# UK Space Agency International Partnership Programme

## Space for Agriculture in Developing Countries

July 2018

UK SPACE AGENCY

https://www.gov.uk/government/organisations/uk-space-agency

The UK Space Agency leads the UK efforts to explore and benefit from space. It works to ensure that our investments in science and technology bring about real benefit to the UK and to our everyday lives. The Agency is responsible for all strategic decisions on the UK civil space programme. As part of the Department for Business, Energy & Industrial Strategy, the UK Space Agency helps realise the government's ambition to grow our industry's share of the global space market to 10% by 2030.

The UK Space Agency:

- supports the work of the UK space sector, raising the profile of space activities at home and abroad
- helps increase understanding of our place in the universe, through science and exploration and its practical benefits
- inspires the next generation of UK scientists and engineers
- regulates and licences the launch and operation of UK spacecraft, launch operators and spaceports
- promotes co-operation and participation in the European Space Agency and with our international partners

### International Partnership Programme

https://www.gov.uk/government/collections/international-partnership-programme

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 (BEIS) Global Challenges Research Fund (GCRF): a £1.5 billion fund announced by the UK Government, which supports cutting-edge research and innovation on global issues affecting developing countries.

Caribou Space

www.caribou.space

Support organisations to bridge the space and development worlds. We work with governments, space agencies, development agencies and private sector space companies.

Caribou Space: Victoria Clause, David Taverner, Tim Hayward

# Contents


**Acknowledgments** 4

**Background** 6

**Executive summary** 8

**Today's agricultural challenges** 14

**The case for space** 16

- Space for agricultural challenges 16
- Space technology can support agriculture in developing countries 17
- Impact and cost-effectiveness of space solutions for agriculture 21

**Seizing the opportunity** 26

- Space solutions 26
- Economic sustainability models and industry trends 32

**Additional information and guidance** 34

- Characteristics of Earth observation data 34
- Sourcing Earth observation data 38
- Processing and analysing Earth observation data 40
- Sourcing Earth observation expertise 41
- Additional reading and resources 45

**Annex A: Current IPP agriculture projects** 46

- CABI: Pest Risk Information Service (PRISE) 46
- Earth-i: Advanced Coffee Crop Optimisation for Rural Development (ACCORD) 49
- Rothamsted Research: Ecological Productivity Management Information System (EcoProMis) for oil palm and rice in Colombia 51
- Environment Systems: EO4cultivar 52
- Rezatec: Mexican Crop Observation, Management and Production Analysis Services System (COMPASS) 55
- Rheatech: Drought and Flood Mitigation Service (DFMS) 57

**Annex B: Rapid review methodology** 60

Glossary 62

# Acknowledgments

UK Space Agency and Caribou Space would like to acknowledge the following organisations for their valuable contributions to this report, in particular contributing authors:

- Jacqueline Parker, Steve Keyworth and Pascale Bodevin, Environment Systems

UK Space Agency and Caribou Space would like to thank the following organisations and persons provided detailed review and feedback:

- Elena Lobo, Satellite Applications Catapult
- Llorenc O'Prey and Endaf Griffiths, Wavehill
- Farooq Sabri, London Economics
- Saravana Gurusamy, Rezatec Limited
- Cambria Finegold, CAB International (CABI)
- Paul Healy and Elma Jenkins, RHEATECH
- Eli Pollak, Apollo Agriculture
- Lorenzo DeSimone, Food and Agriculture Organisation (FAO)
- Giancarlo Pini, World Food Programme (WFP)
- Michael Brobbey and Ruthie Musker, Global Open Data for Agriculture and Nutrition (GODAN)

# *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 or societal benefit to developing countries. Projects within IPP span a wide range of themes including: improving agriculture, reducing deforestation, improving disaster response, reducing maritime pollution and illegal fishing, optimising renewable energy and improving resilience to climate change.

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 agriculture sector, and it is written as an introductory primer on the role of space in agriculture. This report outlines why and how the space industry has a critical role to play in addressing major challenges confronting the agriculture sector in developing economies. It will be part of a series of sector-focused reports, including disaster resilience, forestry and maritime, setting out one view of how space can help, but it is recommended that the report is read alongside other relevant resources, some of which are listed on page 45: Additional reading and resources.

The report draws on examples of the space solutions for agriculture that are supported by IPP, as well as other examples outside IPP. Within IPP there are four agriculture projects that started in January 2017 and are in their early phases, and two agriculture projects that began in early 2018. As it is too soon to identify results and lessons from these projects this document will be updated in the later stages of IPP to capture and communicate results and lessons.

# Executive summary

The global agriculture sector faces many challenges today, many of which are more acute in developing countries. Low agricultural production remains a major issue for the agriculture sector in developing countries and is a contributing factor to on-going hunger and malnutrition in these countries. Concurrently, the growing demand for food and decreasing availability of land for farming caused by global population growth is a major issue. Unpredictable and extreme weather patterns, loss of land and changes in growing conditions caused by climate change presents significant challenges for the agriculture industry globally. Access to natural resources such as land and water is under increasing pressure and the unsustainable use of such resources is a major challenge for the agriculture industry.

Urgent action is needed to tackle these issues, and innovation and collaboration between industries and countries across the globe is more important than ever. This report outlines why and how the space industry has a critical role to play in addressing major challenges confronting the agriculture sector in developing economies. The primary audience is the agriculture sector in developing countries, and it is written as an introductory primer on the role of space in agriculture.

## Structure

There are three broad sections to the report:

- why space solutions are an opportunity to help tackle the major global issues facing the agriculture sector in developing countries
- what types of space solutions currently exist for agriculture, with the different use cases and business models
- outlining the next steps to take once the opportunity is understood – with guidance on: accessing, processing and analysing satellite data; organisations to work with; and where to find further resources

## Audience

The report is intended for different audiences with specific takeaways for each. The primary audience is the development and agriculture sector, and it is written as an introductory primer on the role of space in agriculture.

| Audience | Why read this report? |
|---|---|
| Growers and businesses in agricultural supply chains in developing countries | – Learn about the opportunity for space solutions to benefit your agriculture business or project by increasing production, improving supply chain efficiency, building resilience to climate change or sustainably managing natural resources and demonstrating traceability<br>– Understand the process of accessing and using satellite data, what resources you may need and who to partner with |
| Governments and government agencies involved in agriculture and food security | – Understand the opportunity for space solutions to add value to the agriculture sector and improve national food security<br>– Learn about existing space solutions for agriculture, who to work with and where to find more information |
| NGOs, investors/donors and research agencies in developing countries | – Learn about the opportunity for space solutions to benefit your agriculture business or project, and who you can partner with to integrate a space solution into your business or project<br>– Understand the different ways that your organisation can use satellite data to increase production, improve supply chain efficiency, build resilience to climate change or sustainably manage natural resources and demonstrate traceability<br>– Learn about existing space and agriculture projects funded through IPP |
| Space sector | – Learn about existing collaboration between the UK space sector and agriculture partners in developing countries, and how space technology is tackling agriculture challenges and building local capacity through IPP<br>– Learn more about the agriculture challenges in developing countries, how they differ from developed countries and the consequent market opportunity for space solutions |

## Key points

The major challenges facing the global agriculture sector today include:

- low agricultural production contributing to on-going hunger and malnutrition
- growing demand for food and decreasing availability of land brought about by population growth
- unpredictable and extreme weather patterns, loss of land and changes in growing conditions caused by climate change
- declining access to natural resources such as land and water due to unsustainable use of such resources

Space solutions are well placed to address agriculture challenges impacting developing countries, with many positive outcomes and impacts.

Space solutions can support four key actions to tackle these challenges:

**1. Increase production - Earth observation (EO)[1] improves the accuracy and relevance of decision support tools and affordability of credit products.**

The lack of accurate and timely information available to growers to support the best farming decisions is one of the major contributing factors to the yield gap. EO provides information for improved decision support tools that can empower growers and agricultural support services to make more informed farming decisions, at the right time. EO provides high-quality data, for example on crop performance, competing land use and for modelling to identify factors causing lower yield. Small-scale producers also lack access to affordable credit, which contributes to the on-going low productivity in developing countries. The analysis of EO data can deliver information on risk, yields and land degradation, which can be used by organisations providing finance to small-scale producers to reduce uncertainty and thus to make finance more accessible and affordable.

**2. Improve supply chain efficiency to reduce losses – Earth observation enables supply chain optimisation.**

The lack of accurate information around food supply, poor infrastructure in rural areas and lack of transparency and communication between supply chain stakeholders, leads to food being spoiled and wasted in developing countries. EO provides an additional layer of accurate and timely information to support decision-making at each stage of the supply chain, enabling greater efficiency and reduced losses. EO provides information for improved monitoring and detection of crop productivity at the field and farm scale to help optimise farming operations. Measures of crop productivity, crop growth stage and alerts to where there may be problems with plant health can be developed for specific crops from a time series of EO data in the form of field scale crop intelligence. These analytics can be readily accessed by growers using data services. When provided frequently and in a timely way agronomists and supply chain managers have additional sources of readily useable information during the growing season, which helps with targeting agronomy visits, and planning and logistics for harvest and at key stages in the cropping cycle.

**3. Sustainable management of environmental resources and supply chain traceability - Earth observation improves the range of decision support tools for resource management and traceability.**

An increase in food production needs to be through sustainable intensification of agriculture. Sustainable intensification uses an ecosystem approach, an internationally adopted strategy for the integrated management of land, water and living resources that

1 Wikipedia. Posted at https://en.wikipedia.org/wiki/Earth_observation. Accessed July 2018. "Earth observation (EO) is 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. Earth observation is used to monitor and assess the status of and changes in natural and built environments."

promotes conservation and sustainable use in an equitable way. EO provides a source for identifying types of land cover, aspect, topography, infrastructure and the land management systems in place that are key inputs for ecosystems services mapping. Consistent monitoring of agriculture on a regional and global level using space technology provides visibility into how agriculture can be optimised to be more sustainable in the face of climate change. EO data can provide decision support tools for growers at a localised field scale to farm more efficiently and sustainably through improved management of natural resources and input usage. In the case of certification schemes that provide evidence of sustainable supply chains, EO can be used to enable monitoring of forest cover and changes in land use or destruction of natural ecosystems, resulting in improved audits and verification process at reduced costs.

**4. Resilience to climate change - Earth observation improves the accuracy of early warning systems and affordability of insurance.**

Developing countries typically lack the ability to collect, process and distribute the data needed for accurate predictions of extreme weather patterns and pest outbreaks, which leads to significant crop and livestock losses. EO and meteorological satellites provide an added layer of detailed and accurate data to create effective early warning systems that mean farmers receive advance warning about extreme weather or conditions likely to result in pest outbreaks and can proactively take the necessary actions to avoid loss. Crop and livestock insurance can make small-scale producers more resilient to climate change but currently there are few affordable products available to the small-scale producers. With EO data, insurance providers can reduce premiums making them more widely affordable in the agriculture sector.

## Space solutions for the agriculture sector can be grouped into three thematic areas:

**1. Decision support tools -** To increase production of food in a sustainable way, to manage natural resources and use inputs more efficiently and to optimise supply chains and build traceability. Stakeholders along the agriculture value chain need accurate, relevant and timely information to make informed decisions. EO provides additional data that can support better decision-making along the value chain, from the farm level up to regional and national level.

**2. Early warning systems -** Many developing countries lack the data to accurately predict pest and disease outbreaks or the occurrence of extreme weather events including drought and flooding. EO provides data to monitor the environmental factors associated with the onset of such events and allow countries to build early warning systems to forecast these events allowing them to take mitigating action to prevent or reduce losses.

**3. Insurance and credit products -** EO enables accurate mapping of land use and monitoring of changes in crops and the land itself. This data is useful for finance companies that need access to data concerning land used by growers in order to be able to offer them financial products such as insurance or credit. For many small-scale producers in developing countries, these financial products are prohibitively expensive, not designed for their needs, or simply not available at all.

### Space solutions potentially provide a cost-effective means to make an impact:

There is a growing body of evidence highlighting the positive economic, social and environmental impacts of space solutions in agriculture. The distance of space-based assets (particularly EO) from the earth means that they possess the following strengths relative to alternative methods of data collection (e.g. planes, unmanned aerial vehicles (UAVs) or ground-based teams):[2]

- collection of data at regular frequency (temporal resolution)
- collection of data over large areas (scale) and in remote, inaccessible areas
- 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

As a result, satellite-based platforms are suitable for providing an important source of monitoring data to underpin agricultural applications in the developing world – more cost effectively than alternatives.

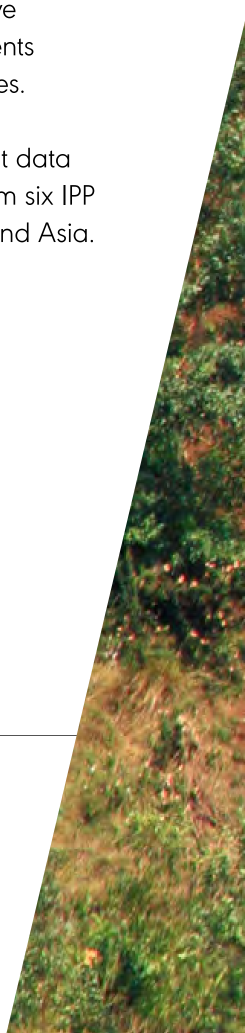
**Space solutions in the agricultural sector require an economic sustainability model** that will ensure continuity of the project beyond the initial funding to set up the project, wherever that may come from. Stakeholders need to identify sufficient revenue streams to cover operational costs in the long term, thereby ensuring the continuation of the solution and the positive impact in country. A range of sustainability models is possible, including:

- commercial revenue
- government investment/revenue
- donor funding

## Conclusions

The space sector is well placed to contribute new types of information and tools to form part of the solution to the major challenges facing the agriculture sector today, in both developed and developing countries. The unique benefit that space solutions provide is global, repeatable, accurate and scalable data that can be used to deliver high value insights, cost effectively, about how issues are impacting our planet. This allows action to be taken to make a positive impact in many different areas and this represents a significant opportunity for developing countries.

This report will be updated in 2021 with impact data and cost-effectiveness analysis (CEA) data from six IPP agriculture projects in Africa, South America and Asia.



2 London Economics (forthcoming). 'Value of satellite-derived Earth Observation capabilities to the UK Government'.

# *Today's agricultural challenges*

The global agriculture sector faces many challenges today, many of which are more acute in developing countries.

**Low agricultural production remains a major issue for the agriculture sector in developing countries and is a contributing factor to on-going hunger and malnutrition.** After steadily declining for over a decade, and despite great advances in food production, global hunger appears to be on the rise, with 815 million people still said to be hungry today[3] and micronutrient deficiency affecting an additional 2 billion.[4] In developing countries, hunger and malnutrition rates remain high due in part to greater poverty and the absence of welfare systems.

**Concurrently, the growing demand for food and decreasing availability of land for farming caused by global population growth presents a major challenge for agriculture stakeholders.**

The human population is set to increase to around 10 billion by 2050[5] and most of the additional 2 billion[6] people will live in developing countries. Agriculture must transform itself if it is to feed a growing population and provide the basis for economic growth and poverty reduction.[7]

**Unpredictable and extreme weather patterns, loss of land and changes in growing conditions caused by climate change present significant challenges for the agriculture industry globally.**

We are seeing increasingly unpredictable and damaging weather patterns, crop failures or destruction, and climate effects interacting with other conditions leading to increased susceptibility to pests and diseases.[8] Climate change has a greater effect on small-scale producers who typically don't have capacity to respond effectively; they have limited assets and risk-taking capacity to access and use technologies and financial services to adapt their production systems.[9] Many smal-scale producers rely on rain-fed agriculture and do not have access to irrigation, for example. More broadly, climate change affects food supply chains, food prices and international trade.

