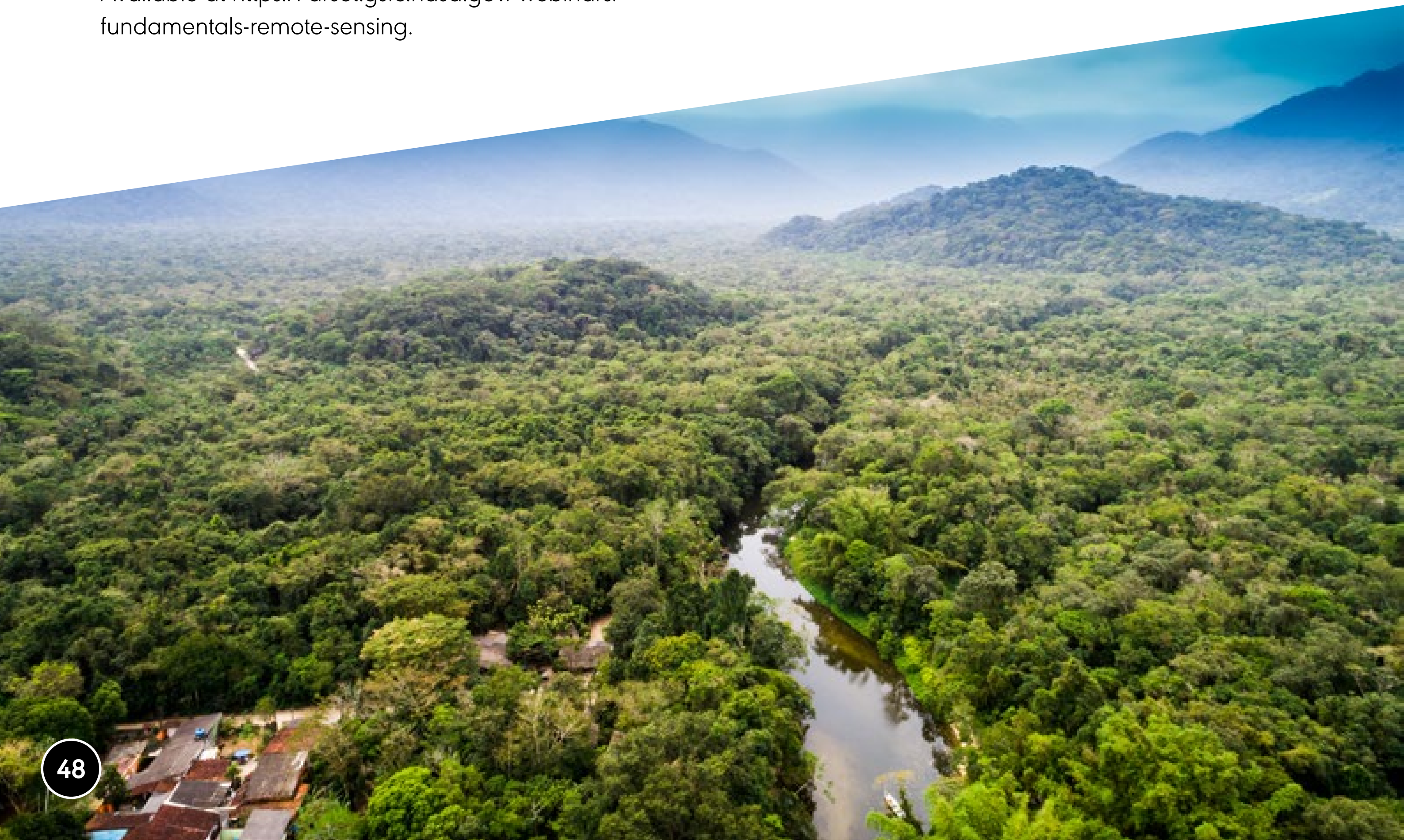
NASA's Applied Remote Sensing Training (ARSET) program. 'Fundamentals of Remote Sensing'. Available at https://arset.gsfc.nasa.gov/webinars/fundamentals-remote-sensing.

NASA's Applied Remote Sensing Training (ARSET) program. 'Land Management'. Available at https://arset.gsfc.nasa.gov/land.

Food and Agriculture Organisation of the United Nations. 'Voluntary Guidelines on National Forest Monitoring'. Available at http://www.fao.org/3/a-i6767e.pdf.

Woodhouse, I.H. Thirteen Short Chapters on Remote Sensing. 2013.

World Bank Group. Forests Sourcebook: Practical Guidance for Sustaining Forests in Development Co-operation'. Available at https://siteresources.worldbank.org/EXTFORSOUBOOK/Resources/completeforestsourcebookapril2008.pdf.



Annex A: The value of forests

Forests provide a range of benefits such as timber, biodiversity, and soil fertility. For timber, the financial values are clear since it is sold in established markets. Today there are approximately 300 million hectares of plantation forests and 900 million hectares of natural forests, together supplying 2 billion cubic metres of industrial wood worth $200 billion.[64]

Since many of these products and services are not traded in everyday markets it is difficult to value them[65], so economists use a variety of non-market valuation techniques, such as stated preferences and cost-based methods, to make their value explicit. Stated preference is a valuation technique that uses surveys and allows individuals to describe their future behaviour in a hypothetical market, for instance how much extra tax would they pay in order to see more trees planted in a park. An example of a cost-based method is the social cost of carbon, which is a measure of the long-term damage done by a tonne of carbon dioxide emissions in a given year.[66]

Given the difficulty of valuing ecosystems, one solution to try to secure funding for the management of ecosystems is to use Payment for Ecosystem Services schemes. This is where beneficiaries of services like fresh water supply pay for the continued provision of that service, for example by paying upstream farmers to maintain trees on their land. This creates quasi-markets for ecosystem services by placing a value on the service. The carbon market seeks to place a price on carbon conserved in forest projects. A general rule is that forest biomass is approximately 50% carbon[67], and so one may use carbon prices to estimate the value of avoiding the loss of a given amount of forests.

Estimates of the cost of damage caused by the destruction of natural systems can also reveal the value of forests. For instance, one of the IPP forestry projects works with the government of Malaysia, who estimate that their combined costs of flooding, marine pollution and illegal logging is $12.5 billion in one year.[68] Flooding is related to deforestation and forest deforestation, since the removal or trees and clearance of land decreases the lag time between rainfall and water entering river channels, and moderating water flow over time. Illegal logging has the double impact of lost tax revenues and increasing flood risks on slopes where the moderating effect on water flow during rainstorms is reduced.

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[64] Harsh Choudhry and Glen O'Kelly, 2018. 'Precision forestry: A revolution in the woods'. McKinsey and Company. https://www.mckinsey.com/industries/paper-and-forest-products/our-insights/precision-forestry-a-revolution-in-the-woods?cid=other-eml-alt-mip-mck-oth-1806&hlkid=6df6e7a96eb143b49d8e145a78fbf02a&hctky=2299592&hdpid=0a048adc-3fff-4cb5-81ac-46ffd087bf21. Accessed November 2018.