**Access to natural resources such as land and water is under increasing pressure and the unsustainable use of such resources is a major challenge for the agriculture industry.**

The Earth's natural assets, including soil, air, water and living organisms, exist as complex ecosystems which provide a range of services to humans.

---

3 Food and Agriculture Organisation (FAO). 'The State of Food Security and Nutrition in the World 2017'. Posted at http://www.fao.org/state-of-food-security-nutrition/en/. Accessed July 2018.

4 Thomson Reuters. 'How Will We Fill 9 Billion Bowls by 2050?'. Posted at http://reports.thomsonreuters.com/9billionbowls/. Accessed July 2018.

5 United Nations Department of Economic and Social Affairs. 'World population projected to reach 9.8 billion in 2050, and 11.2 billion in 2100'. Posted on 21 June 2017 at https://www.un.org/development/desa/en/news/population/world-population-prospects-2017.html. Accessed July 2018.

6 Food and Agriculture Organisation (FAO). 'How to Feed the World in 2050'. Posted at http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf. Accessed July 2018.

7 Food and Agriculture Organisation (FAO). 'Climate-Smart Agriculture Sourcebook'. Posted at http://www.fao.org/docrep/018/i3325e/i3325e.pdf. Accessed July 2018.

8 Food and Agriculture Organisation (FAO). 'Keeping plant pests and diseases at bay: experts focus on global measures'. Posted at http://www.fao.org/news/story/en/item/280489/icode/. Accessed July 2018.

9 Food and Agriculture Organisation (FAO). 'Climate-Smart Agriculture Sourcebook'. Posted at: http://www.fao.org/docrep/018/i3325e/i3325e.pdf. Accessed July 2018.

The unsustainable use of this natural capital means it is being degraded at an ever-increasing rate.[10] Depleting and degrading our natural reserves, for agricultural purposes, may irreversibly reduce the availability of benefits to future generations.[11] This current behaviour is impacting crop yields, adding to potential food crises, and biodiversity loss and ecosystem collapse is affecting the pollination and genetic diversity of crops that we rely on. Global population growth, urbanisation and industrialisation is increasing demand for land and natural resources at a time when climate change already puts severe pressure on them.

These challenges are a concern for all societies, but arguably it is in developing countries where the impacts are most gravely felt. The number of people who rely on agriculture for their livelihood, and are therefore directly affected by these challenges, is significantly higher in developing countries: for example, 70% of Africans are dependent on agriculture for their livelihoods.[12] Many small-scale producers are already affected by a degraded natural resource base and the adoption of sustainable agriculture practices is far behind that of more developed countries. Sustainable intensification of agriculture production is needed.

Governments and societies need to put in place steps to address these major challenges in the agriculture sector to help achieve the goals of food security, defined as "the condition in which all people, at all times, have physical, social and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life",[13] and couple this with moving to agriculture and foods systems that are sustainable and more resilient to risks, shocks and climate change.

---

10 Food and Agriculture Organisation (FAO). 'Natural Capital Impacts in Agriculture: Supporting Better Business Decision Making'. Posted at http://www.fao.org/fileadmin/templates/nr/sustainability_pathways/docs/Natural_Capital_Impacts_in_Agriculture_final.pdf. Accessed July 2018.

11 European Commission. 'In-depth Report 16. Taking Stock: progress in natural capital accounting'. Posted at http://ec.europa.eu/environment/integration/research/newsalert/pdf/natural_capital_accounting_taking_stock_IR16_en.pdf. Accessed July 2018.

12 World Economic Forum. '70% of Africans make a living through agriculture, and technology could transform their world.' Posted at: https://www.weforum.org/agenda/2016/05/70-of-africans-make-a-living-through-agriculture-and-technology-could-transform-their-world/. Accessed July 2018.

13 Food and Agriculture Organisation (FAO). 'An Introduction to the Basic Concepts of Food Security'. Posted at http://www.fao.org/docrep/013/al936e/al936e00.pdf. Accessed July 2018.

# The case for space

## Space for agricultural challenges

The space sector, with support from national governments, has been developing solutions for the agriculture sector for many decades. Since the launch of the Landsat-1 satellite in 1972,[14] satellites have been used to remotely monitor and collect images of the Earth's surface, providing valuable data for the agricultural sector. More recent programmes such as Copernicus,[15] led by the European Union, and its Land Monitoring Service launched in 2012, have made vast amounts of data from satellite and in-situ observations available to stakeholders involved in agriculture.

The space sector is well placed to contribute new types of information to form part of the solution to the major challenges facing the agriculture sector today, in both developed and developing countries. The unique benefit that remote sensing space solutions provide is global, repeatable, accurate and scalable data that can deliver high value insights about how issues are impacting our planet, allowing action to be taken to make a positive impact in many different areas.

Earth observation is 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.[16] There are three main types of observations:

- in situ surface or subsurface data collection, such as weather stations, which capture information from their immediate surroundings
- non-satellite observations collected by sensors on aircraft or Unmanned Aerial Vehicles (UAVs, including drones)
- satellite EO from sensors on satellites (see detail in 'Characteristics of Earth observation data')

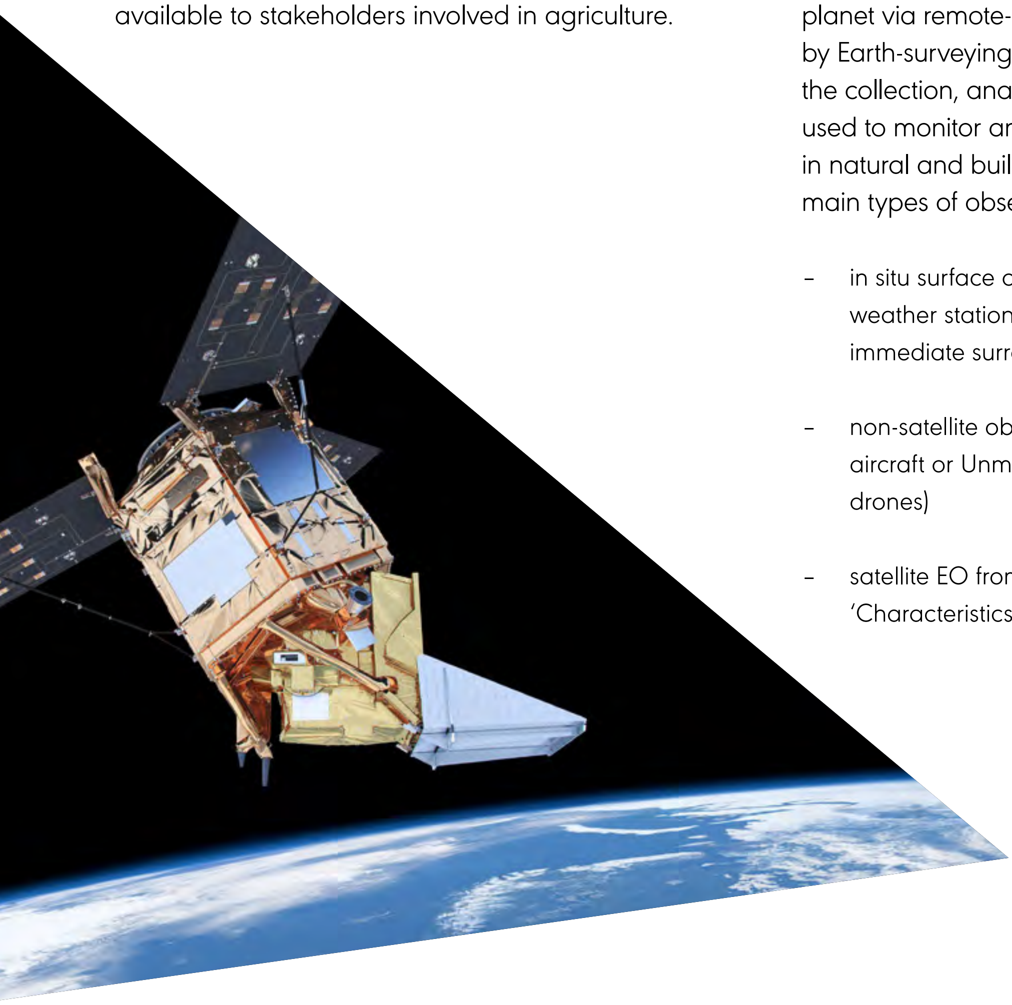


Photo: ESA/ATG medialab

14 Landsat is a joint effort of the United States Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA). Website: https://landsat.usgs.gov/landsat-project-description. Accessed July 2018.

15 Copernicus is a European Union programme aimed at developing European information services based on satellite Earth observation and in situ (non-space) data. Website: http://www.copernicus.eu/main/overview. Accessed July 2018.

16 Wikipedia. Posted at https://en.wikipedia.org/wiki/Earth_observation. Accessed July 2018.

Data from EO satellites has many advantages for agricultural purposes:

**Coverage and quality:** Satellites have regular revisit times, as they orbit the earth and provide consistent observations of land features, making it possible to monitor agriculture and scale up as appropriate from field and farm to catchment, landscape, regional, national and global scale in an accurate and repeatable way.

**Range of data:** Satellites collect data via a number of sensor types. This allows identification of crop and vegetation types and the monitoring of many different environmental conditions including moisture, temperature, soil condition and vitality of leaf vegetation.

**Analysis ready data:**[17] Satellite data can be processed to defined industry standards and organised in a form that allows immediate value-addition and analysis, for example as inputs to models, such as those being developed in IPP. Field, farm or regional scale measures can be derived automatically using satellite imagery and presented as simple outputs in the form of maps, dashboards, spreadsheets and graphs compatible for use with geographic information systems (GIS), farm and business management platforms. Satellite data services enable these products to be delivered directly to agricultural stakeholders.

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

**Speed of delivery:** Increasingly, analysis-ready EO data is available for use soon after it is acquired, which is important for crop production monitoring or in disaster situations where a rapid response is required. Satellite data services enable stakeholders to quickly receive the EO derived information they need.

## Space technology can support agriculture in developing countries

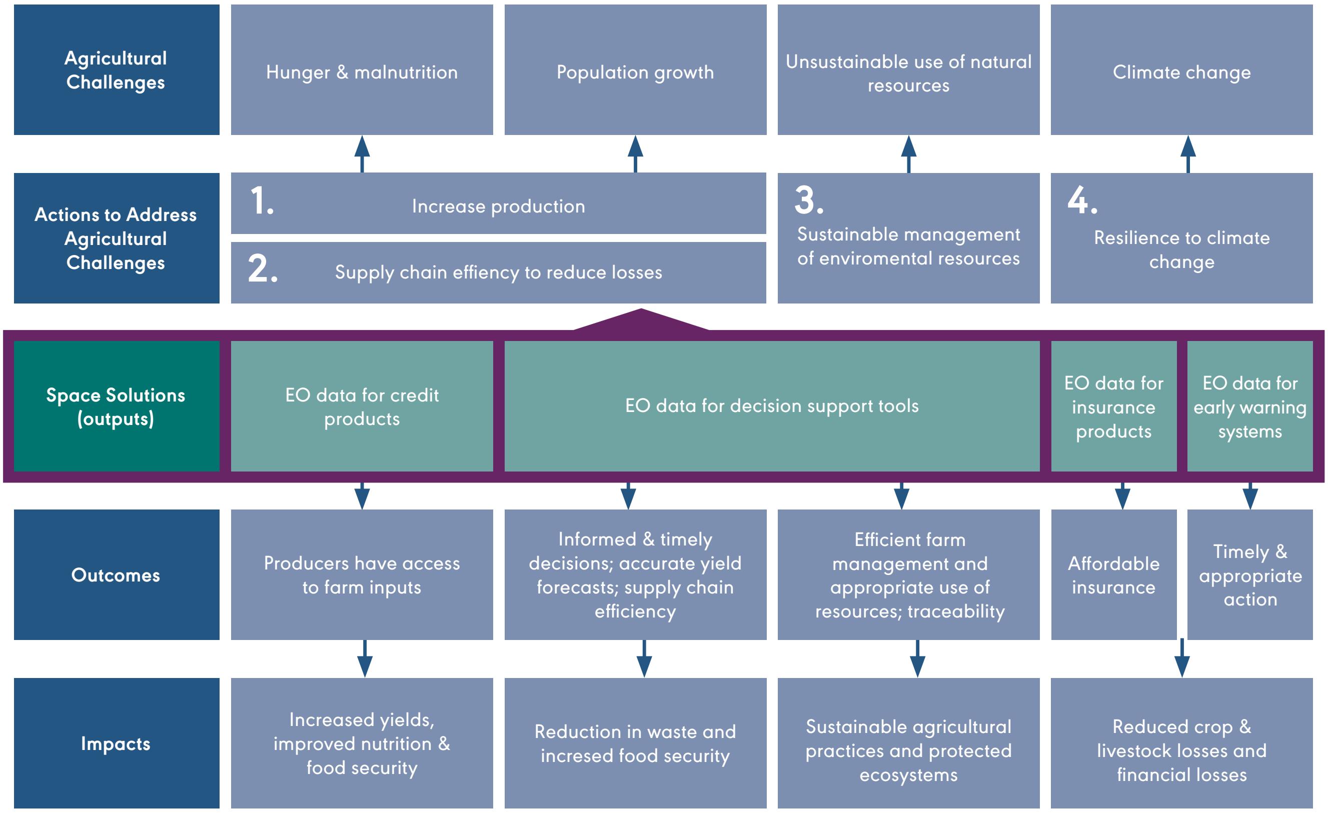
While there have been significant advances and impacts from using satellite technology in agriculture in developed markets, the opportunity to use space solutions in agriculture in developing countries is now increasingly being recognised. For the space industry, these markets offer significant growth potential due to the sheer scale of the challenges. For example, the scope for agricultural productivity gains using space technology can be significantly higher than in developed markets where many farmers have already achieved high productivity.[18]

Two factors are important to consider in this context: the ability for developing country stakeholders to pay for space solutions, and the complex nature of agriculture value chains in these markets. Consequently, space industry players need to form appropriate partnerships with intermediaries, such as government authorities, agribusinesses or cooperatives, in order to reach end-user growers. Figure 2 below highlights the specific opportunities where space solutions are well positioned to address agriculture challenges in developing countries.

17 UNGWG Satellite Task Team Report. 'Earth Observation for Official Statistics'. Posted at https://unstats.un.org/bigdata/taskteams/satellite/UNGWG_Satellite_Task_Team_Report_WhiteCover.pdf. Accessed July 2018.

18 Satellite Applications Catapult. 'Agricultural Technology – Market Review'. Posted at https://sa.catapult.org.uk/services/market-reports/. Accessed July 2018.

Figure 2: Space solutions address agricultural challenges in developing countries[19]




As Figure 2 illustrates, space solutions are well placed to address agriculture challenges impacting developing countries, with many positive outcomes and impacts. Space solutions can support four key actions to tackle these challenges:

**1. Increase production: Earth observation improves the accuracy and relevance of decision support tools and affordability of credit products**

Agricultural productivity in developing countries is significantly lower than in developed markets; yields of wheat and rice in low-income countries are currently about half those in high-income countries.[20]

With a growing human population, food production needs to increase and concurrently production of more nutritious foods needs to be a priority to tackle on-going malnutrition.

The agricultural sector is of critical importance to many developing country economies, where in some countries the sector contributes between 20% and 30% of national Gross Domestic Product (GDP).[21] Experience of countries that have succeeded in reducing hunger and malnutrition shows that economic growth does not automatically ensure success, the source of that growth matters too. Growth originating in agriculture, in particular the smallholder

19 Caribou Space. 2018.

20 Food and Agriculture Organisation (FAO). 'The Future of Food and Agriculture, Trends and Challenges'. Posted at http://www.fao.org/3/a-i6583e.pdf. Accessed July 2018.

21 Food and Agriculture Organisation (FAO). 'Review of the available remote sensing tools, products, methodologies and data to improve crop production forecasts'. Posted at http://www.fao.org/3/a-i7569e.pdf. Accessed July 2018.

sector, is at least twice as effective as growth from non-agriculture sectors in benefiting the poorest.[22] Increasing productivity and incomes contributes to the agricultural transformation needed to benefit smallholder farmers at a time where those involved in subsistence agriculture will, in the longer-term, need to transition to off-farm job opportunities for sustained wealth creation and a self-financed exit from poverty.[23]

The lack of accurate and timely information available to growers to support the best farming decisions is one of the major contributing factors to the yield gap. EO provides information for improved within-season crop monitoring at the field and farm scale. EO provides high-quality data, for example on crop performance, competing land use and for modelling to identify factors causing lower yield. Using these decision support tools can help growers and agricultural support services to make more informed farming decisions, at the right time.

Small-scale producers also lack access to affordable credit with which to purchase appropriate inputs at the start of the growing season. This contributes to the on-going low productivity in developing countries. EO data can be used to develop innovative criteria and algorithms to assess a farmer's credit-worthiness, thereby reducing the cost of face-to-face assessments and making finance more affordable to small-scale producers. EO can also play a role in monitoring risk for finance providers.

**2. Supply chain efficiency to reduce losses: Earth observation enables supply chain optimisation**

Enough food is produced today to feed our global population, but food loss arising from a range of challenges along the supply chain remains a significant problem. Of the food that we do grow the United Nations estimates that 30% goes to waste somewhere in the production and delivery process.[24] The lack of accurate information around food supply, poor infrastructure in rural areas and lack of transparency and communication between supply chain stakeholders, leads to food being spoiled and wasted. This not only has an economic impact for growers, but also for consumers and the wider economy. It is not only food that is wasted but also the finite resources used to produce it.

EO provides an additional layer of accurate and timely information to support decision-making at each stage of the supply chain, enabling greater efficiency and reduced losses. EO provides information for improved monitoring and detection of crop productivity at the field and farm scale to help optimise farming operations. Government departments and other stakeholders in the agricultural value chain can use regionally derived data for strategic purposes to set policy on where to incentivise or target appropriate financial support, for example for crop diversification programmes, infrastructure investment, or to plan distribution of inputs and optimise logistics. The appropriate resources can be assigned to better match supply and demand and thereby reduce waste.

**3. Sustainable management of environmental resources and supply chain traceability: Earth observation improves the range of decision support tools for resource management and traceability**

Food demand needs to be met from existing agricultural land, since opening up new land for agriculture carries major environmental costs such as pollution of freshwaters that are already under abstraction, pollution and erosion stress and desertification from over grazing and deforestation.[25] Agriculture drives 80% of tropical deforestation[26] and supply chains are under increasing pressure

22 Food and Agriculture Organisation (FAO). 'How to Feed the World in 2050'. Posted at http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf. Accessed July 2018.

23 Department for International Development (DFID). 'DFID's Conceptual Framework on Agriculture'. 2015. Posted at https://www.gov.uk/government/publications/dfids-conceptual-framework-on-agriculture. Accessed July 2018.

24 Thomson Reuters. 'How Will We Fill 9 Billion Bowls by 2050?' Posted at http://reports.thomsonreuters.com/9billionbowls/. Accessed July 2018

25 Campbell et al (2014). 'Sustainable intensification: What is its role in climate smart agriculture?' Posted at https://www.sciencedirect.com/science/article/pii/S1877343514000359. Accessed July 2018.

26 Rainforest Alliance. 'Conserving Forests and Improving Livelihoods'. Posted at https://www.rainforest-alliance.org/issues/food. Accessed July 2018.

to become more sustainable and traceable as consumers become more aware of the environmental impacts of production.

An increase in production needs to be through sustainable intensification of agriculture. Sustainable intensification uses an ecosystem approach,[27] an internationally adopted strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. It recognises the interdependence between economic development, societal wellbeing and environmental protection, and draws on nature's contribution to crop growth – soil organic matter, water flow regulation, pollination and natural predation of pests. It applies appropriate external inputs at the right time, in the right amount, to improved crop varieties that are resilient to climate change. It also uses nutrients, water and external inputs more efficiently.[28]

Mapping provides a powerful tool to enable us to visualise ecosystem services provision for local, regional and even national scales. EO provides a source for identifying types of land cover, aspect, topography, infrastructure and the land management systems in place that are key inputs for ecosystems services mapping. Consistent monitoring of agriculture on a regional and global level using space technology provides visibility into how agriculture can be optimised to be more sustainable in the face of climate change. EO data can provide decision support tools for growers at a localised field scale to farm more efficiently and sustainably through improved management of natural resources and input usage.

Agriculture stakeholders are increasingly investing in certification schemes such as the Rainforest Alliance and the Round Table on Sustainable Oil (RSPO), which are market-based approaches to respond to customer demand for more evidence of sustainability and traceability in supply chains. Certification schemes such as Rainforest Alliance can benefit from EO which enables monitoring of forest change over a set period of time and historical satellite imagery[29] can be used to identify changes in land use or destruction of natural ecosystems, resulting in improved audits and verification process at reduced costs.

27 Convention on Biological Diversity. 'Ecosystem Approach'. Posted at https://www.cbd.int/ecosystem. Accessed July 2018

28 Bruce M Campbell et al (2014). 'Sustainable intensification: What is its role in climate smart agriculture?' Posted at https://www.sciencedirect.com/science/article/pii/S1877343514000359. Accessed July 2018.

29 Rainforest Alliance. 'Module 2: Biodiversity Conservation. Sustainable Agriculture Standard'. Posted at https://www.rainforest-alliance.org/business/sas/wp-content/uploads/2018/01/81_Technical-Module-P2_en.pdf. Accessed July 2018.

**4. Resilience to climate change: Earth observation improves the accuracy of early warning systems and affordability of insurance**

Climate change has brought devastating impacts to developing countries where increasing temperatures and changing rainfall patterns have left many farmers vulnerable to more frequent or severe pest outbreaks, flood and drought events. Developing countries typically lack the ability to collect, process and distribute the data needed for accurate predictions of extreme weather patterns and pest outbreaks, which leads to significant crop and livestock losses. EO and meteorological satellites provide an added layer of detailed and accurate data to create effective early warning systems that mean farmers receive advance warning about extreme weather or conditions likely to result in pest outbreaks and can proactively take the necessary actions to avoid loss.

Crop and livestock insurance can make small-scale producers more resilient to climate change but currently there are few affordable products available to the small-scale producers. With EO data, insurance providers can reduce the prohibitive costs of on-ground data collection and assessment, and thereby reduce the insurance premiums making them more widely affordable in the agriculture sector.

## Impact and cost-effectiveness of space for agriculture

There is a growing body of evidence highlighting the positive economic, social and environmental impacts of space solutions in agriculture. The following section provides an overview of the IPP's approach to expanding this evidence base and highlights examples of where space solutions have resulted in positive change in agriculture in developing countries.

### IPP approach to assessing the impact and cost-effectiveness of space solutions for agriculture

As an ODA[30] funded programme, IPP is required to evaluate and communicate its impact on development challenges around the world. IPP has developed a rigorous Monitoring and Evaluation (M&E) framework using UK Government and OECD[31] best practice. This includes measuring the cost-effectiveness of the space solutions for agriculture, to assess the relative cost of achieving the agricultural impacts relative to alternative, existing methods.

A detailed CEA of all IPP projects, including the agriculture projects, is currently being undertaken and UKSA will publish programme-level results of this analysis in 2019. This report will be updated in 2021 with impact data and CEA data from IPP agriculture projects in Africa, South America and Asia. Central to investment in space solutions for developing countries is that:

Space solutions (specifically EO, although this can be combined with location data from GNSS)[32]provide the least costly method for achieving a series of specified improvements within the agricultural sector (specifically in developing countries) without having any negative impact on the sector or more broadly.

The benefits brought by space-based assets (particularly EO) means that they possess the following strengths relative to alternative methods of data collection (e.g. planes, UAVs[33] or ground-based teams):[34]

30 Official Development Assistance

31 The Organisation for Economic Co-operation and Development

32 Global Navigation Satellite System

33 Unmanned Aerial Vehicles

34 London Economics (forthcoming) 'Value of satellite-derived Earth Observation capabilities to the UK Government'.

- collection of data at regular frequency (temporal resolution)
- collection of data over large areas (scale) and in remote, inaccessible areas
- 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

As a result, satellite-based platforms are suitable for providing the monitoring data that underpin agricultural applications in the developing world – often more cost effectively than other methods.

## Forecasted impacts from IPP agriculture projects

Agriculture is a major sector within the IPP portfolio with six projects with ~£21 million of funding from IPP. Within these projects there are 29 UK space sector and academic institutions supporting 19 international partners (agri-business, government agencies, research agencies, academic institutions, NGOs). These projects are across Latin America (three countries) and Africa (five countries). The projects focus on a wide range of crops including potatoes, grapes, bananas, wheat, sugarcane, coffee, rice and palm oil.

Four of these projects launched in 2017 and two in 2018 and all will conclude by 2021. As such the final results are yet to emerge from the projects, however each project's M&E workstream forecasts out the project impacts. Projects in the IPP portfolio support key (interrelated) actions to tackle hunger and food security by:

**Increasing agricultural productivity** through more accurate and relevant decision support tools and affordable credit products.

- Five IPP projects are looking at improving productivity by providing better quality data and analysis to farmers as advice. This is mainly in the form of decision support tools that will enable farmers to increase productivity, reduce negative environmental impacts, optimise supply chain coordination, monitor regional/national market operation and support crop insurance accuracy.
- Most projects are aiming for modest productivity gains in the 3-5% range (for crops like wheat, sugarcane, grapes, bananas and livestock), for nearly 5,000 farmer/growers in 10 countries. One project is aiming to double yields (by boosting productivity and reducing losses) and double incomes for its 25,000 smallholders.

**Improving efficiency and reducing losses** within supply chains.

- Pests, disease, drought and floods are the main causes of crop losses in agricultural supply chains. IPP projects provide real time risk information and advice on how best to protect their harvest from being susceptible to these supply chain risks, thus limiting losses and improving farmers' ability to feed their own families.

**Improving management of natural resources and inputs** to maximise the sustainable intensification of agriculture.

- Eight IPP projects are engaging in widespread EO to identify the best land, inputs and other resources needed to increase production without increasing the negative environmental costs of agriculture.
- IPP will bring nearly one million hectares of land under sustainable management (EO based) practices to help with land use planning, crop monitoring, input selection and more.

**Improving the accuracy of early warning systems and affordability of insurance** making thousands of farmers more resilient to the effects of climate change.

- Four IPP projects are actively approaching or working with insurance companies to increase the number of farmers insured and/or the affordability of insurance premiums for those smallholders.

Projects are aiming for a range of 5-25% increases in insurance penetration and an average decrease in premiums of 10%.

## Evidence of the impact and cost-effectiveness of space for agriculture

Quantifying and communicating the impact and cost-effectiveness of space solutions within agriculture is crucial to accelerating their adoption. There is an expansive evidence-base supporting the returns on investment arising from general agricultural research, development, and extension across a range of contexts, including in developing countries.

However, for space-based solutions in agriculture, while the identified evidence supports the assessment that they can deliver positive economic, social and environmental impact, the evidence base appears to be more limited.[35]This may be due to a number of factors, including that space-based solutions are an emerging technology.

The identified evidence explores a broad range of space-based technologies, covering differing contexts, methodological approaches and outcomes of interest. There is a body of evidence, for example, that explores the impact of public investment in EO. While this evidence does not always explicitly explore impacts on agriculture, it is helpful in establishing the efficacy of a range of relevant approaches in the management and distribution of EO data.[36]

No public domain literature has been found to specifically show the cost-effectiveness of space solutions for agriculture against other possible agricultural investments, such as ground-based agronomist teams or UAVs for monitoring crops. This is not to state that space solutions are not cost-effective, but that there is limited or no public domain evidence on this topic and this is a critical knowledge gap. Therefore, IPP is investing heavily to build up the evidence for cost-effectiveness.

While the limitations need to be noted, the evidence base identified and reviewed provides a number of important observations that are indicative of the potential impact of space-based technologies. These include cost savings as well as other important economic, social and environmental impacts:

35 A rapid review of the evidence supporting the cost-effectiveness of space-based solutions was conducted in the preparation of this report. Please refer to Annex B for more information on the review's methodology and limitations.

36 Häggquist and Söderholm (2015). 'The economic value of geological information: Synthesis and directions for future research Resources Policy Volume 43' (Pages 91-100). March 2015. Posted at https://core.ac.uk/download/pdf/82368086.pdf. Accessed July 2018.

| Space for agriculture | Evidence of impact in developing countries |
|---|---|
| Decision support tools | EO data has been 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. In India, EO has been used to understand and improve decision-making around optimal sowing dates. Drawing together experimental evidence with EO data, it was estimated that the decision to sow wheat one week earlier on average led to an overall yield gain of 5% nationally.[35]<br><br>At the national level, in India, EO is used to provide in-season crop forecasting in support of strategic decisions surrounding food security. The increases in accuracy of data offered by EO have enabled more targeted and effective government responses to issues such as drought.[36] EO has also provided the basis for decisions concerning a land reclamation project in Uttar Pradesh that sought to improve soil quality. It was estimated that the project led to a 50% increase in family income, and net returns over costs of US$16 million.[37]<br><br>At the supranational level, the European Marine Observation and Data Network (EMODnet) seeks to improve the quality and availability of EO data to both public and private organisations. It estimated that the increased accuracy of EO over in-situ measurements offered planners greater levels of certainty in decision-making. They estimated that a 25% improvement in the accuracy of observations delivered cost savings of €183 million a year.[38] |
| Insurance | EO can also support the development of sustainable financial products and services in areas where there is little or no provision. In Thailand, for example, EO data has been used to develop risk prediction tools that could enable insurers to better manage risk and offer more affordable insurance products that are actuarially sound.[39] |

37 Lobell, David B. & Ortiz-Monasterio, J. Ivan & Sibley, Adam M. & Sohu, V.S., 2013. 'Satellite detection of earlier wheat sowing in India and implications for yield trends'. Agricultural Systems, Elsevier, vol. 115(C), pages 137-143. Posted at https://www.sciencedirect.com/science/article/pii/S0308521X12001400 Accessed July 2018.

38 Jayaraman et al (2008). 'Rejuvenation of agriculture in India: Cost benefits in using EO products.' Posted at https://www.sciencedirect.com/science/article/pii/S009457650700358X?via%3Dihub. Accessed July 2018.

39 Srivastava, 2011. 'Case Study: Harnessing new tools and techniques for making agricultural statistics more efficient and evidence based to support food security policy decisions in India'. Posted at https://wpqr4.adb.org/LotusQuickr/agstat_ap/Main.nsf/h_Toc/B4354BBD9836357D48257DF70038873F/$FILE/Harnessing%20new%20tools%20and%20techniques%20for%20making%20agricultural%20statistics%20more%20efficient%20and%20evidence%20based%20to%20support%20food%20security%20policy%20decisions%20in%20India.pdf. Accessed July 2018.