[65] Rudolf De Groot and others, 2012. 'Global estimates of the value of ecosystems and their services in monetary units'. Ecosystem services, 1(1), pages 50-61.

[66] United States Environmental Protection Agency. 'The Social Cost of Carbon. Estimating the benefits of Reducing Greenhouse Gas emissions'. https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html. Accessed November 2018.

[67] IPCC. 'IPCC guidelines for National Greenhouse Gas Inventories. Japan: Prepared by the National Greenhouse Gas Inventories Programme'. IGES; 2006.

[68] UK Space Agency. 'Satellite Applications Catapult (Malaysia) Environmental Monitoring'. https://www.gov.uk/government/case-studies/satellite-applications-catapult-malaysia-environmental-monitoring. Accessed November 2018.

Forest valuations within the IPP: case study of Vivid Economics in Ivory Coast

Vivid Economics uses two different proxies to understand the value of forest: carbon and biodiversity. Carbon is the most straightforward proxy due to the development of the carbon markets, and the prospect of a carbon project bringing revenues to developing country forest managers. Biodiversity was also considered important by stakeholders because conservation and preservation are a big source of overseas funding in developing countries.

Valuing carbon stocks: Vivid used Côte d'Ivoire's REDD field biomass data to assess how much biomass was stored in Côte d'Ivoire's forests. To estimate carbon sequestration and storage, Vivid used the IPCC's methodology to relate biomass to carbon stored in forests in tonnes of carbon dioxide equivalent. To calculate the value of this carbon, the team multiplied the total volume by the social price of carbon.

Valuing biodiversity: Biodiversity is important to local stakeholders but remains difficult to value. As such, Vivid Economics uses forest connectivity as the main parameter to assess the value of forest configuration for biodiversity. Connected habitats allow animals to move, maintain breeding populations and disperse the seeds. Ultimately, stakeholders wish to develop a metric that reflects the marginal value of each forest patch to the overall forest network connectivity. They also wish to identify areas of non-forest where conversion to forest would most benefit connectivity, and understand the relationship between connectivity and species dispersion.

Vivid intends to use carbon and biodiversity values alongside their deforestation risk index to carry out scenario modelling, and to understand the impacts on land cover of Côte d'Ivoire's policy making. The aim of this modelling is to enable local partners to design the policies that balance carbon storage and forest connectivity for biodiversity.

Annex B: IPP forestry projects

IPP currently has six forestry projects which started in 2017/18. As they are in their early phases it is too soon to identify results and lessons. These case studies will be updated in the later stages of IPP to capture and communicate results and lessons.

CGI: PASSES (Peatland Assessment in Southeast Asia by Satellite)

Project overview

Target countries: Indonesia and Malaysia

Project lead: CGI IT UK LTD

Project consortium:

- Centre for Hydrology and Ecology
- Geomatic Ventures Ltd
- Liverpool John Moores University
- University of Leicester
- University of Nottingham
- Liverpool John Moores University
- IPE Tripleline

International partners:

- Peatlands restoration agency (BRG)
- Asia Pacific Resources International (APRIL)
- World Resources Institute Indonesia (WRI)
- Geospatial Agency (Badan Informasi Geospatial, BIG)
- Institut Pertanian Bogor (Indonesian University)
- an NGO will be incorporated into the project during 2018
- Global Environment Centre (GEC), Malaysia

United Nations Sustainable Development Goals

15 LIFE ON LAND

Project summary

Tropical forest fires affect over 20 million people in Southeast Asia. The inhalation of smoke generated from the forest fires leads to significant deteriorations in public health and is associated with premature mortalities. Fires also contribute substantially to global carbon dioxide emissions and other widespread negative environmental impacts. Many fires occur over drained peatland areas.

Climate change and existing land use trends such as the draining and clearing of forests for palm oil, pulp and paper plantations contribute to the reduced hydrology of the peatland, causing a significant fire risk. Without intervention, peat fire frequency and impact are expected to increase. The only long-term intervention is to retain the natural hydrology of intact peat swamp forests and raise water levels in disturbed areas. However, the costs of restoring and maintaining peat condition across huge peatland areas (around 250,000 square kilometres in Southeast Asia) are enormous. The planning and prioritisation of such activities, as well as monitoring intervention effectiveness, is therefore vital. Furthermore, better observations of peat condition also enable improved understanding of the delivery of peatland ecosystem services.

Satellite observations of peat condition can play a hugely valuable role in peatland monitoring, but currently are under-exploited. The PASSES project will use the latest satellite measurement techniques to develop a comprehensive peatland monitoring service. PASSES will also demonstrate that comprehensive, routine, wide-area monitoring of peatland can now also be cost effective. This is through exploitation of freely available, continuous observations from Sentinel satellites and exploitation of emerging industrial hosted processing capabilities.

Satellite solution

Tropical peatlands are highly dynamic systems, which occur across large, often remote and inaccessible areas, and are highly vulnerable to land use change. Understanding, managing and protecting these systems requires monitoring capabilities which are frequent, reliable and cover a wide area. Satellite remote sensing provides the only cost-effective option.

Key to realising a comprehensive and cost-effective satellite-enabled monitoring solution are the Sentinel satellites (S-1, S-2 and S-3). Dense time series from S-1 provide the input for a novel InSAR technique developed by the University of Nottingham that is core to PASSES and enables observation of vertical displacement of peatland. This is a key indicator of condition, since drained and degraded peat subsides. Recovering peat (in response to re-wetting interventions) instead swells and rises. The SAR-enabled vertical displacement observations will be complemented by other SAR and optical-derived measurements. These will include observations of vegetation, hydrology and fire regime. Together these observations will enable a comprehensive characterisation of peat condition, which, if observed over time, can inform an enhanced understanding of condition change.

Project impact

- Improved management and condition of peatland in Southeast Asia.
- Demonstrable evidence of improvement in key peat condition metrics in regions where PASSES has been included in decision-making, compared to those where it has not.