40 European Commission Maritime Affairs and Fisheries, 2011. 'Legal and socio-economic studies in the field of the Integrated Maritime Policy for the European Union. Study on the economic effects of Maritime Spatial Planning. Final Report'. Posted at: https://ec.europa.eu/maritimeaffairs/sites/maritimeaffairs/files/docs/body/economic_effects_maritime_spatial_planning_en.pdf. Accessed July 2018.

41 Chantarat, Rakwatin & Chutatong Charumilind, 2017. 'Farmers and Pixels: Toward Sustainable Agricultural Finance with Space Technology', PIER Discussion Papers 75, Puey Ungphakorn Institute for Economic Research, revised Oct 2017. Posted at https://www.pier.or.th/wp-content/uploads/2017/10/pier_dp_075.pdf. Accessed July 2018.

| Space for agriculture | Evidence of impact in developing countries |
|---|---|
| Supply-chain optimisation | EO has been applied to a range of supply chain challenges. For individual farms, space-based technologies and EO data has supported the transition towards precision crop management. These efforts broadly seek to reduce inputs, such as water, fertilisers and pesticides, and therefore the overall environmental footprint of farming practices. They ultimately seek to increase outputs including yield and profitability. Although there are many approaches to precision agriculture, there is a growing body of evidence to suggest that certain applications are cost-effective.[40] Much of this research has been undertaken in developed country settings, but due to the higher potential for yield increases in developing countries it is likely that more evidence will unfold to show higher cost effectiveness in developing countries.<br><br>More broadly, resolving issues within the supply chain are an important factor in ensuring food security. EO data can help predict potential problems within the supply chain, both for inputs and outputs. EO provides a range of agroclimatology data for the Famine Early Warning Systems Network,[41] which develops models that seek to provide yield estimates. This enables a range of organisations to plan for extreme events that could disrupt the supply of food. The extent to which such efforts are cost-effective is difficult to determine given the complexity of the social, political and environmental systems that influence food security. |
| Resource management | A key aspect of supply-chain optimisation is the efficient management of resources, or inputs. Recent advances in EO, for example, have markedly improved the sensitivity and accuracy of measurements including evapotranspiration and surface soil moisture. EO represents a cost-effective approach to collecting data for large-scale applications compared with in-situ and airborne acquisitions. This information has been used to improve water management practices through applications such as precision irrigation. Agriculture and Agri-Food Canada, for example, have developed models that incorporate a range of surface soil moisture observations to improve risk monitoring and reporting. Whilst these and other developments show promise in improving resource management, they may need further refinement to be relevant for certain farmers, including smallholders.[42] |
| Early warning systems | A key advantage of EO is the ability to make assessments of a given situation in almost real time and over broad geographic areas. This enables the development of early warning systems that can flag issues relating to agriculture as well as broader society. The Malaria Early Warning System (MEWS), for example, aggregates precipitation estimates with other EO measures to help malaria control planners assess candidate areas for malarial outbreaks. This enables planners to allocate resources more efficiently and effectively. Estimates suggested that the system led to 2.5% annual decrease in malaria cases and 5% in deaths, however the results were statistically insignificant.[43] A World Bank analysis of the benefits of upgrading hydro-meteorological information production and early warning capacity in all developing countries estimated that it could save up to 23,000 lives a year, as well as around US$4 billion a year in preventable asset losses.[44] |

42 Lowenberg-DeBoer, J. (1996). 'Precision Farming and the New Information Technology: Implications for Farm Management, Policy, and Research: Discussion'. American Journal of Agricultural Economics, vol. 78(5), pages 1281–1284.

43 More information is available at: http://www.fews.net

44 Petropoulos et al (2018). 'Earth Observation-Based Operational Estimation of Soil Moisture and Evapotranspiration for Agricultural Crops in Support of Sustainable Water Management'. Posted at http://www.mdpi.com/2071-1050/10/1/181/pdf. Accessed July 2018.

45 Booz Allen Hamilton, 2013. 'Measuring socioeconomic impacts of earth observations – a primer'. NASA, The Earth Science Division, The Applied Sciences Program.

46 Hallegatte, Stephane, 2012. 'A cost effective solution to reduce disaster losses in developing countries: hydro-meteorological services, early warning, and evacuation'. Policy Research Working

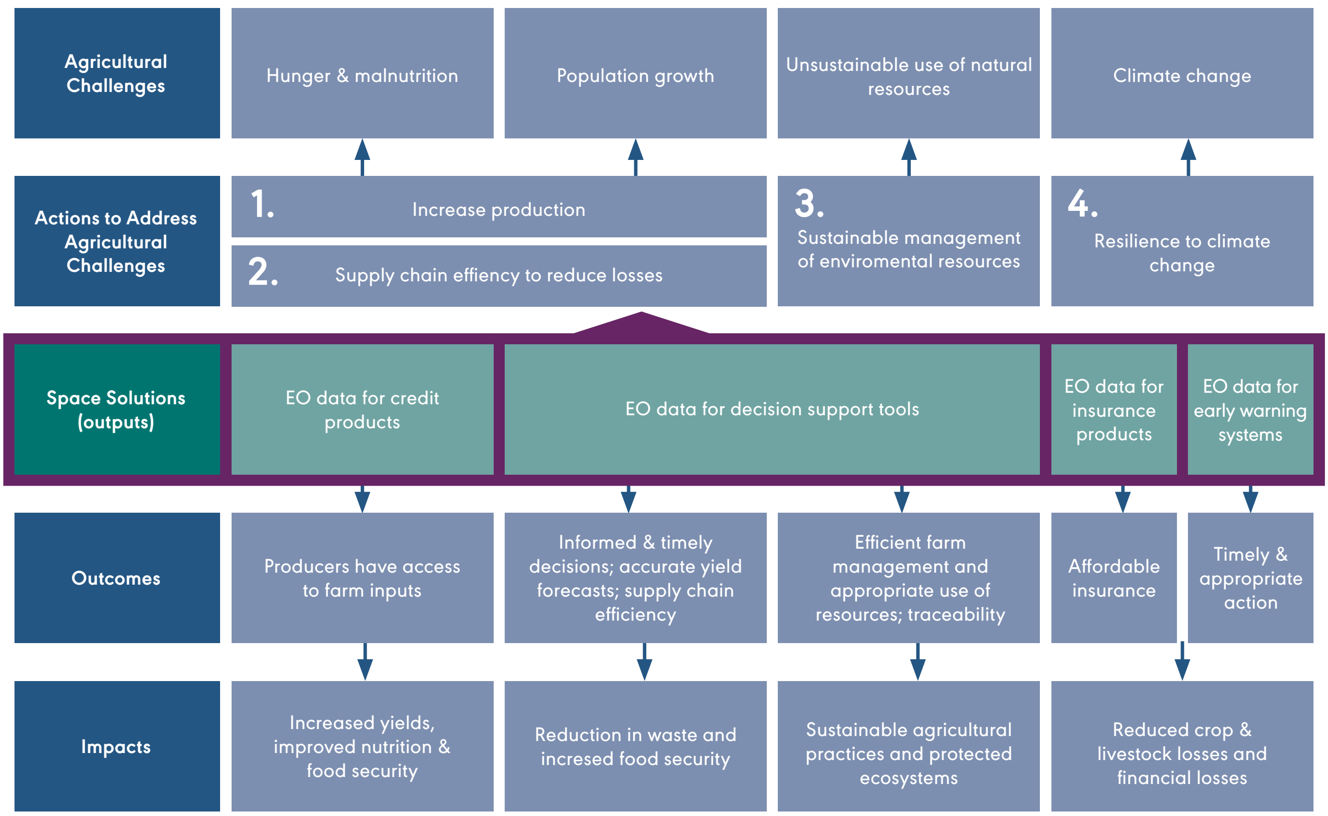
# *Seizing the opportunity*

There is a clear role and opportunity for space solutions to contribute and address some of the major challenges facing the agriculture 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/ business models. These are outlined in this section.

## Space solutions

The space solutions highlighted as outputs in the figure below can be grouped into three thematic areas:

- Decision support tools
- Early warning systems
- Insurance and credit products



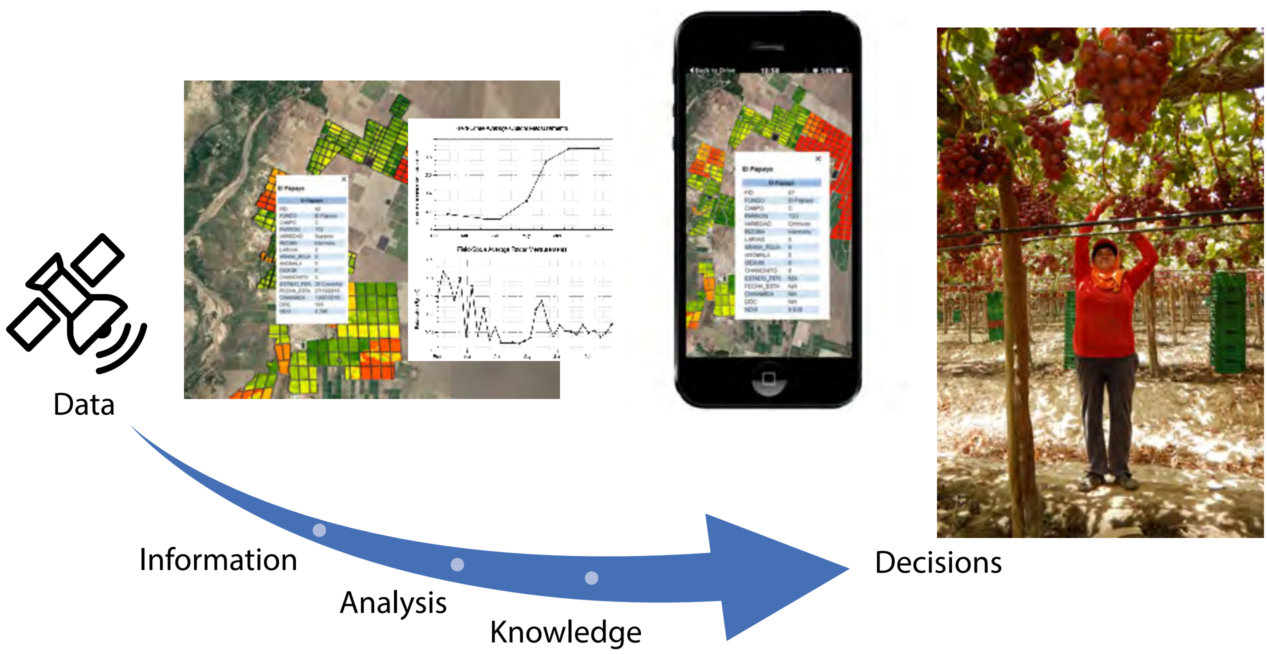
## Decision support tools

To increase production of food in a sustainable way, manage natural resources, use inputs more efficiently, and to optimise supply chains, stakeholders along the agriculture value chain need accurate, relevant and timely information to make informed decisions. EO provides additional data that can support better decision-making along the value chain, from the farm level up to regional and national level.

### Data services for crop monitoring and supply chain efficiency

Data services enable timely measures of crop performance at a field and farm scale to be delivered direct to commercial growers and farm advisory services who support small-scale producers. Measures of crop productivity, crop growth stage and alerts to where there may be problems with plant health can be developed for specific crops from a time series of EO data in the form of field scale crop intelligence. These analytics can be readily accessed by growers using data services. When provided frequently and in such a timely way agronomists and supply chain managers have additional sources of readily useable information during the growing season, which helps with targeting agronomy visits and planning and logistics for harvest and at key stages in the cropping cycle. The evidence generated can be used to demonstrate improved supply chain traceability and audit for buyers, support phytosanitary (plant health) management and membership of certification schemes, many of which support sustainable farming methods. Figure 3 illustrates the way satellite data can bring new information to support decision-making.

Figure 3: Use of satellite data for decision-making for crop production and supply chain management (Environment Systems 2017)



## Models for sustainable management of resources and supply chain traceability

Growers and governments are increasingly recognising that they need tools to enable them to take decisions based on a more informed understanding of the interdependencies in the landscape and the competition for limited resources. Simultaneously, consumers are increasingly aware of the environmental impacts of agriculture and are demanding more visibility into supply chains and their sustainability. Modelled data requires robust and well understood data inputs to ensure that stakeholders can identify with the outputs; this provokes a genuine response from stakeholders and land managers to invest in adapting farming techniques and investing funds to build resilience in the local ecosystems and to enhance agricultural yields while conserving biodiversity.

Many agricultural commodities are grown in developing countries where governments may lack the ability to track and monitor the effects on the environment. For example, palm oil is a widely used commodity, present in more than half of all packaged goods and has been linked to deforestation in some regions.[48] As a response to malpractices reported in the sector, RSPO was created to improve sustainability of the palm oil supply chain, ensuring that palm is produced without causing harm to the environment or society. A key step to achieve RSPO certification is the LUCA (Land Use Change Assessments) analysis to determine changes to vegetation and ensure no primary forests have been destroyed, and this assessment is evidenced by EO. Other steps in the certification process that can be supported by EO are the HVC (High Value Conservation) assessment and GHG (Green House Gas) assessment. RSPO Next[49] was recently launched for RSPO members that want to up their sustainable credentials. RSPO Next certification carries zero deforestation, no use of peat and no fire commitments.

## Monitoring and verification for subsidy programmes and food security

EO enables accurate and timely crop mapping and monitoring of land use at regional to national scales – this data, when combined with other on-ground data sources, can be used to underpin the evidence base for payment of farm subsidies by assisting audit checks. EO provides a well-established operational data input for evidencing the correct distribution of public funds to growers[47] and is useful for government subsidy programmes. EO can also be used to estimate cropped areas and forecast the predicted yields in specific regions, giving governments better knowledge and understanding on national food production and enabling more informed decisions to ensure food security. Finally, initiatives promoting the building or rehabilitation of assets that will improve long-term food security and resilience can be monitored in near real time and the impacts in the long term can be evaluated by EO techniques.

---

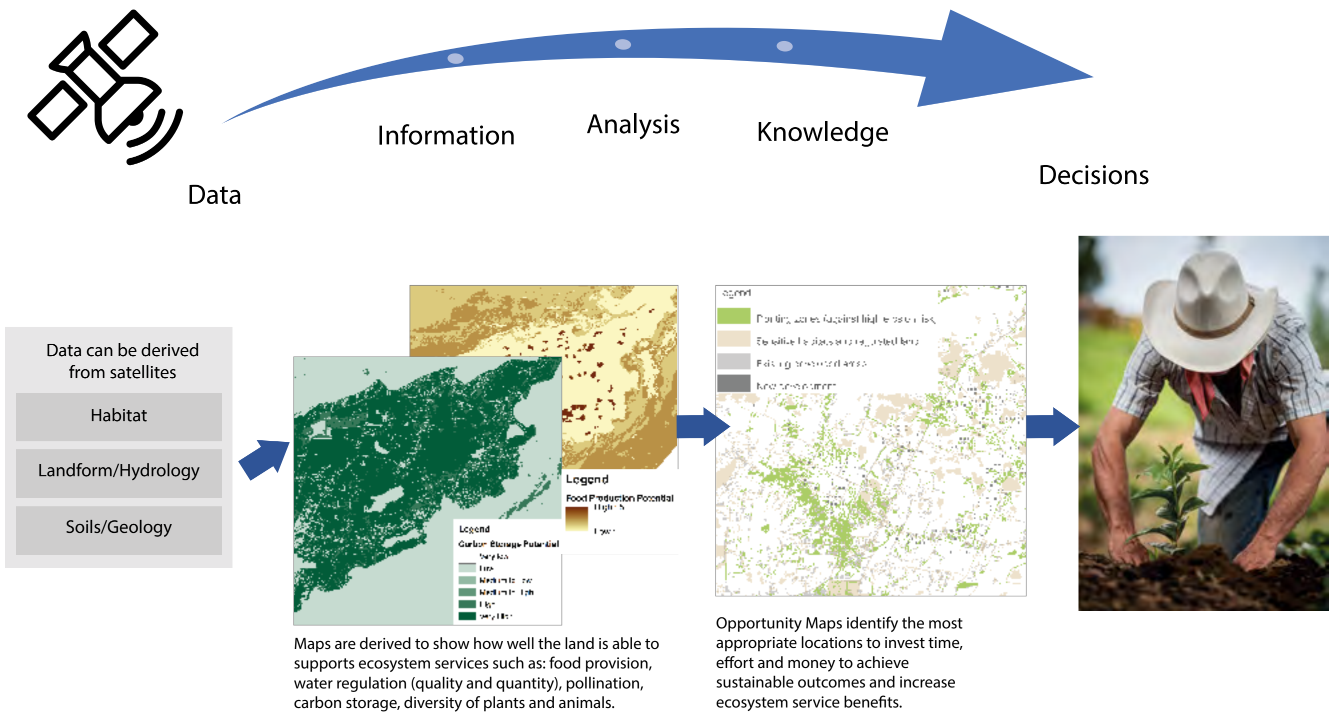
47 European Commission EU Science Hub. 'Agricultural Monitoring'. Posted at https://ec.europa.eu/jrc/en/research-topic/agricultural-monitoring. Accessed July 2018.