Ecometrica: Forests 2020

Project overview

Target country: Indonesia, Brazil, Mexico, Colombia, Ghana, Kenya

Project lead: Ecometrica

Project consortium: University of Edinburgh, University of Leicester (NCEO) and Carbomap

International partners:

- Indonesia: Bogor Agricultural University (IPB), PT Hatfield Indonesia, WRI Indonesia
- Brazil: Instituto Nacional de Pesquisas Espaciais (INPE), Instituto de Pesquisa Ambiental da Amazônia (IPAM), Key Associados
- Mexico: El Colegio de la Frontera Sur (ECOSUR), Pronatura Sur, Ambio, FIPRODEFO
- Colombia: University of Andes (UniAndes), Instuto de Hidrología, Meteorología y Estudios Ambientales de Colombia (IDEAM)
- Ghana: Kwame Nkrumah University of Science and Technology (KNUST), Resource Management Support Centre (RMSC) of the Forestry Commission Ghana
- Kenya: Kenya Forest Service, Kenya Forest Research Institute (KEFRI)

United Nations Sustainable Development Goals

8 DECENT WORK AND ECONOMIC GROWTH

13 CLIMATE ACTION

15 LIFE ON LAND

Project objectives and impacts

Forests 2020 aims to use EO data from satellites to improve monitoring and management of forests in six developing countries: Indonesia, Brazil, Mexico, Colombia, Ghana and Kenya. The project works with end users such as government ministries and regional forestry organisations to reduce deforestation and degradation. It works to increase restoration by improving their ability to monitor forests at risk, respond to fires and other drivers of land use change.

Ultimately, the project aims to achieve improved forest governance across 300 million hectares of forest in the six countries. it aims to contribute to avoided forest loss of 4 to 6 million hectares with an estimated value of £25 billion by 2020. It will contribute to the Bonn Challenge goal of restoring 7.5 million hectares in Mexico and Columbia by 2020 and 19.1 million hectares in Brazil, Ghana and Kenya by 2030. In addition, Forests 2020 will provide improved accountability and targeting of UK and international official development assistance to forests.

Satellite solution

Forests 2020 will tackle these forest management challenges through five channels.

Improving forest change detection: This will be done by automating processing chains for data acquired from ESA's Sentinel 1 (radar) and Sentinel 2 (optical) satellites. Maps of forest cover and forest change will feed into national forest inventory systems that are mainly based on manual interpretation of LANDSAT data. Within the improved system, data is processed in the cloud and alerts can be sent via Ecometrica's EO Lab infrastructure or mobile phone applications.

Degradation mapping: Forest degradation is the removal of above ground biomass from an area that remains forest after disturbance. It is much harder to map than deforestation as it can be subtle and, in the tropics, might cover an area 2 to 10 times greater than the extent of deforestation. It is important to quantify the area and magnitude for REDD+ historically, in the present and the future. This component of the solution will develop and test a new type of field plot specifically to create training data for the creation and validation of remote sensing maps of forest degradation. These plots will be used to test existing methods of degradation and test new methods. This will result in the production of forest degradation maps for the window areas in each country, and the know-how will be transferred via capacity building to in-country partners to scale up to other areas.

Modelling and mapping risk of fire: This will use dynamic ecosystem models to help identify areas susceptible to fires or conversion pressures across forested areas and quantify the evolution of fire risk over the next several decades.

Biomass restoration dynamics: All six countries have made international commitments to restore areas of forest as part of the Bonn Challenge, but identifying the best areas for forest restoration is challenging. Restoration potential mapping efforts in multiple countries (such has ROAM) have had limitations as they are based on socioeconomic conditions rather than biophysical.

The model will quantify opportunities for forest regrowth and restoration potential which will complement existing efforts, by quantifying the deficit between current and potential biomass stocks (such as how much biomass the landscape can support) and quantify forest regrowth dynamics (such as how long will restoration or reforestation would take).

Digital infrastructure – EO Lab: This is establishing the digital infrastructure needed to improve access to and processing of satellite data, with the ability to deliver EO-derived products and information to end users. The EO Lab is a cloud-based spatial content management system that enables institutions to manage the large spatial datasets generated by EO on the cloud using browser-based interaction. The EO Lab allows better sharing of information and allows non-technical users to access relevant information.

Sustainability model

The project is well aligned with internationally supported efforts to improve forest governance and reduce forest loss, notably the UN-REDD+ component of the international climate change agreement. This is where developing countries are able to access a combination of needs-based and results-based payments for reducing emissions from deforestation and degradation. The UK, along with partner donors, are key contributors to this instrument. Both needs and results-based financial flows to forests require effective monitoring of changes to forest area and condition, and a portion of these flows should be made available to ensure the continuity of monitoring systems.

The approach is to develop a business case tailored to each country for the maintenance and continued improvement of forest monitoring systems in countries supported by IPP forest related projects.

Satellite Applications Catapult: Earth and Sea Observation System (EASOS)

Project overview

Target country: Malaysia

Project lead: Satellite Applications Catapult

Project consortium: Janus TCD, Geocento, Ambiental, Plymouth Marine Laboratory, AutoNaut, Riskaware, Telespazio Vega, EO Inc, Leicester University, Oxford University, eOsphere

International partners: National Defence University of Malaysia (NDUM) and 25 Malaysian Agencies and Departments

United Nations Sustainable Development Goals

1 NO POVERTY

14 LIFE BELOW WATER

15 LIFE ON LAND

Project objectives and impact

The primary objective of EASOS is to develop a solution that provides high-quality information in an integrated dashboard. It will act as a decision support tool and improve planning capabilities, prevention strategies and response to major events related to floods, marine pollution, and illegal logging. In addition to reducing costs of these events, EASOS aims to assist Malaysian authorities to:

- reduce the number of people affected by flooding by:
    - improving overall awareness of flood risks across the country
    - generating alerts that support rapid decision making during a flooding incident, that show recommended evacuation routes and activate flood defences in a timely manner
    - providing improved advanced warning times on flood risk, better information about impacted areas and population at risk, and prediction of improving or worsening conditions
- reduce the number of marine pollution events in the Malacca Straits by:
    - forecasting oil dispersal direction and providing an indicator of risk to environmentally sensitive areas to enable evasive action such as deployment of booms
    - enhancing oil detection from satellite and locating illegal discharges from ships
    - assisting the Malaysian coastguard to interdict offending vessels and in the long-term deter vessels from illegal discharges
- reduce illegal logging activity by:
    - processing optical and radar data to show images of overall shape of deforestation over large geographical areas, enabling agencies to make informed decisions about forestry management
    - providing frequent change detection of the forest canopy over smaller areas of interest (hotspots)
    - providing alerts to illegal logging activity, and allowing comparisons of the change with the logging register for validation purposes
    - tagging trees harvested legally using remote applications which enables officials to monitor timber through the supply chain to provide end-to-end traceability

Satellite solution

EASOS offers a world-leading situational awareness platform designed to monitor and manage flood risk, oil pollution and deforestation from illegal logging. It combines terrestrial data with satellite derived EO data, providing near real-time information that can be used as a decision support tool for these environmental challenges. The platform will integrate data from multiple sources including EO, satellite imagery, GIS mapping, useful datasets (soil, road, asset location), databases and historic information.