48 The Guardian. 'It's up to us: why business needs to take a stand on palm oil'. Posted at https://www.theguardian.com/sustainable-business/2017/jun/26/palm-oil-business-consumers-sustainability-indonesia-leuser-mondelez-marks-spencer-lush. Accessed July 2018

49 Roundtable on Sustainable Palm Oil. Website: https://rspo.org/certification/rspo-next. Accessed July 2018.

In terms of resource management, consistently captured data for regional scale modelling may not be available in developing countries, or may be difficult to obtain, difficult to understand or out of date. The use of EO satellite data provides an opportunity to look across the landscape incorporating the agricultural zones as well as natural and abandoned land that is part of the present ecosystem. By using EO data to generate information about habitats, landform and land management, it is possible to produce mapped outputs of how well land supports a range of different ecosystems services. These maps can be readily understood by decision makers both in terms of investment and when actually farming the land. It is often the case that more than one ecosystem service is being delivered, for example forests can provide water quality improvements and reduce flood risk. The maps can be used at a strategic level, providing not only a snapshot of the state of existing natural assets, but informing decision-making for future development, both in terms of risks and opportunities to achieve sustainable intensification, where productive agriculture conserves and enhances natural resources.

Figure 4: Use of satellite data for decision-making for sustainable management of resources using the SENCE[50] approach (Environment Systems 2017)




50 SENCE – Spatial Evidence for Natural Capital Evaluation uses multiple datasets and scientific knowledge to model ecosystem services and produce maps and data.

It is worth noting that very high resolution EO data is required for ecosystem services mapping at sub-national level and such imagery is available from commercial sources, which may not be affordable for developing countries. Partnership models can be developed to enable developing countries to better access this data.

### Models for increasing production

EO makes it possible to understand what is growing where and to monitor crops at scale and consistently collect high-quality data on crop performance such as crop canopy measurements of leaf area index (LAI)[51] and normalised difference vegetation index (NDVI).[52] This data, when combined with ground data such as planting date and seed variety, can be used to estimate crop yields. It is then possible to use these datasets (the crop yield estimates) to analyse farm productivity against farm management practices such as crop rotation, and understand the impact of the farm management practices on yield. This analysis can benefit individual farmers who can assess the impact of their specific farm management practices, as well as regional bodies who can monitor yield differences across a large area.

When the impact of farm management practices is monitored across a large area it is possible to build models that can help individual farmers make fundamental farming decisions such as which crop to cultivate in a specific location to achieve the optimal yield in a sustainable way, or how much fertiliser or plant protection to use and where. EO data can improve the accuracy of decision support tools but the importance of on-ground data and the challenges of collecting and accessing this data in developing countries, should not be underestimated.

## Early warning systems

Many developing countries lack the data to accurately predict pest and disease outbreaks or the occurrence of extreme weather events including drought and flooding. EO provides data to monitor the environmental factors associated with the onset of such events and allow countries to build early warning systems to forecast these events allowing them to take mitigating action to prevent or reduce losses.

### Models for predicting pest outbreaks

In the case of pest outbreaks, a range of satellite data at different scales can be used to provide pest risk models with environmental information they need, including data on temperature, humidity and wind, which are the environmental factors that drive the growth, spread and mortality of a pest population. This environmental data must be combined with data collected from the field as well as weather data. Effective modelling on a countrywide scale requires data that accurately represents local weather conditions for agricultural zones. To meet these needs, meteorological data from satellite technology such as Meteosat SEVIRI, Terra/Aqua MODIS and Sentinel-3 SLSTR can be used to drive pest risk models. The models are designed to create an alert when the environmental conditions are favourable for a pest outbreak.

### Early warning for drought and flood

In the case of drought and flood early warning, EO enables near real-time monitoring of environmental conditions across large areas of land, which is necessary in order to create accurate and timely information for decision makers. EO provides large-scale and high-quality data on vegetation cover and rainfall estimate which can be used alone or combined with ground-based data from other sources, such as weather stations and river gauges, to provide more accurate assessment and forecasts of drought or flooding.[53] In this context drought and flood risk monitoring systems can include artificial intelligence and workflows or tools for citizen data sharing using mobile apps. Early warning

51 Leaf area index (LAI) represents the amount of leaf material in an ecosystem and is geometrically defined as the total one-sided area of photosynthetic tissue per unit ground surface area. Source: FAO. Posted at http://www.fao.org/tempref/docrep/fao/011/i0197e/i0197e15.pdf. Accessed July 2018.

52 Normalized Difference Vegetation Index (NDVI) quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). Source: GIS Geography. Posted at http://gisgeography.com/ndvi-normalized-difference-vegetation-index/. Accessed July 2018.

53 See Appendix A for an example in Mexico with the COMPASS project.

systems for drought and flooding enable governments to adjust their food security and natural disaster plans and ensure enough food is imported or moved from different regions of the country to make up for losses suffered and putting in place emergency plans.

## Insurance and credit products

EO enables accurate mapping of land use and monitoring of changes in crops and the land itself. This data is useful for finance companies that need access to data concerning land used by growers in order to be able to offer them financial products such as insurance or credit. For many small-scale producers in developing countries, these financial products are prohibitively expensive, not designed for their needs, or simply not available at all.

### Improved accuracy of index-based insurance products

In the case of insurance, the high cost of traditional insurance products is partly due to the challenges insurance companies face in collecting the required data to calculate an insurance premium, and the cost of assessing individual farms and losses when claims are made. For many insurance companies it does not make business sense to offer insurance products to small-scale producers due to these costs of assessing individual losses, which is difficult and expensive, as well as open to fraud. With access to a range of types of EO data and derived products, insurance companies can develop index-based insurance products to compensate farmers for their loss, based on an assessment of the severity of the drought in the region, for example. With EO data, insurance companies can track vegetation coverage across a region or identify areas where yields are low and use this data to trigger payouts in agriculture and pastoral insurance schemes. They can check whether a particular field was affected by a flood or storm event that has resulted in the destruction of crops. When on-ground verification is still required, EO data also helps companies to efficiently target where they need to send staff to make assessments before making a payout.

In addition, solutions that help farmers to log their field activities can increase their access to reduced premiums because insurance companies are able to see evidence of better farm management practices that help to reduce the likelihood of loss.[54]

### Models for credit products

EO can be used by finance companies to generate new data that is useful for assessing the credit worthiness of a small-scale producer. By developing algorithms that estimate features such as farm size, farm production or size of a farmer's house based on EO and incorporating these features into alternative credit scoring methods, finance companies can gain a greater understanding of small-scale producers and reduce risk. One of the key benefits of using EO is the reduced cost of data collection compared to collecting data on multiple farms by foot and the ability to estimate historical data about a farm based on EO archives.

54 A good example of this is the Food and Agriculture's global Agricultural Stress Index System (ASIS). For more information see: http://www.fao.org/3/a-i5246e.pdf

## Economic sustainability models and industry trends

Space solutions in the agricultural sector require a sustainability model that will ensure continuity of the project beyond the initial funding to set up the project, wherever that may come from. Stakeholders need to identify sufficient revenue streams to cover operational costs in the long term, thereby ensuring the continuation of the solution and the positive impact in country. A range of sustainability models is possible, including commercial revenues, government investment/revenue, and donor funding.

**Commercial revenue:** Organisations including commercial agribusinesses (buyers, growers, input companies) and large farmer groups in developing countries are key beneficiaries of space solutions and are well placed to purchase a space solution that benefits their business. This business-to-business (B2B) model is common among agriculture projects within IPP[55] and offers a potential route to commercial sustainability.

Revenue from direct sales of space solutions to farmers is more common in developed countries where large, commercial growers can afford to purchase tailor-made solutions. In developing countries, the business to consumer (B2C) model – selling direct to small-scale producers – is not yet feasible as costs of procuring, processing, storing and analysing data are prohibitive for small-scale producers.

A 'freemium' sustainability model allows providers to offer some elements of the product or service for free while other elements are charged at a premium. For example, donor funding could be used to develop a solution that is freely available to small-scale producers in developing countries, while larger agribusiness and customers in developed countries pay a premium for the solution. Another example is where grower federations or advisory services pay for the solution on behalf of a large number of growers and then add value themselves to the information before sharing the crop intelligence with the growers.

55 See Appendix A for more information on the IPP projects. For information on open data in EO see GEO

**Government investment/revenue:** As a primary user of space solutions in agriculture, government bodies such as the Ministry of Agriculture are often a source of funding. Business to government (B2G) is a common sustainability model in the IPP agriculture projects. Government bodies have a clear need for such solutions to aid with food production planning and food security overall, insurance products, as well as decision support tools for the farmers and agriculture sector in their country.

In this scenario, the revenue required would come from government paying a fee for access to the solution outputs (e.g. pest risk assessment) 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.

**Donor funding:** Many space solutions developed for agriculture 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.

As the space sector continues to advance and increase its influence in developing countries, some trends and alternative business models are emerging. Designing and building, or adapting an existing space solution for agriculture for a particular geography or agriculture value chain requires significant investment, resources, and skills at the outset. Once set up, these solutions can be more easily adapted for different geographies and different crops. This can allow agriculture solution providers to scale up quickly and achieve operational sustainability.

Secondly, global trends around open data and making EO data freely accessible to all[56] are influencing business models. Agriculture organisations interested in the opportunity for space solutions will benefit from open data policies in agriculture 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.

Different business models are also emerging among private organisations in the space sector such as Earth-i and Planet who are redefining the way satellites are built and drastically reducing the cost. Earth-i is working with UK company Surrey Satellite Technology (SSTL) on the first constellation in the world able to provide full-colour video – and the first European-owned constellation able to provide both video and still images.[57] In general, full colour video offers the ability to more accurately survey activities on the ground and how they change over time, including industrial and agricultural infrastructure. It can also provide specific information to agricultural modelling such as accurate elevation maps of terrain and the three dimensional canopy structure of vegetation. Research is underway into the correlation of these 3D and time varying variables to factors such as crop yield and crop type. Organisations like Planet are able to offer data that is frequently updated across a wide geography and at resolutions relevant for smallholder farming. However, the volume of data generated by these organisations also significantly increases the importance of complex processing and requirement for increased computational power. Further information is provided on these and other organisations in the following section.

56 For more information on open data in agriculture see GODAN (Global Open Data in Agriculture and Nutrition) http://www.godan.info and for more information on open data in EO see GEO (Group on Earth Observations) https://www.earthobservations.org/open_eo_data.php

57 Earth-i . 'Earth-i Orders Satellites from SSTL for World's First Full-Colour Video Constellation'. Posted at: http://earthi.space/press/earth-i-orders-satellites-worlds-first-full-colour-video-constellation/. Accessed July 2018.

# Additional information and guidance

The preceding chapters of this report highlight the opportunity for space solutions to bring benefits to agriculture, as well as the different business models being tested. In order to realise the opportunity for using satellite data in agriculture, it is necessary to partner with organisations that have the required expertise, skill and infrastructure. This chapter provides 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

Data from EO satellites 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 from other sources such as sunlight. Examples of passive sensor include instruments and cameras that can detect visible wavelengths, infra-red and thermal (for surface temperatures), and microwave wavelengths (for surface roughness, soil moisture and salinity).

Active sensors both emit and receive signals and include radars such as synthetic aperture radar (SAR), scatterometers, radar altimeters and sonar. Another active sensor, Light Detection and Ranging (LIDAR), is also commonly used from aerial platforms and compliments satellite observations.

EO solutions are dependent on the satellite input data used, the other data they are combined with and the analytics applied to it all. The satellite input data vary in terms of spectral, spatial and temporal resolutions and it is important when choosing a source of satellite data, to consider the characteristics of the features to be examined.

### Spectral resolution

EO sensors use the electromagnetic spectrum (Figure 5) 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 e.g. land cover as there is more information and therefore more discriminating power in the image.

#### Optical sensors

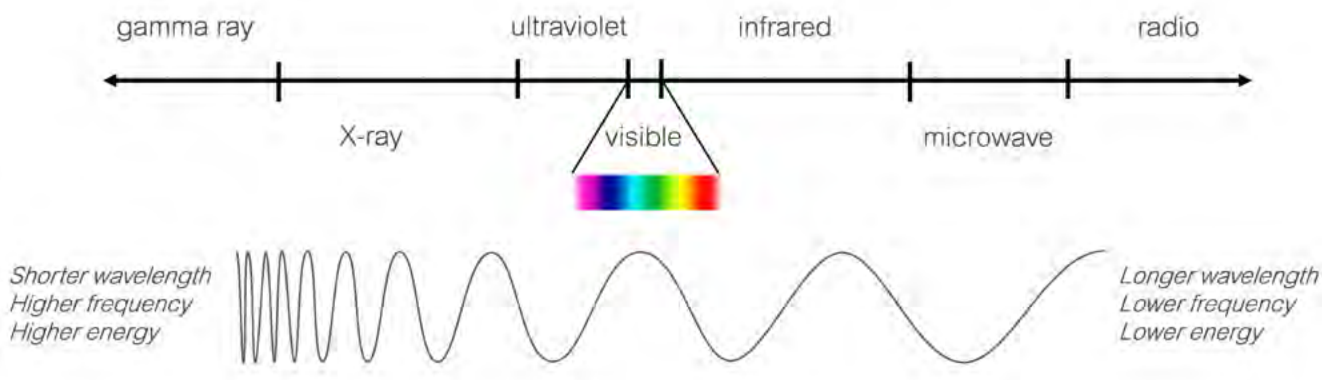
Multi-spectral satellites are common in EO (often referred to as optical satellites) providing images of the Earth's surface and atmosphere captured in the visible and infrared portion of the electromagnetic spectrum. They have a broad set of applications including agriculture, land-cover mapping, damage assessment associated with natural hazards and urban planning, but are limited to cloud-free conditions and daytime operation.[58] Optical data

58 European Space Agency. 'Optical Missions'. Posted at http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Optical_missions. Accessed July 2018.

are easier to process and understand are therefore a more easily transferable technology.

Multi-spectral sensors generally capture information from around 3-16 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 see the unseen; the many characteristics of the land surface that the human eye cannot see. However, having so many bands increases the complexity of data quality management and handling. In addition, the cost of acquiring hyperspectral images (airborne) is relatively high and is therefore better suited to smaller scale, targeted surveys.