FloodWatch:

Flood forecasting: The flood forecast is simulated using current and forecasted rainfall and live telemetry. The system uses ground-based rainfall radar inputs and water level sensors. The platform models the current catchment state and makes predictions based on rainfall forecasts, modelling flood hazards up to seven days in the future. Outputs are refreshed every hour. Predictions are shown by either flood event maps, or flood levels and depths and impact forecasting regarding affected populations and infrastructure damage.

FloodMap: Sophisticated flood hazard maps are produced for fluvial (river), pluvial (flash) and tidal (sea) flooding based on historic and current satellite data. Surface flood water maps analyse multiple layers of data to provide insight into additional types of flooding, with higher precision, enabling better land use planning process and pro-active disaster risk management.

Risk analysis: Catastrophe modelling analysis which considers the combination of hazard and exposure to model flood impacts to support flood risk management.

MarineWatch:

Oil slick detection: Synthetic Aperture Radar (SAR) satellite observation penetrates cloud cover and provides high resolution imagery (up to 10 metres) in all weather conditions. Data is typically available once every 12 days, reducing to every 6 days when Sentinel 1-b data is available online. Algorithms identify dark areas with descriptive statistics that distinguish likely oil spills and highlight these on imagery aligned to maps. Using known events, the algorithms are trained to identify spills in open waters with greater accuracy that are difficult to detect with any other method.

Oil destination modelling: This model forecasts the path and dispersion of the oil slick at hourly intervals for 72 hours into the future, from when the slick was detected. The oil particle tracking uses oil properties, ocean depth (bathymetry), tides and forecast data (ocean currents, meteorology and wave height). It offers early warning of potential coastal pollution and an indicator of likely risk and impact to environmentally sensitive areas from a pollution event.

Satellite ship detection: Source estimation modelling is an inverse modelling technique that runs backward from a detected slick predicting the possible sources of the oil. The Automatic Identification System datastream will be augmented by SAR imagery to help identify offending vessels.

Autonaut: An autonomous self-powered vessel for marine surveillance and monitoring. Instruments can identify oil types (crude or refined), and marine environmental health indicators such as turbidity (the cloudiness of water), which is a key test of water quality.

ForestWatch:

Change detection over a large geographical area: Satellite detection covering large geographical areas, such as at state level, provides regular and pre-planned monitoring within forest areas every 24 days. It shows the user whether deforestation activities are in licenced or non-licenced logging areas.

Change detection over a small geographical area: Users can target a change detection every four days for smaller areas of interest for as long as needed. Higher resolution imagery reports on changes above 50 square metres of forest canopy which are detected automatically and alert the user if change is detected.

Change validation over a small geographical area: This potentially twice daily service allows users to visually identify activity in areas informed by the change detection. It provides remote sensing expert users with information from within the previous 12 hours, and detects features such as new access routes, heavy plant machinery and forest edge movement.

Forest+: Offering supply chain traceability that digitally tracks logs from the felling site to the community concession and through to the timber mill. It is designed to provide a real-time notification system via a smartphone app.

Sustainability model

To ensure sufficient capacity building in Malaysia to operate and maintain EASOS, a significant training effort will be implemented throughout the operational trial phase of the project. This will demonstrate how the analysis and information alerts provided via the EASOS dashboard can support effective decision making and achieve the intended impact in each of the three areas of the project.

EASOS is both ground-breaking and ambitious. Malaysia is the first country to bring together 26 government agencies and departments that could access data across a whole range of applications. The EASOS system currently addresses three areas, however it could be scaled up to include other sectors, such as precision agriculture or renewable energy.

The commercial sustainability of EASOS will depend on procurement by the Malaysian government and their commitment to investing in the ongoing monitoring of environmental challenges faced by the country.

Stevenson Astrosat: Forestry Management and Protection (FMAP)

Project overview

Target country: Guatemala

Project lead: Stevenson Astrosat Ltd

Project consortium: EO Inc, Deimos, Telespazio Vega

International partners: National Forestry Institute (INAB), National Council of Protected Areas (CONAP), Guatemala Environmental Police Force (DIPRONA), Ministry of Agriculture (MAGA), Public Ministry, ARCAS Guatemala

United Nations Sustainable Development Goals

8 DECENT WORK AND ECONOMIC GROWTH

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

13 CLIMATE ACTION

15 LIFE ON LAND

Project objectives and impacts

The Forestry Management and Protection (FMAP) project provides a centralised platform based on satellite EO and GNSS technologies. It will enable intelligence-led governance and policing that have the largest impact on tackling the problem of deforestation. The ultimate impact this project seeks is a reduction in deforestation rates in Guatemala. The core goals to support this impact are:

- increased capacity of Guatemalan Government Agencies to conserve Guatemala's forestry environment
- reduction in the rate of deforestation in the Mayan Biosphere Reserve
- increase in the total area of ecosystems under sustainable management
- increase in the number of detections of illegal forestry activities

Satellite solution

With over 3.7 million hectares of forests in Guatemala, EO offers the most effective way of monitoring activities which would not be possible from the ground. The project aims to produce a system that fuses technologies which tackle the key challenges and make that information available in a single dashboard in a cross-ministry manner. This will enable the Guatemalan government agencies to more effectively counter illegal deforestation through better intelligence-led governance and policing.

The main technologies used, include EO data of land use and change, and the Forest+ system, which uses GNSS technology to greatly increase the efficiency of locating trees to harvest.

The FMAP system will deliver a step change in forest management capability as it allows for the monitoring of wide areas and periodic data acquisition, which would not be possible as often or in as much detail if the data was to be gathered on the ground. Also, the satellite perspective is unique because of the use of multispectral sensors as well as SAR imagery, which allows observation even in areas of common cloud cover such as rainforest.

It also provides the addition of new, space-derived, multi-spectrum datasets to improve insight, knowledge and understanding of changes on the ground. Deimos will use numerous satellites including Digital Globe, Deimos Imaging, RapidEye, Landsat and Sentinel 2 to provide the EO data. Telespazio Vega will use their own Cosmo SkyMed satellites for their EO data. The Forest+ system uses GNSS technology to greatly increase the speed and efficiency of providing locations of trees.

It will integrate existing discrete management systems into one interactive dashboard. It will present information appropriate to user role, from the judicial and government administration levels, through to growers and enforcement officers working in remote locations.

Flexible modular design will also facilitate future expansion with datasets in response to developments in scope and tasking.

Sustainability model

The primary sustainability concept is that the minimum viable product for each dashboard (Land Crime, Concession and Forestry Incentive Programme) will be left in the country post-project and that capacity will be built within the users' organisations for dealing with operations, maintenance and training.

There will be additional services available to the customers, which will include improved resolution and detail from commercial EO data. These additional services will be proven via the trials to provide a spend-to-save model for the organisations, allowing them to save money on their operational and maintenance costs by using FMAP.