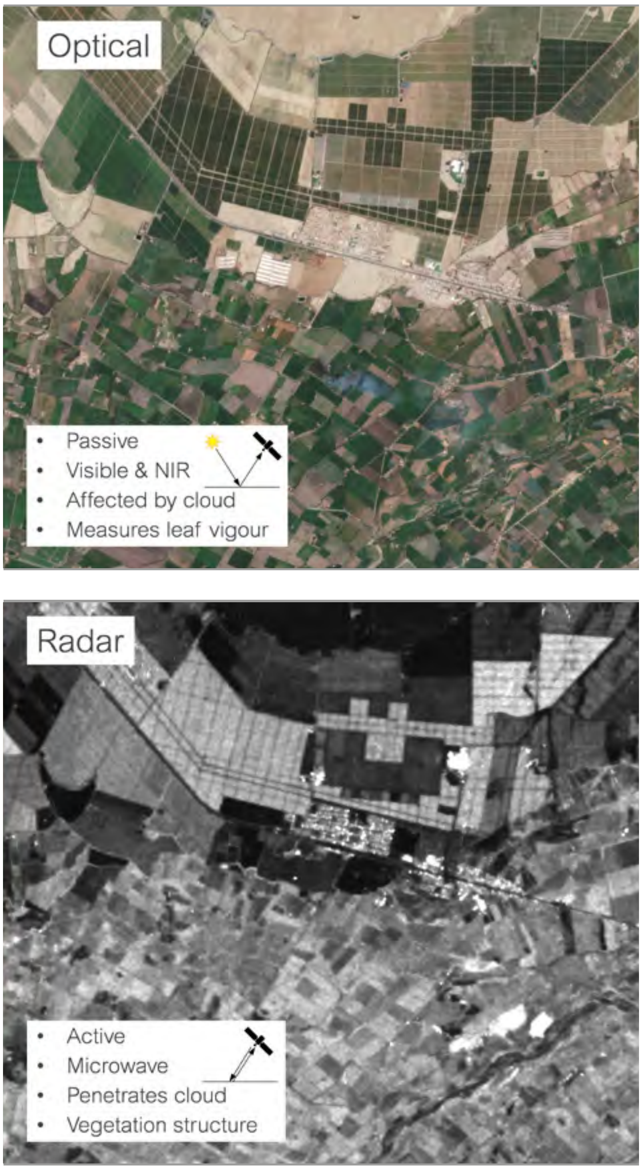
Figure 5: The electromagnetic spectrum



### Synthetic Aperture Radar (SAR)

SAR is an active system that transmits a beam of radiation in the microwave region of the electromagnetic spectrum. The data captured reveals information about the structural characteristics of the Earth's surface. This has many applications including monitoring growth and change in crop and vegetation cover. Radar complements optical data because it can provide additional information about the timing of agricultural operations extracted from certain optical sensors (cultivation, harvesting) which can be interpreted alongside data from optical sensors and to deduce the likely crop present.

Figure 6: The differences between optical and radar satellites




### Light Detection and Ranging (LIDAR)

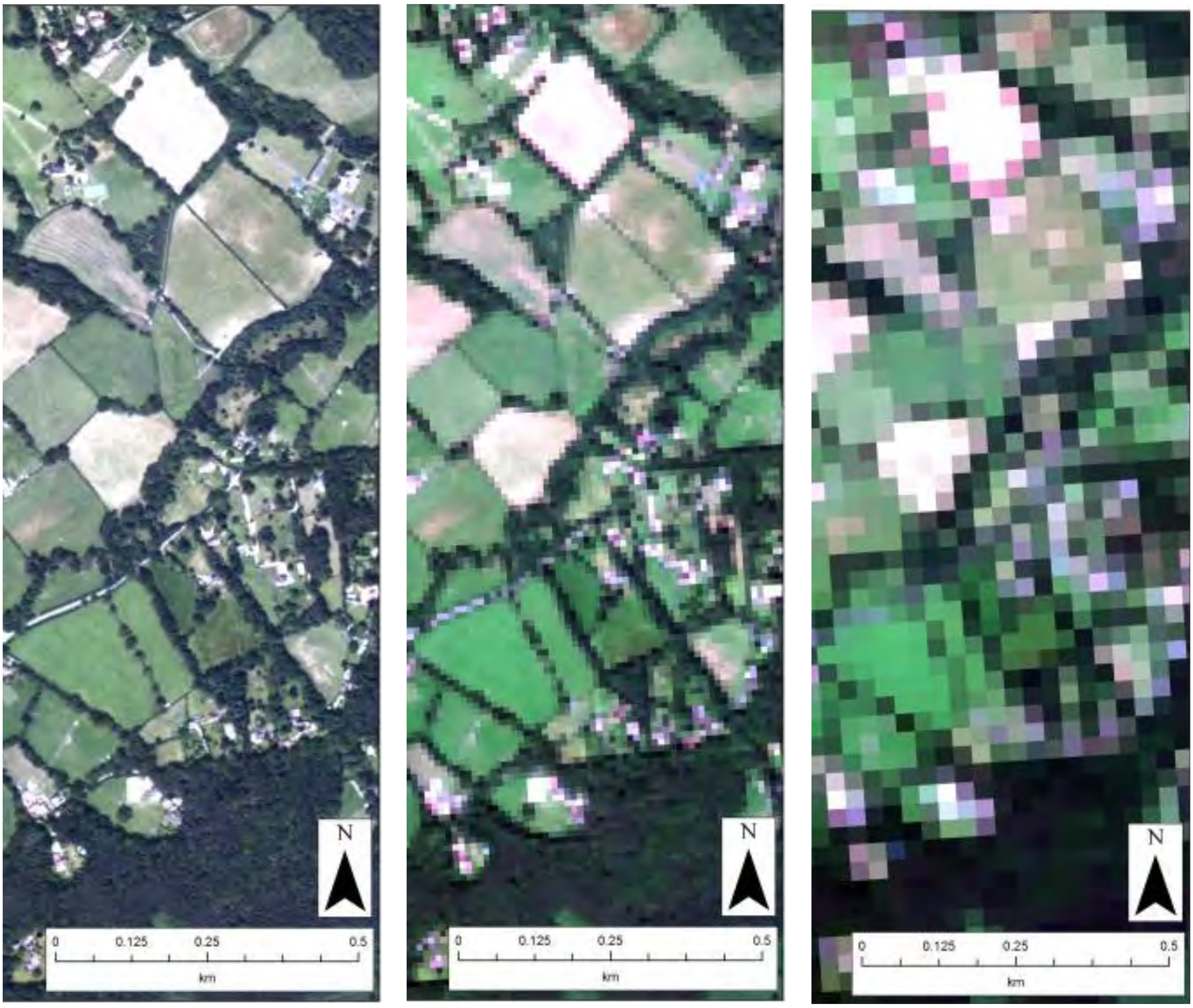
LIDAR is a surveying method that measures distance to a target by illuminating that target with a pulsed laser light, and measuring the reflected pulses with a sensor. Differences in laser return times and wavelengths can then be used to make digital 3D-representations of the target. LIDAR overcomes issues such as low cloud cover, rough terrain and can penetrate forest canopies. However, at present LIDAR does not have sufficient range to be mounted on satellites and is instead used with airborne platforms e.g. planes and unmanned aerial vehicles (UAVs) which limits the geographic coverage.

## 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 (Figure 7). Typically, a higher spatial resolution means a smaller image extent (the area covered by a single image). When discussing the resolution of imagery i this report the following terminology is used:

| Abbreviation | Image resolution (metres) |
|---|---|
| LR (low resolution) | 20+ |
| MR (medium resolution) | 10-20 |
| HR (high resolution) | 5-10 |
| VHR (very high resolution) | 1-5 |
| AP (aerial photography) | 0.3-0.5 |

Figure 7: Representation of a WorldView-2 image (VHR, 1.84m2 pixels), Sentinel-2 image (HR, 10 m2 pixels) and a Landsat 8 image (LR, 30m2 pixels) for the same area




## Temporal resolution

Temporal resolution is related to the repeat frequency with which a system can acquire images of the same location. 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, e.g. the weather independent availability of Sentinel-1 SAR provides, to give ultra-high tempo data as the basis for analytics.

## Image analysis

To extract useful information from satellite imagery there are generally two main approaches. The first is a statistical analysis of the image values of pixels in the image, or groups of pixels that are identified as objects (e.g. within a field). This can in many cases be performed using software that is not specifically designed for remote sensing purposes. Applying artificial intelligence to analyse images (e.g. machine learning algorithms) is an increasingly common approach. Another form of statistical analysis involves using a rule-based approach.

Alternatively, a visual interpretation can be used; this can work well for a small number of images over a small area, but the scaling value of satellite analytics is lost.

## Sourcing Earth observation data

Satellites are one of the most extensive forms of 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.[59]

There are numerous sources of EO data that can be accessed for use in the agriculture sector. The Food and Agriculture Organisation (FAO) has created an extensive list of EO/remote sensing portals, tools, data and products that can be used to improve crop monitoring. These data sources can be accessed for space solutions in agriculture including early warning systems, decision support tools and insurance and credit products. The list of data sources compiled by the FAO is included in Table 1 and 2 below, with some additional data sources added. It is recommended that readers also consult the full report, 'Review of the available remote sensing tools, products, methodologies and data to improve crop production forecasts',[60] for a full understanding of available EO data for use in agriculture.

59 The Parliamentary Office of Science and Technology. 'Environmental Earth Observation.' Posted at: http://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-PN-0566#fullreport. Accessed July 2018.

60 Food and Agriculture Organisation (FAO). 'Review of the available remote sensing tools, products, methodologies and data to improve crop production forecasts'. Posted at http://www.fao.org/3/a-i7569e.pdf. Accessed July 2018.

Table 1: List of freely available remote sensing portals, tools, data and products

Several freely available remote sensing portals (geoportals), tools, data and products currently exist to serve the need for agricultural crop production and forecasting demands. These include but are not limited to those listed in the table below.

| Source | Description (from organisation website) | Link to access data |
|---|---|---|
| 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, starting from the In-Orbit Commissioning Review (IOCR). | 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 |
| European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) data portal | 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 data sets on key indicators of interest including faPAR, Fractional Vegetation Cover (FVC), LAI, Land Surface Albedo, Surface Soil Moisture, active re monitoring product, Daily Evapotranspiration (ET), Fire Risk Map (FRM), LST, and Burnt Area products. | https://www.eumetsat.int/website/home/Data/index.html |
| Group on Earth Observations' Global Agricultural Monitoring Initiative (GEOGLAM) | GEOGLAM is the Group on Earth Observations' Global Agricultural Monitoring Initiative. It strengthens global agricultural monitoring by improving the use of remote sensing tools for crop production projections and weather forecasting. GEOGLAM provides co-ordinated Earth observations from satellites and integrates them with ground-based and other in-situ measurements. The initiative contributes to generating reliable, accurate, timely and sustained crop monitoring information and yield forecasts. | http://www.geoglam.org/index.php/en/ |
| The Global Information and Early Warning System on Food and Agriculture (GIEWS) Earth observation portal | The Global Information and Early Warning System on Food and Agriculture (GIEWS) continuously monitors food supply and demand and other key indicators for assessing the overall food security situation in all countries of the world. It issues regular analytical and objective reports on prevailing conditions and provides early warnings of impending food crises at country or regional level. | http://www.fao.org/giews/en/ |
| U.S. Geological Survey (USGS) Famine Early Warning Systems Network (FEWS NET) data portal | The USGS FEWS NET data portal provides access to software tools, geospatial data, satellite image products, and derived data products in support of FEWS NET drought monitoring efforts throughout the world.<br><br>The Africa data portal provides remote sensing and modelled geospatial data and information for monitoring agrometeorological conditions throughout Africa. | https://earlywarning.usgs.gov/fews |
| VEGETATION/ Proba-V Data Portals | The VEGETATION programme, developed jointly by France, the European Commission, Belgium, Italy and Sweden, provides accurate measurements of basic characteristics of vegetation canopies on an operational basis to support scientific studies (e.g. regional and global scale experiments over long time periods that develop models of biosphere dynamics interacting with climate models) or systems designed to monitor important vegetation resources (e.g. crops, pastures and forests). | http://proba-v.vgt.vito.be/en |
| Radiant.Earth | Radiant.Earth provides open access to geospatial data for positive impact. Radiant.Earth exposes imagery across the globe, date and spectrum and it provides technology and tools for global development practitioners to analyse geospatial data. It works with the community to create new, open standards and it focuses thought leadership, market analytics and capacity development programmes. | https://www.radiant.earth |

Table 2: List of remote sensing portals, tools, data and products available for a fee

EO data portals provide commercial data useful for agricultural crop production and forecasting. The following list is not exhaustive but provides a flavour of what is currently available.

| Source | Description (from organisation website) | Link to access data |
|---|---|---|
| Airbus Defence and Space | Airbus Defence and Space offers various optical and SAR imagery that supports agricultural applications, including crop acreage, and other biophysical parameters that can support crop yield forecasting. The suite of satellite imagery includes SPOT, Pleiades, and TerraSAR. | https://www.intelligence-airbusds.com/en/11-products-services |
| DigitalGlobe imagery | DigitalGlobe offers optical imagery and leverages its high-resolution multispectral satellites to provide Red-Edge detection. | https://www.digitalglobe.com |
| DMCii | Disaster Monitoring Constellation for International Imaging (DMCii) delivers high-resolution Earth imaging services from co-ordinated satellites of the international DMC Constellation. | http://www.dmcii.com |
| Earth-i | Earth-i is developing the world's first commercial full-colour, full-motion satellites, ultimately raising revisit rates to several times a day, and delivering near real-time video and still images from space.<br><br>Earth-i currently operates an interactive portal with over 170,000 images including from the DMC3/TripleSat Constellation and the KOMPSAT series of optical and radar satellites. | http://earthi.space/image-data/ |
| Planet | Planet is working towards imaging the whole Earth everyday with optical satellite data. They have a number of constellations in space including the Doves based on cubesat technology (3-5m), Rapid Eye that includes Red-Edge band (5m) and TerraBella/SkySat (video).<br><br>Planet data is used in a wide range of applications, including agriculture. | https://www.planet.com/ |

## Processing and analysing Earth observation data

The software tools for processing and analysing satellite data include GIS and image processing software. This software includes specialised tools that correct and adjust images to improve location accuracy and provide the ability to identify features on the map. To automate these processes, these systems use algorithms and functions to extract information from the image. There are four phases to extract information from imagery:

**Acquisition of raw data:** 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 feature(s) of interest.

**Conversion of raw data into analysis ready format:** This process can include, but is not limited to, orthorectification, georeferencing and radiometric/atmospheric corrections.[61] [62] [63] 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.

61 Orthorectification: The process of correcting the geometry of an image so that it appears as though each pixel were acquired from directly overhead. Orthorectification uses elevation data to correct terrain distortion in aerial or satellite imagery Source: https://support.esri.com/en/other-resources/gis-dictionary/browse/o

62 Georeferencing: aligning geographic data to a known co-ordinate system so it can be viewed, queried, and analysed with other geographic data. Source: https://support.esri.com/en/other-resources/gis-dictionary/browse/g

63 Radiometric correction: Procedures that correct or calibrate aberrations in data values due to specific distortions from such things as atmosphere effects (such as haze) or instrumentation errors (such as striping) in remotely sensed data. Source: https://support.esri.com/en/other-resources/gis-dictionary/browse/r

**Analysis of the data:** This is a diverse phase that can include manual interpretation (e.g. a human interpretation of the imagery), automated interpretation (e.g. through using algorithms to quantitatively analyse the features of interest), delineating their spatial location, extent and, in some cases, extraction of ancillary information about the objects. EO big data and cloud computing can greatly benefit from artificial intelligence and, more specifically, machine learning algorithms as these can analyse terabytes of data and discover hidden patterns and hence make very accurate predictions which become more accurate as more data is fed to the algorithm. Things to consider here include types of features to be mapped, extent to map, availability of technology and skills.

**Validation of the outputs:** This involves assessing the validity of the results either by comparing with known values or using reference data (e.g. field observations to compare with the outputs from the image analysis). Things to consider here include the expertise to understand expected values and the logistics and costs involved when collecting reference 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. There are a number of options available to end-users to overcome this. For example, the European Union's Copernicus programme recently launched the Copernicus Data and Information Access Services (DIAS)[64] 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.[65] In addition to this, there are operational commercial services that are providing cloud-based access to analysis-ready and value-added data specifically targeted at the agricultural sector.[66]

## Sourcing Earth observation expertise

Currently, the use of space technology and data in agriculture is complex and requires significant skill, capability and computing infrastructure. Considerable skills and capabilities are required in the fields of software engineering, GIS, machine learning and user interface design to convert the EO data into a decision support system. Computing infrastructure is required including significant data storage capacity, internet bandwidth and processing power.

Therefore, organisations active in agriculture, such as private sector agribusinesses, government bodies, donors and NGOs, will need to source specialist expertise to support them to apply EO data. Table 3 lists some organisations that are part of the UKSA's IPP with the required skills and experience working with EO in agriculture. This list is not intended to be exhaustive as there are many other organisations with experience in this sector.

64 European Space Agency Website: http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Accessing_Copernicus_data_made_easier. Accessed July 2018.

65 ibid.

66 Environment Systems Data Services: http://www.envsys.co.uk/data-services/. Accessed July 2018.

Table 3: List of EO expert organisations in agriculture in UKSA IPP

| Company | Description (from organisation website) |
|---|---|
| Assimila Limited | Assimila is a consultancy company focusing on bringing the benefits of advanced science and technology, particularly EO, to government and commercial clients seeking to monitor, understand, and predict the environment. |
| Deimos Space UK | Deimos Space UK was created in 2013 to address the UK and UK-export market for space systems, services and applications. The company offers expertise in flight systems, ground segment systems, space situational awareness, satellite navigation, applications and services. The knowledge of satellites, data systems and location-based services puts the company in a unique position when developing satellite applications. |
| Earth-i | Earth-i supplies high-resolution image data services from the DMC3/TripleSat Constellation and the KOMPSAT series of satellites to clients across the globe. Their range of services, from data processing to analytics, help the policy makers and innovators of today take more effective decisions, more rapidly. |
| Environment Systems | Environment Systems is an environmental and agricultural data company and a trusted provider of evidence and insight to governments and industry across the world. The consultancy delivers bespoke advice and solutions for land management, monitoring and policy. The data services deliver always-on, accessible data insights from satellite EO. |
| Rothamsted Research | Rothamsted Research is a world-leading, non-profit research centre that focuses on strategic agricultural science to the benefit of farmers and society worldwide. |
| Rezatec Limited | Rezatec is the leading specialist geospatial data analytics company providing valuable and actionable landscape intelligence as a critical decision support tool to help drive the smart management of land-based assets. |
| RHEATECH | RHEATECH is a wholly owned subsidiary of the RHEA Group of companies. RHEATECH provides systems engineering, security and software solutions, and on-site engineering support to its customers. Key activities include Mission Operations preparation tools, Solar Orbiter operations preparation and AIV support, Concurrent Design and Engineering, Space Weather, and Cyber Security for NATO and ESA. |
| Pixalytics Ltd (UK) | Pixalytics is an independent consultancy company specialising in EO. Pixalytics combines cutting-edge scientific knowledge with satellite and airborne data to provide answers to questions about our planet's resources and behaviour. |

## International organisations

Intergovernmental organisations (IGO)[67] and international non-governmental organisations (INGO)[68] have an important role in the use of EO for agriculture. These organisations have significant knowledge, influence on regulation and policy, networks and funding opportunities within their respective mandates.

67 Wikipedia. 'Intergovernmental organisation'. Posted at https://en.wikipedia.org/wiki/Intergovernmental_organization. Accessed July 2018.

68 Wikipedia. 'International non-governmental organization'. Posted at https://en.wikipedia.org/wiki/International_non-governmental_organization. Accessed July 2018.

Table 4: International organisations supporting space solutions for agriculture

| Company | Description (from organisation website) |
|---|---|
| Committee on Earth Observation Satellites (CEOS)[65] | CEOS ensures international co-ordination of civil space-based EO programmes and promotes exchange of data to optimize societal benefit and inform decision-making for securing a prosperous and sustainable future for humankind.<br><br>CEOS has several working groups[66] that address topics such as calibration/validation, data portals, capacity building, disaster management, climate, and common data processing standards shared across a wide range of EO domains. CEOS also has data and tools[67] available on their website. |
| European Space Agency (ESA)[68] | Led by the European Commission and supported by ESA, Copernicus is the largest environmental monitoring programme in the world. It provides a unified system through which a myriad of data are fed into a range of thematic information services designed to benefit the environment, the way we live, humanitarian needs and support effective policy-making for a more sustainable future. Copernicus is free and open to all worldwide.<br><br>ESA's EO4SD (Agriculture and Rural Development Cluster project) demonstrates the benefits of EO-based geo-information products and services to support agricultural monitoring and management tasks, development bank programmes and projects that deal with land degradation, soil erosion, food security and irrigation systems management. |
| Group on Earth Observations (GEO)[69] | GEO is an IGO working to improve the availability, access and use of EO for the benefit of society.<br><br>GEOGLAM is the GEO Global Agricultural Monitoring Initiative. Launched in 2011, GEOGLAM will strengthen global agricultural monitoring by improving the use of remote sensing tools for crop production projections and weather forecasting. |
| SERVIR[70] | A joint development initiative of NASA and United States Agency for International Development (USAID), SERVIR works in partnership with leading regional organisations world wide to help developing countries use information provided by Earth observing satellites and geospatial technologies for managing climate risks and land use.<br><br>SERVIR is improving awareness, increasing access to information and supporting analysis to help people manage challenges in the areas of food security, water resources, land use change and natural disasters. |

69 Committee on Earth Observation Satellites. 'Overview'. Posted at http://ceos.org/about-ceos/overview/. Accessed July 2018.

70 Committee on Earth Observation Satellites. 'Working Groups'. Posted at http://ceos.org/ourwork/workinggroups/. Accessed July 2018.

71 Committee on Earth Observation Satellites. 'Data and Tools'. Posted at http://ceos.org/data-tools/. Accessed July 2018.

72 European Space Agency. 'Disaster Relief and Emergency Management'. Posted at http://www.esa.int/Our_Activities/Preparing_for_the_Future/Space_for_Earth/Space_for_health/Disaster_Relief_and_Emergency_Management. Accessed July 2018.

73 Group on Earth Observations. 'Earth Observations for the Benefit of Humankind'. Posted at http://earthobservations.org/index2.php. Accessed July 2018.

74 SERVIR. 'About SERVIR'. Posted at https://servirglobal.net/#aboutservir. Accessed July 2018.

| Company | Description (from organisation website) |
|---|---|
| UNITAR's Operational Satellite Applications Programme (UNOSAT)[71] | Through the use of GIS and satellite imagery, UNOSAT 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, including remote monitoring of development projects and sharing of geographic data using web services. |
| United Nations Office for Outer Space Affairs (UNOOSA)[72] | UNOOSA is the United Nations office responsible for promoting international co-operation in the peaceful uses of outer space. UNOOSA's areas of work include environmental monitoring, natural resource management, biodiversity and ecosystems management. |
| World Food Programme (WFP)[73] | The WFP Seasonal Monitor examines satellite imagery of rainfall and vegetation in order to assess the development of the growing season and how such conditions might 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.<br><br>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. |

Table 5: Regional organisations supporting space solutions for agriculture

| Company | Description (from organisation website) |
|---|---|
| AGRHYMET Regional Centre | The AGRHYMET Regional Centre was established in 1974 as a specialized institute of the Permanent Interstate Committee for Drought Control in the Sahel (CILSS) composed of nine member States (Burkina Faso, Cape Verde, Chad, Gambia, Guinea Bissau, Mali, Mauritania, Niger, Senegal). Its main objectives are the contribution to achieving food security and increased agricultural production in the CILSS member states and the improvement of natural resources management in the Sahelian region. |
| Centre de Suivi Ecologique (CSE) | The Centre de Suivi Écologique (CSE) is a national entity located in Senegal whose core activities include environmental monitoring, natural resources management and conducting environmental impact assessments. It has built partnerships at local (subnational) and national levels, as well as with international donors, to develop climate change projects and programmes, particularly in the areas of environment, agriculture and livestock. |
| The Regional Centre for Mapping of Resources for Development (RCMRD) | RCMRD was established in 1975 under the auspices of the United Nations Economic Commission for Africa (UNECA) and the African Union (AU). It is an inter-governmental organisation and currently has contracting member states in the eastern and southern Africa regions. The RCMRD offers various satellite imagery data products. |

75 UNITAR. 'UNITAR's Operational Satellite Applications Programme – UNOSAT'. Posted at https://unitar.org/unosat/. Accessed July 2018.

76 UNOOSA. Posted at http://www.unoosa.org/oosa/index.html. Accessed July 2018.

77 World Food Programme. 'Seasonal Monitor'. Posted at https://www.wfp.org/content/seasonal-monitor. Accessed July 2018.

## Additional reading and resources

- Caribou Space. 'Space for Development' website. https://www.spacefordevelopment.org/topic/2018/06/agriculture/

- CEOS and ESA. 'Satellite Earth Observations In Support Of The Sustainable Development Goals. The CEOS Earth Observation Handbook'. Special 2018 Edition. Website: http://eohandbook.com/sdg/

- David Lobell, Professor at Stanford University in the Department of Earth System Science and Deputy Director of the Center on Food Security and the Environment. Various publications on the use of satellite data in agriculture in emerging markets. Website: https://fse.fsi.stanford.edu/people/david_lobell

- Department for International Development (DFID). 'DFID's Conceptual Framework on Agriculture'. 2015. Website: https://www.gov.uk/government/publications/dfids-conceptual-framework-on-agriculture

- Devex, Inmarsat and UK Space Agency. 'Satellites for Sustainability'. Website: https://pages.devex.com/satellites-for-sustainability.html

- FAO. 'Review of the Available Remote Sensing Tools, Products, Methodologies and Data to Improve Crop Production Forecasts'. 2017. Website: http://www.fao.org/3/a-i7569e.pdf

- FAO. 'The State of Food and Agriculture'. 2017. Website: http://www.fao.org/state-of-food-agriculture/en/

- Global Strategy to improve Agricultural and Rural Statistics (GSARS). 'Handbook on Remote Sensing for Agricultural Statistics'. 2017. Website: http://gsars.org/wp-content/uploads/2017/09/GS-REMOTE-SENSING-HANDBOOK-FINAL-04.pdf

- NASA's Applied Remote Sensing Training (ARSET) program. Webinar on the 'Fundamentals of Remote Sensing': https://arset.gsfc.nasa.gov/webinars/fundamentals-remote-sensing and Land Management: https://arset.gsfc.nasa.gov/land

- Thompson Reuters. 'How Will We Feed 9 Billion Bowls by 2050?'. Website: http://reports.thomsonreuters.com/9billionbowls/

- UNOOSA. 'Space for Agriculture Development and Food Security: Use of Space Technology within the United Nations System'. Website: http://www.unoosa.org/res/oosadoc/data/documents/2016/stspace/stspace69_0_html/st_space_69E.pdf

# Annex A: Current IPP agriculture projects

Within IPP there are four agriculture projects that started in January 2017 and are in their early phases, and two agriculture projects that began in early 2018. As it is too soon to identify results and lessons from these projects, this report will be updated in 2021 to include final results from the projects.

## CABI: Pest Risk Information Service (PRISE)

### Project overview

- **Target country:**
  Ghana, Zambia, Kenya

- **Project lead:**
  CABI

- **Project consortium:**
  Assimila, Kings College London, Centre for Environmental Data Analysis

- **International partners:**
  Ghana: Plant Protection & Regulatory Services Directorate (PPRSD)
  Kenya: Kenya Agricultural and Livestock Research Organisation (KALRO), Ministry of Agriculture, Livestock and Fisheries (MOALF)
  Zambia: Zambia Agricultural Research Institute (ZARI)


### Project objectives and impact

The PRISE project aims to improve the livelihoods of smallholder farmers, contribute to a reduction in hunger and increase food security in Zambia, Ghana and Kenya. It will do this by enabling farmers to reduce crop losses from pest outbreaks and thus will contribute to an increase in the average annual farming income of farmers in the project areas, and a reduction in crop losses from pest damage.

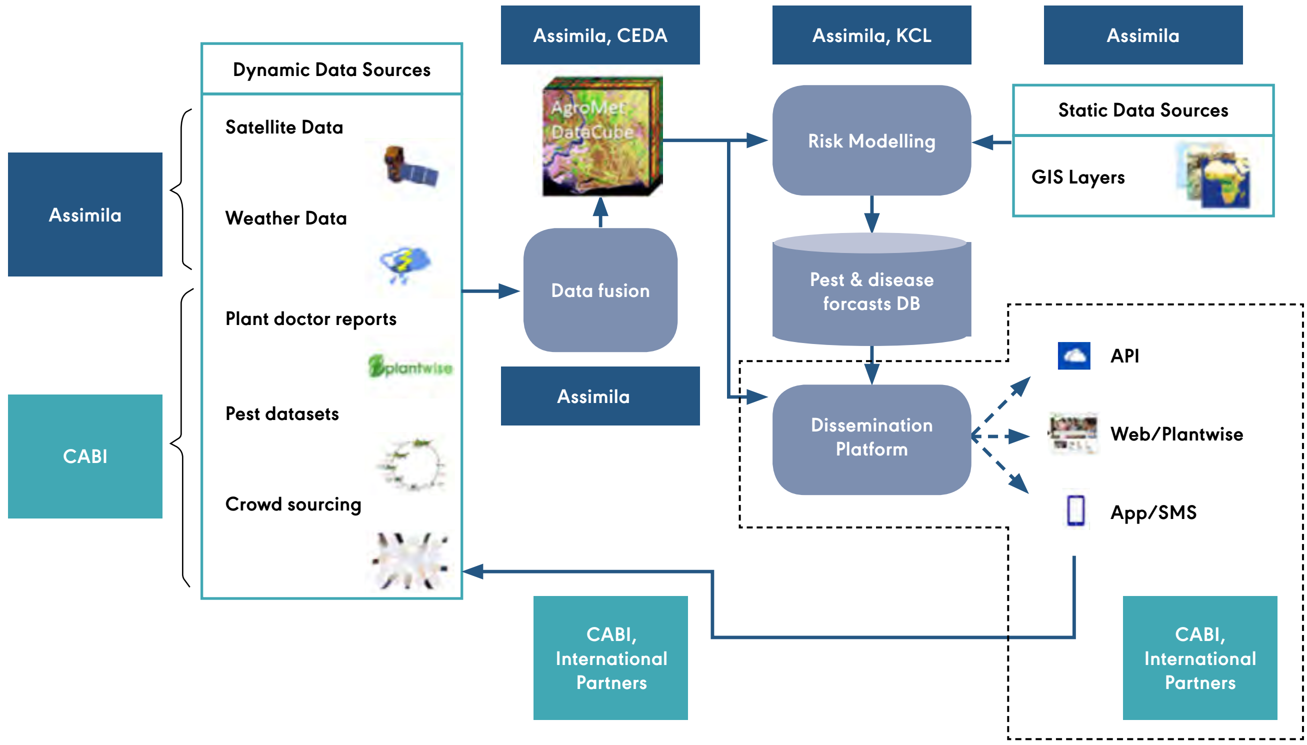
### Satellite solution

This project brings together novel EO technology, satellite positioning, plant health modelling and on-the-ground real-time observations to deliver a science-based PRISE for sub-Saharan Africa. It is an early-warning system that collects and combines disparate datasets, manipulates data using computational and modelling expertise, and leverages well-established international development networks.