For the additional services, the consortium is considering building a business to government to business model, where the Guatemalan organisations will pay for tailored products. The users, such as concessions systems and farmers will pay for some part of the FMAP service, such as a FIP size report or a concession tree area map. This concept is based on a similar model that is currently being used in Guatemala (SEINEF system), which shows that these Guatemalan organisations see the value in the proposed solution.

Vivid Economics: Remote mapping and socioeconomic valuation tools to support planning and implementation in land use interventions in Peru

Project overview

Target country: Peru

Project lead: Vivid Economics

Project consortium: Remote Sensing Applications Consultants Ltd (RSAC)

International partners: Regional Government of San Martin and National Forestry and Wildlife Service (SERFOR), Amazon Interregional Council, Alternative Development Mechanisms (MDA)

United Nations Sustainable Development Goals

8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
15 LIFE ON LAND

Project objectives and impact

This project focuses on combining satellite imagery with economic valuation tools to map and quantify the economic and ecological value of different land uses. In doing so it will support national processes to monitor deforestation, improve land use and plan for climate resilient growth. It aims to address the interlinked challenges of deforestation and rural poverty by improving land use titling, better targeting infrastructure investments, and supporting sustainable production in the San Martin region of Peru. The project delivers a decision-making tool to help international partners more easily design and implement critical policies and programmes at both a national and a regional level.

In the long-term, this project should enable the Peruvian government to:

- increase the allocation of land ownership rights by 25% in specific project areas.
- reduce net deforestation of primary forest in San Martin to 25% below the baseline scenario

Satellite solution

The tool will produce three key outputs that will allow decision makers to better understand the socioeconomic dynamics of deforestation, design better land use policies and allocate land titles. The three components of the tool are detailed below.

The Land Use Inventory classifies surface cover (see Figure 11). Remote Sensing Applications Consultants use newly available optical and radar data from the Copernicus Sentinel satellite missions to categorise surface cover at 10 metre resolution. The land use inventory shows the location of forests and other land uses, offering distinction between different types of agricultural land, settlements and water features.

Figure 11: Preliminary Land Use Inventory[69]

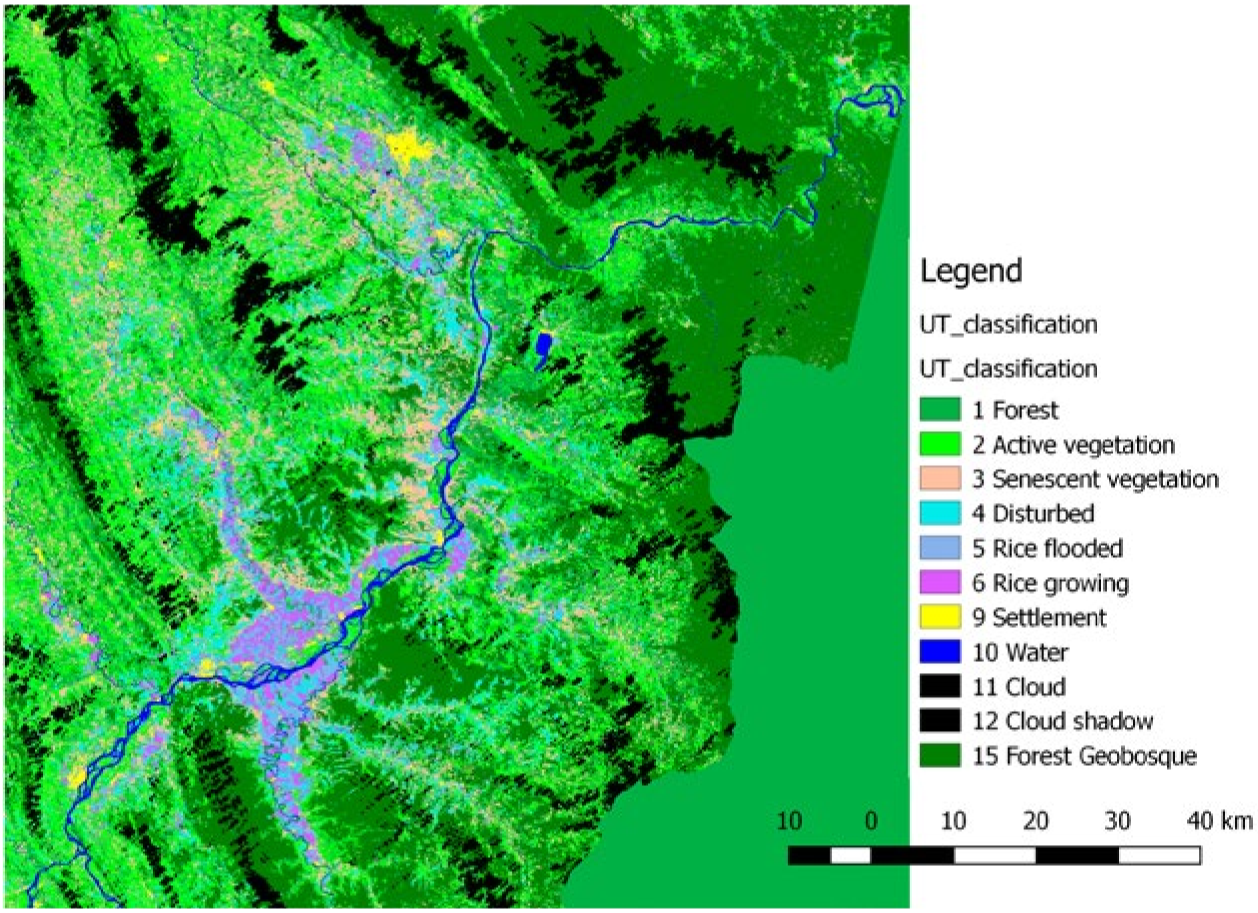

Table 8: Example policy matrix

	Low Ecosystem Value	**High Ecosystem Value**
Low value agricultural production	Classify areas suitable for alternative revenue generating activities	Prioritise reforestation
High value agricultural production	Investment in increasing agricultural productivity	Increase protection of remaining forests

A natural capital valuation framework informs national reforestation, forest protection and economic development strategies. Building on the land use inventory, this tool integrates socioeconomic data to create value maps that allows users to assess the costs and benefits of reforesting or protecting areas in comparison with alternative scenarios of agricultural development. The information allows spatial strategies, such as those shown in Table 8, to be developed.

Finally, a set of plot level maps will be developed based on very high-resolution satellite data and UAV surveys as a pilot for a new local land titling process. The pilot seeks to improve existing processes by overcoming two important barriers: the lack of recorded boundaries for individual level plots, and the licensing fee. The project consortium is working with local farmers and the regional government to agree and record plot boundaries, and then develop valuations of the ecosystem services provided by the

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[69] Vivid Economics

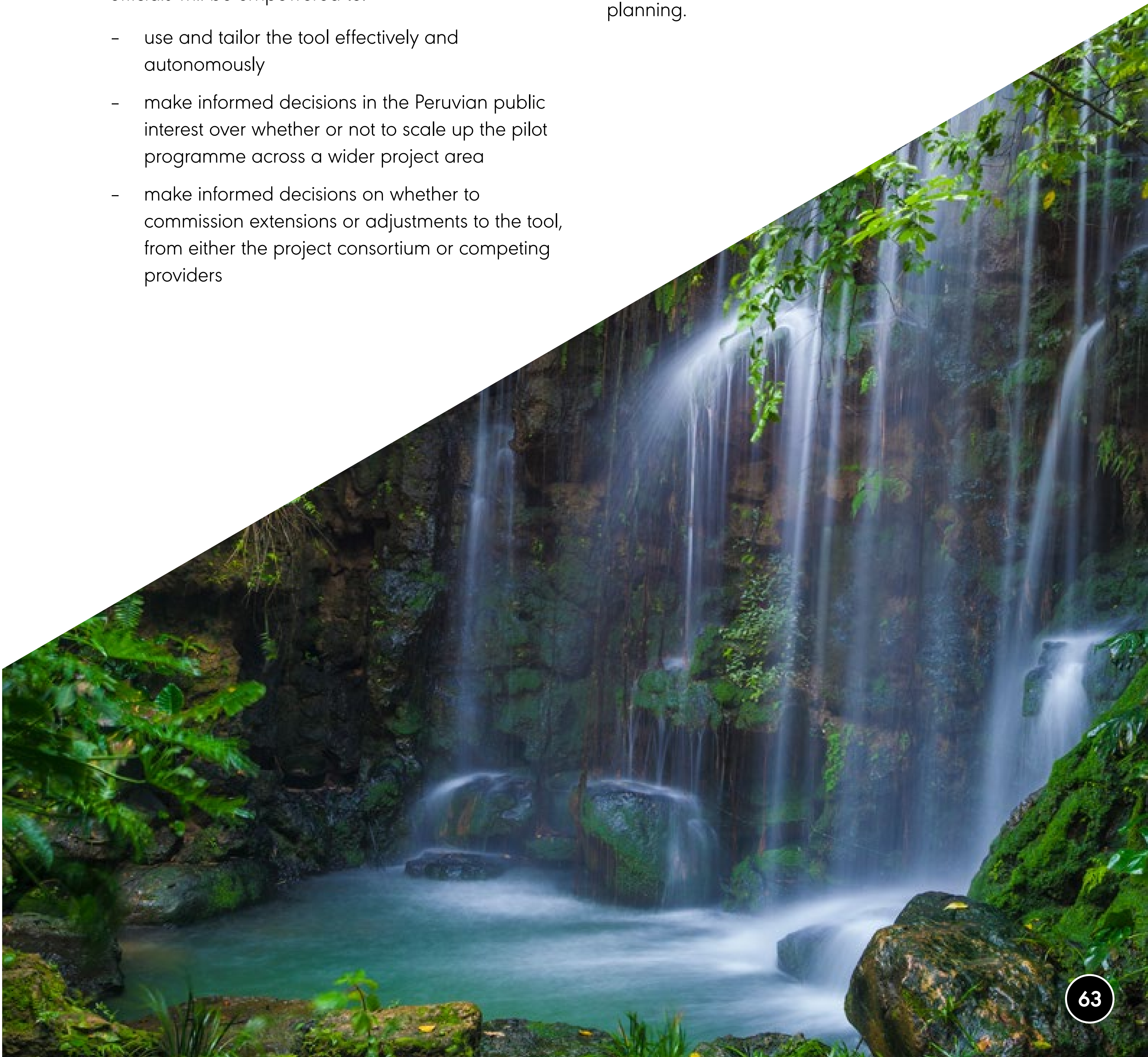
standing forest to be submitted in lieu of a licensing fee. As a result, the process could vastly increase issuance of conditional titles and optimise the regional government's ability to enforce and monitor the zero-deforestation pledge associated with them.

Sustainability model

The methods and tools are being developed in close consultation with international partners and a series of workshops will be run to ensure full knowledge transfer to Peruvian authorities. A key objective will be that, by the end of the project, relevant Peruvian officials will be empowered to:

- use and tailor the tool effectively and autonomously
- make informed decisions in the Peruvian public interest over whether or not to scale up the pilot programme across a wider project area
- make informed decisions on whether to commission extensions or adjustments to the tool, from either the project consortium or competing providers

To ensure commercial sustainability of the model, the consortium is working closely with government officials and donors with active forestry projects in the Amazon region. A key component of the sustainability strategy is to align the project with complementary government policies and ensure processes are as low cost and replicable as possible. In this way, the project can leverage the substantial funding already committed to the goals of enhancing rural development and property rights, while conserving important local ecosystems. It is highly likely that other Amazon states in Peru and abroad will be interested in exploring the potential of the tool for land use planning.



Vivid Economics: Deforestation prevention with land use monitoring and valuation in Côte d’Ivoire

Project overview

Target country: Côte d’Ivoire

Project lead: Vivid Economics

Project consortium: Remote Sensing Applications Consultants Ltd (RSAC), Impactum

International partners: Ministry of Planning and Development, Society for Forest Development (SODEFOR), The Office of Parks and Reserves (OIPR), REDD Permanent Executive Secretariat (SEP- REDD)

United Nations Sustainable Development Goals

8 DECENT WORK AND ECONOMIC GROWTH

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

15 LIFE ON LAND

Project objectives and impact

This project seeks to support rural economic growth, increase the sustainability of global supply chains, improve the efficiency of forest protection agencies and increase the value for money of reforestation programmes in Côte d’Ivoire. This will be achieved through the use of satellite-based information to:

- identify priority areas for reforestation
- better anticipate and prevent instances of deforestation
- support existing certification schemes and the development of payments for ecosystem services

In the long-term, this project should enable the Côte d’Ivoire government to move to zero-deforestation agriculture in the project region by 2020, and across the country by 2023.

Solution

The project helps policy makers, forestry protection and reforestation agencies, agricultural and budget officials, commodity buyers and growers and other local actors to make better decisions. It provides them with the IMAGE toolkit for up-to-date information on land use, economic statistics and deforestation. By showing the value of natural capital and vastly improving forest monitoring, the programme could substantially contribute to improved economic and environmental outcomes. Remote Sensing Applications Consultants use newly available optical and radar data from the Copernicus Sentinel satellite missions to detail surface cover at 10 metre precision.

IMAGE’s three components detailed below.

The land use inventory shows the location and quality of forests, offering unprecedented distinction between cacao, oil palm, rubber, coconut, intact and degraded forest and identifies settlements and water features.

A Natural Capital Valuation Framework informs national reforestation, forest protection and economic development strategies. Building on the land use inventory, this tool integrates socioeconomic data to create a value map so users can assess the costs and benefits of reforesting or protecting areas in comparison with alternative scenarios of agricultural development. The information allows spatial strategies, such as those shown in Table 9, to be developed.

An early warning system monitors and anticipate deforestation. Using Sentinel-1 data covering the project area, RSAC will identify new forest clearings and forest degradation approximately fortnightly. The resulting change maps will improve knowledge of illegal activity and allow faster response on the ground.

Sustainability model

The long-term impact of IMAGES depends on local users continuing to keep the IMAGE datasets up to date. Hence, the project will make assessments to measure international partners' resources and invest in capacity building and securing ongoing budget commitments where appropriate.

While the core users in Côte d'Ivoire will have royalty-free access to IMAGE, there is potential for other users in Côte d'Ivoire to make use of the system to ensure its commercial sustainability. This is particularly in the commodity supply chains, which include some multinational enterprises. The interactive interface of IMAGE will accommodate a wide range of these user requirements.

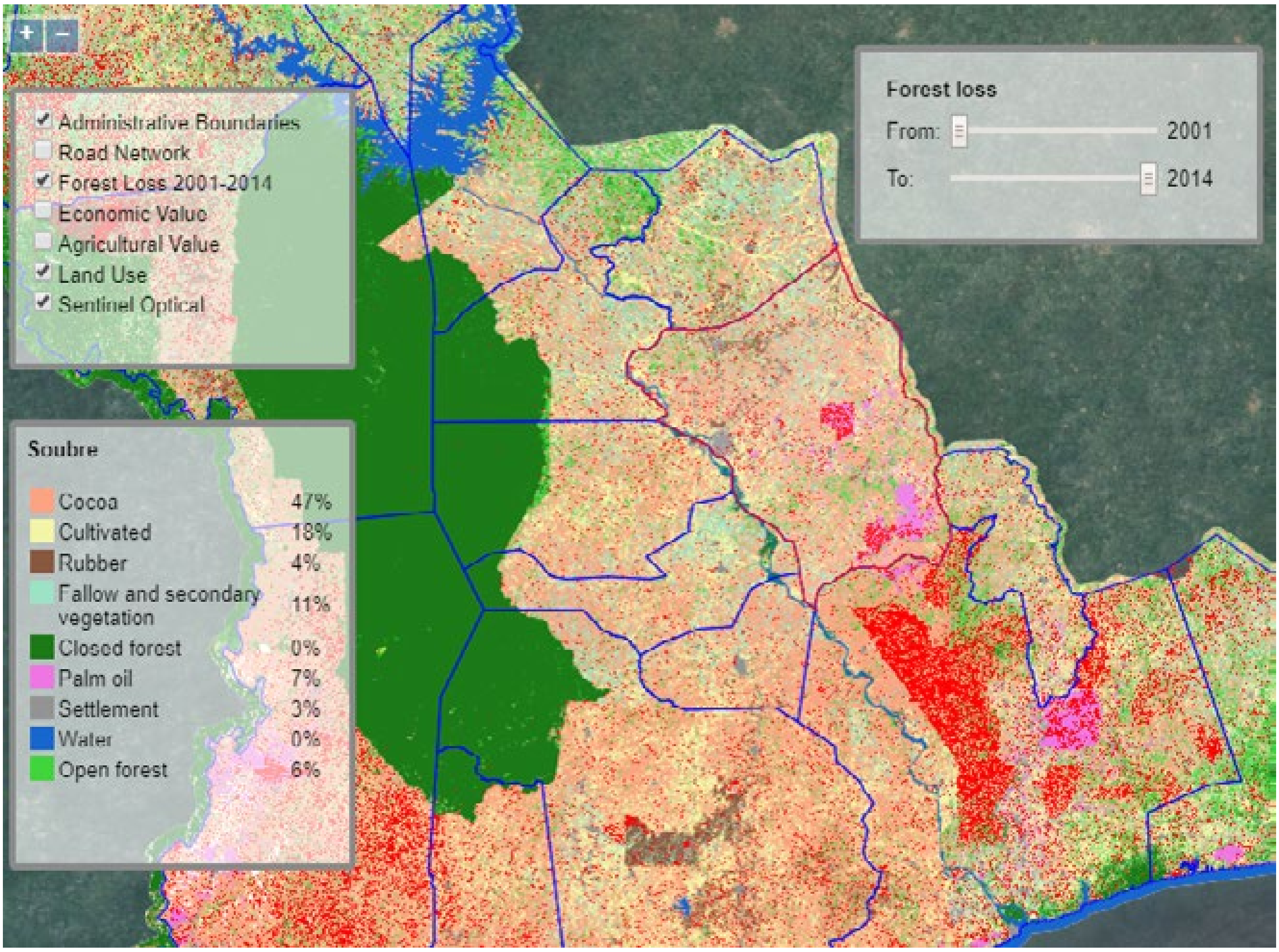
Other potential sources of commercial sustainability include:

- development banks and international government donors (especially those currently active in deforestation work in Côte d'Ivoire)
- individual companies involved in the cocoa supply chain through the zero-deforestation cocoa initiative
- companies within other supply chains, including palm oil and rubber
- other countries, such as regional or cocoa-producing

Table 9: Example land use classification

	Low Ecosystem Value	High Ecosystem Value
Low value agricultural production	Classify areas suitable for alternative revenue generating activities	Prioritise reforestation
High value agricultural production	Investment in increasing agricultural productivity	Increase protection of remaining forests

Figure 12: Illustration of the IMAGE Interface



☑ Administrative Boundaries
☐ Road Network
☑ Forest Loss 2001-2014
☐ Economic Value
☐ Agricultural Value
☑ Land Use
☑ Sentinel Optical

Forest loss
From: 2001
To: 2014

Soubre

🟧	Cocoa	47%
🟨	Cultivated	18%
🟫	Rubber	4%
🟩	Fallow and secondary vegetation	11%
🟩	Closed forest	0%
🟪	Palm oil	7%
⬜	Settlement	3%
🟦	Water	0%
🟩	Open forest	6%

Annex C: Methodology

The first step was to integrate information from the parallel UKSA IPP reports on Space for Agriculture in Developing Countries[70] and Space for Disaster Resilience in Developing Countries[71] and maintain the same flow of information as these. This was supplemented with the sectoral expertise knowledge of the authors, on the application of satellite data and analysis to challenges in the forestry sector.

In order to develop the summary profiles of each of the IPP forestry projects, we sourced background materials from each of the projects, including any prospectuses, presentation slides, and reports available. We followed these up with hour-long interviews over telephone and Skype, and in some cases supplemented these with direct meetings with the project leads. These interviews sought to provide better understanding of the challenges being addressed in each country, the technical solutions being offered, and the problems encountered during implementation. In these meetings, we explored further detail of the projects concerning project sustainability and the challenges encountered during project implementation. We sought to integrate these findings into key themes that would provide useful findings to present to organisations considering space solutions for forestry in developing countries.

One component of the report is the effectiveness of space solutions. To report on this, we used searches of Web of Science, including variations with highly-cited papers in field, and refining searches with check-boxes on forestry and recent publications, with search terms using:

- cost effective OR evaluation OR benefit OR public good
- forests AND satellites AND cost-effectiveness

We further used Google Scholar to identify key grey literature material using:

- forests and satellites OR earth observation AND cost-effectiveness

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[70] UK Space Agency and Caribou Space. 'Space for Agriculture in Developing Countries'. https://www.spacefordevelopment.org/library/space-for-agriculture-in-developing-countries. Accessed November 2018.

[71] UK Space Agency and Caribou Space. 'Space for Disaster Resilience in Developing Countries'. https://www.spacefordevelopment.org/library/space-for-disaster-resilience-in-developing-countries/. Accessed November 2018.

Annex D: Glossary

AGB – Above Ground Biomass, the biomass of trees per unit area, usually given in Mg/ha (also tonnes/ha, which is identical).

ALOS PALSAR – Advanced Land Observing Satellite Phased Array L-band SAR, a widely-used L-band radar satellite operated by the JAXA. Followed by ALOS-2 PALSAR-2.

CEA – Cost-effectiveness analysis is a value-for-money analysis. It compares the relative cost of achieving the same impact using alternative approaches and can be used to assess whether one solution provides the least costly method to achieve desired results.

Commission error – The proportion of pixels within a class in a classified map that in fact belong to a different class according to the reference data. Its complement is the user's accuracy.

Copernicus – The European Union's Earth Observation Programme, looking at our planet and its environment for the ultimate benefit of all European citizens. It offers information services based on satellite EO and in situ (non-space) data. The programme is co-ordinated and managed by the European Commission. It is implemented in partnership with the member states, the European Space Agency (ESA), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the European Centre for Medium-Range Weather Forecasts (ECMWF), EU Agencies and Mercator Océan.[72]

Deforestation – An anthropogenic disturbance to a forest area, that results in that area no longer meeting the relevant forest definition.

Degradation – There is no consensus on how forest degradation is defined. In this review, it is considered as an anthropogenic disturbance to a forest area, that reduces its above ground biomass, but after which it still meets the relevant forest definition.

Earth observation (EO) – The gathering of information about the physical, chemical, and biological systems of the planet via remote-sensing technologies, supplemented by earth-surveying techniques, which encompasses the collection, analysis, and presentation of data. EO is used to monitor and assess the status of and changes in natural and built environments.[73]

Electromagnetic spectrum – The range of frequencies of electromagnetic radiation and their respective wavelengths and photon energies.[74]

ESA – European Space Agency

ETM+ – Enhanced Thematic Mapper+, the main sensor on Landsat 7. Similar bands to TM, but with additional 15 metre resolution panchromatic band.

JAXA – Japanese Space Exploration Agency

LiDAR – A surveying method that measures distance to a target by illuminating the target with pulsed laser light and measuring the reflected pulses with a sensor. Differences in laser return times and wavelengths can then be used to make digital 3D representations of the target.[75]

Machine learning – A data analysis and prediction technique involving a computer developing an algorithm itself, normally from a multi-dimensional data, without explicit programming.

Monitoring and evaluation – An objective process of understanding how a project was implemented, what effects it had, for whom, how and why.[76]

MRV – Measurement, reporting and verification, normally discussed in the context of the monitoring and reporting requirements for countries to take part in the UNFCCC's REDD+ scheme.

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[72] Copernicus. 'What is Copernicus'. http://www.copernicus.eu/main/overview. Accessed November 2018.

[73] Wikipedia. 'Earth Observation'. https://en.wikipedia.org/wiki/Earth_observation. Accessed November 2018.

[74] Wikipedia. 'Electromagnetic Spectrum'. https://en.wikipedia.org/wiki/Electromagnetic_spectrum. Accessed November 2018.

[75] Wikipedia. 'Lidar'. https://en.wikipedia.org/wiki/Lidar. Accessed November 2018.

[76] Caribou Digital.

MSS – Multi-Spectral Scanner, the main sensor used on Landsat 1-3, also present on Landsat 4/5.

NASA – US National Aeronautics and Space Administration

Neural network – A widely used type of machine learning technique.

ODA – Official development assistance is a term defined by the Development Assistance Committee (DAC) of the Organisation for Economic Co-operation and Development (OECD) to measure aid.[77]

OECD – The Organisation for Economic Co-operation and Development is an intergovernmental economic organisation with 37 member countries, founded in 1961 to stimulate economic progress and world trade.[78]

OLI – Operational Land Imager, the main sensor used on Landsat 8. Similar bands and resolution to ETM+, but much higher dynamic range (pixel values from 0-4095 rather than 0-255).

Orthorectification – Uses elevation data to correct terrain distortion in aerial or satellite imagery.[79]

Omission error – The proportion of the reference data for a class that is allocated to a different class. Its complement is producer's accuracy.

Producer's accuracy – The proportion of reference data from a class correctly allocated to that class in an output map. Its complement is omission error.

Radar – A method of imaging using pulses of microwave radiation. Unlike optical data usually only a single wavelength is used, named by single letters (e.g. L-band, C-band, X-band).

Random forest – A machine learning technique often employed in remote sensing classification and regression.

REDD+ – Reducing Emissions from Deforestation and forest Degradation in developing countries, and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries, a part of the UNFCCC agreements.

Radiometric correction – The process of removing the effects of the atmosphere on the reflectance values of images taken by satellite or airborne sensors.[80]

SAR – Synthetic Aperture Radar satellites are a form of radar using the motion of the satellite to create a larger 'virtual' antenna that is used to create two or three-dimensional images of objects, such as landscapes.[81]

TM – Thematic Mapper, the main sensor on Landsat 4/5

UNFCCC – United Nations Framework Convention on Climate Change

User's accuracy – the proportion of all reference data assigned to a particular class in a classified map that are truly that class in the ground truth dataset. Its complement is commission error.

UAV – An unmanned aerial vehicle, commonly known as a drone, is an aircraft without a human pilot aboard.[82]

UKSA – UK Space Agency

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[77] Wikipedia. 'Official development assistance'. https://en.wikipedia.org/wiki/Official_development_assistance. Accessed November 2018.

[78] Wikipedia. 'OECD'. https://en.wikipedia.org/wiki/OECD. Accessed November 2018.

[79] ESRI. 'GIS Dictionary' https://support.esri.com/en/other-resources/gis-dictionary. Accessed November 2018.

[80] As above

[81] As above

[82] Wikipedia. 'Unmanned aerial vehicle'. https://en.wikipedia.org/wiki/Unmanned_aerial_vehicle. Accessed November 2018.

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