Combining EO data with data on the biology of pests, PRISE models pest development to predict when conditions match the necessary environment that allow pest populations to grow problematically. In-country data collected from the field will be fed into the model, and also used to ground-truth results, enabling iterative improvements to the system.

The most ambitious aim for the system is to incorporate Plantwise knowledge bank data and crowdsourced data directly into PRISE, using adapted data assimilation techniques. Data assimilation is usually used to bring observations with well-understood uncertainties into a model which also has well-quantified uncertainties. The data from the Plantwise knowledge bank and from crowdsourcing, however, is likely to be a simple statement of pest presence or perhaps a binary statement of 'pest present/absent'. Incorporating this data into the models will be a significant step, not only to making best use of CABI's data, but also to obtaining the most accurate answers possible. The research and development (R&D) required to make this work is considerable and is likely to contribute to scientific knowledge in the field of using crowdsourced data operationally.

Figure 8: Risk forecasting schematic identifying responsible partners




## Sustainability model

There are three initial targets for generation of income to PRISE for project sustainability:

- **government/donor income:**
  contributions from public and third sector partners that support the development objectives of PRISE

- **commercial service revenue:**
  revenue derived from customers willing to pay for services deriving from all or part of the PRISE system

- **project income:**
  PRISE participation within other funded projects (it is expected that this source of income will primarily enable research and development activity or extension of services into new thematic or geographic domains)

The PRISE team will liaise closely with core government partners from each country. As primary stakeholders responsible for development and support to the least wealthy farmers, government partners are the primary guide and support for PRISE at central, regional and local level.

Previous studies and CABI engagement with private sector representatives indicate that commercial service revenue is a distinct possibility. Further market analysis and engagement with potential customers will validate how PRISE can be used commercially and define the best route to meet customer needs. Recent years have seen the appearance of innovative web and mobile based information service providers aimed at agriculture users in developing countries. PRISE could be a valuable addition to the service offerings.

CABI and the PRISE partners have existing networks of contacts that could be used to generate project income. Actions will be put in place to identify such sources, estimate the potential value and determine a mechanism to bid for and secure such income sources. For instance, there is the expectation that the following have potential to be sources of R&D income: international programmes, international donor organisations, national budgets including both government development agencies/departments, research councils, space agencies.

# Earth-i: Advanced Coffee Crop Optimisation for Rural Development (ACCORD)

## Project overview

- Target country: Rwanda and Kenya
- Project lead: Earth-i
- Project consortium: WeatherSafe, Oxford Policy Management, San Francisco Bay Coffee Ltd
- International partners: Coffee Management Services Ltd, Rwanda Kinini Coffee Ltd

## Project summary

Coffee is a global commodity with growing demand globally, with revenues directly benefitting farmers in developing countries. Despite this, in Kenya and Rwanda 67% and 80% of people respectively live in poverty, including most smallholder coffee farmers. Easy access to information on management practices and weather and nutrient monitoring can drastically increase earning potential by improving coffee quality and quantity.

Coffee farmers must make critical decisions, such as whether and when to apply fertilisers, pesticides or fungicides at potentially short notice. Correct, early advice makes a huge difference to the effectiveness of these decisions and enables improvements in the yields of high-quality coffee which increase incomes.

ACCORD provides farmers with access to timely, geo-targeted advice through a simple mobile application. The unique and proven method employed by the consortium combines satellite imagery with ground observations, and a custom high-resolution localised weather forecast model, in a cost-effective manner. All the data is integrated and analysed to create clear advice through the mobile-enabled platform to agronomists, cooperatives and farmers. Access to this highest quality advice is not available at scale through any other method.

## Project objectives and impact

The ACCORD project will lead to Kenya and Rwanda being empowered to grow more speciality coffee through more efficient and timely crop management. The primary benefits that we expect the ACCORD project to realise will be:

- **improved yield:** measured through annual data from coffee washing stations and validated with a sample of interviewed farmers. We forecast that yield will double over a three-year period
- **improved coffee quality:** measured through annual data from independent cupping tests and corroborated through increased price/kg of coffee achieved by the farmers for their crop (our target is 25% improvement in cupping scores)
- **improved farmer income:** validated with a sample of interviewed farmers (our target is doubling of smallholder coffee income by year three of the project)

Secondary impacts of these improvements include the increased taxation revenues to Kenyan and Rwandan governments from the increased production.

## Satellite solution

A regular feed of EO data can be used to monitor each plantation and provide information on crop health. The varying field sizes lend themselves to EO imagery to capture detail, and the crop cycles require regular data acquisition during the growing season – something not possible with UAVs.

Very high-resolution weather data, created using a custom weather model and accurate topography data, will help to plan around the complex terrain and varying weather conditions between neighbouring coffee plantations. A unique combination of space-based technologies will be used throughout the project. These will include:

- optical satellite imagery that will unlock information on crop health and detect the early warning signs of pests, diseases and nutritional defects

- high-resolution, customised weather forecasts will be created by taking into consideration local topography derived from high-resolution satellite data, as well as by integrating public sources

- detailed mapping of coffee plots and nearby infrastructure will provide reference data on size and facilities for smallholders, producers and exporters

## Rothamsted Research: Ecological Productivity Management Information System (EcoProMis) for oil palm and rice in Colombia

### Project overview

- Target country: Colombia
- Project lead: Rothamsted Research
- Project consortium: Agricompas, Pixalytics, Elastacloud
- International partners: CIAT, Cenipalma, Fedearroz, Solidaridad


### Project summary

Rothamsted will be working with Agricompas, Pixalytics and Elastacloud in the UK and CIAT, Cenipalma, Fedearroz and Solidaridad in Colombia to develop an EcoProMis. This system will provide crop production knowledge to growers and decision support to key stakeholders in oil palm and rice value chains. This new knowledge will optimise production, efficiency and resilience to deliver solutions that enhance the environmental footprint of smallholder farmers and improve social and economic wellbeing.

Colombian smallholder rice and oil palm farmers need to improve productivity and stabilise incomes to allow them to compete globally and improve their livelihoods, while responding to climate change and realising a positive environmental impact.

The project will engage with smallholder farmers through outreach programmes to collect data and provide training so that their skills and understanding on how crop management affects productivity, income and sustainable ecosystems is developed. Smartphones are used to communicate data and knowledge directly from and to farmers in the field.

EcoProMis will create a management information system that combines crop production knowledge per field with economical, environmental and social information to provide commercial decision support to a wide range of stakeholders across value chains such as input providers, (food) processors, insurance firms and governments to create a sustainable platform for knowledge to partners and decision support to crop stakeholders.

The project will create on-going impact through a public-private partnership of farmers, research institutes and Agricompas that builds comprehensive sets of crop and ecosystem data and models to provide near real-time knowledge that is made freely available for the partners to improve the environmental, technical and financial efficiency of their processes.

### Project objectives and impact

- Land managers adopt sustainable land management processes, which mitigate greenhouse gas emissions, adapt to climate change and maintain ecosystems
- Farmer incomes increase in oil palm and rice growing areas by US$30 million per annum by adopting more efficient production and through premium prices by reporting on sustainability

### Satellite solution

The project uses satellite EO combined with crop production data to research the impact of crop and ecosystem management on biodiversity and greenhouse gas (GHG) emissions. Sentinels -1 and -2 will be used for SAR and optical imaging to provide information on crop health and biomass.

## Environment Systems: EO4cultivar

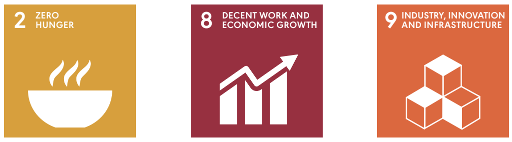
### Project overview

- **Target country:**
  Peru and Colombia

- **Project lead:**
  Environment Systems Ltd

- **Project consortium:**
  Barfoots, Geoseren, Joint Nature Conservation Committee (JNCC), Aberystwyth University, The Open University, EDINA, Wavehill (subcontractor)

- **International partners:**
  Peru: ITP CITE Agroindustrial Ica, CITE Chavimochic, Danper, DM Agricola
  Colombia: Geits, Campo Vivo, ASBAMA




### Project objectives and impact

The overarching objective of the EO4cultivar project is to strengthen commercial agricultural supply chains operating between Colombia, Peru and the UK. It aims to develop a better understanding how to increase production, improve margins, improve crop forecasts and identify opportunities for growth and sustainable land management. The project will achieve this by delivering enhanced advice to growers, supporting them to adapt farming practices in response to new knowledge. It will also increase skills levels in countries by delivering and supporting the use of data derived from EO.

Specifically, the project will:

- increase the area of land in both countries under sustainable, EO based management practices

- increase the number of small-holder farmers directly benefiting from information derived from satellite imagery

- increase the yield rates and revenues for participating grower organisations for specified crops

The project will also support three fully-funded PhDs for Latin American students to study in UK partner universities on research designed to support future development of satellite data services for Latin American markets.

## Solution

While high volumes of satellite data are freely available from the Sentinel and Landsat programmes, there is a high barrier to using this data, due to the complexity of processing and interpreting the imagery. EO4cultivar will develop a cloud-based processing and storage infrastructure to deliver data services derived from radar and optical data from ESA's Sentinel satellites. The EO4cultivar data service will include:

- field scale crop monitoring during the growing season
- field scale crop forecasting tools
- regional monitoring products

Commercial growers, buyers, NGOs and farmer advisory services will use secure data services to access 'analysis ready' maps, images and data that they can use in the office or on portable devices. This might be for individual fields, farms or regional areas

Figure 9: Sentinel 2 satellite image of agricultural land in La Libertad region, Peru

and will reflect the demand for timely information to improve crop production and biosecurity, support resilient and sustainable farming practices and manage risk.

At present growers do not have regular access to this kind of data and rely on a limited number of staff to monitor very large areas of crop through periodic in-field checks. Growers need data throughout the season for decision-making; the project's extensive use of all-weather Sentinel-1 radar data ensures that crop monitoring data is available reliably and regularly throughout the growing season.

Involving Latin American PhD students on associated research delivers capacity building and ensures there is activity to support next generation products for the data services to maintain a competitive edge for Latin American producers.

Case studies will be developed in Peru and Colombia to demonstrate how different users can make the best use of data products and services, alongside existing local knowledge, to inform activities that support sustainable livelihood development. These case studies will adopt a natural capital approach to developing resilient business models for international partners and small-holder farmers. They will demonstrate the potential for using EO as part of nature-based solutions and incorporating an ecosystem services approach into decision-making at varying scales.

### Sustainability model

The EO4cultivar project is effectively an operational demonstration. It will show that the data services are fit-for-purpose, transferable, cost effective and, importantly, that there is a viable business delivery model that can generate commercial revenue from data services and consultancy.

The methods and approaches used in case study development will be tailored to ensure that the techniques are transferrable to other agricultural production systems and supply chains, thus ensuring the outputs of EO4cultivar can inform sustainable development beyond the initial focal regions.

Organisations wanting access to EO4cultivar will 'sign up' for data services supported by our partner technology. Services will include generic outputs which can be rapidly deployed in new areas based on demand and more specialist (e.g. crop based) outputs, which are less transferrable but generate more revenue. Key consumers are expected to be large commercial growers, grower federations and buyers in agricultural supply chains, government agencies, NGOs and other organisations that provide advice to small-scale farmers.

## Rezatec: Mexican Crop Observation, Management and Production Analysis Services System (COMPASS)

### Project overview

- Target country: Mexico
- Project lead: Rezatec Ltd
- Project consortium: Booker Tate Ltd, The University of Nottingham
- International partners: International Wheat and Maize Improvement Centre (CIMMYT), College of Postgraduates (COLPOS)


### Project objectives and impact

To transform the Mexican sugarcane and wheat sectors, the COMPASS project aims to address the twin challenges of productivity and income for 1,200 rural farmers. Specifically, it aims to bring about:

- a 5% increase in yield values, net of input costs
- net income growth of Mexican wheat and sugarcane farmers by £13.2 million, due to yield increases and cost reduction

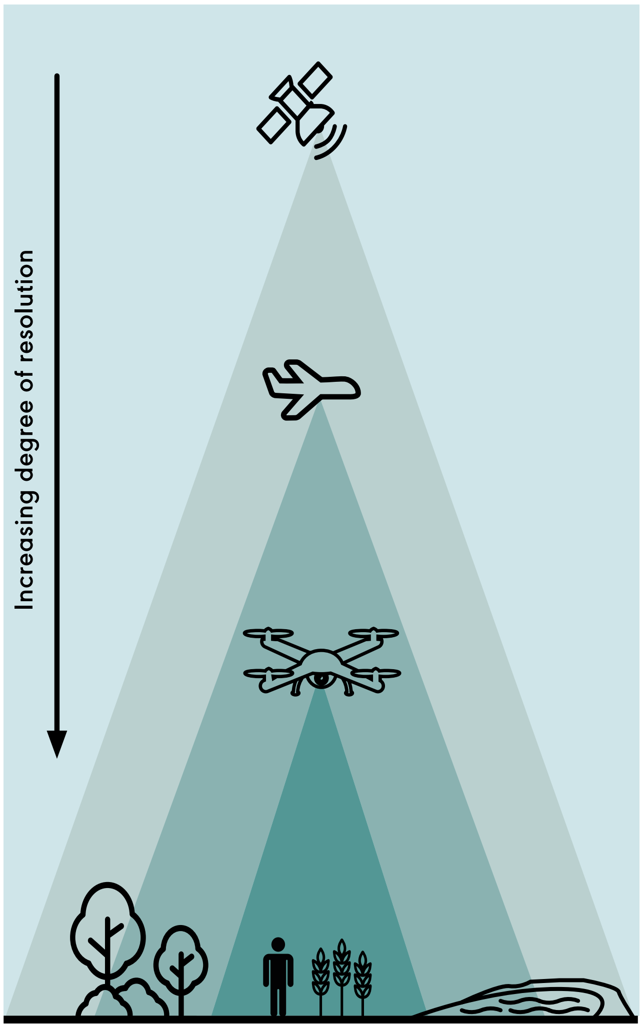
These benefits will ensure that farmer incomes are more stable, directly benefit farming families, and the development of rural communities where they live.

### Solution

The COMPASS project will provide a management decision support tool through Rezatec's web-based 'Life Platform'. The technology developed by the project will use EO satellite data along with in-situ data captured with the farmers to help them identify factors that cause the yield gap between crop potential and actual field performance. Informed by EO and other data sources it is both practical and affordable for smallholders with low levels of formal education, and will help them make better crop decisions and thus benefit their incomes and farm development.

Remote sensing data will be combined with the field-measured crop performance data to monitor crop growth at regular intervals throughout the growing season. Data will be calibrated by ground truthing and used for calibration of the crop growth model. Such an approach has given some success in improving crop predictions made using a growth model for sugar beet by using remote sensing data to refine the calibration. The approach initially involves the acquisition and aggregation of a range of EO data obtained from satellite systems. This information will be further supported by remote sensing data gathered using a UAV, which will be flown over the experimental areas at intervals to coincide with the key crop measurements, as well as satellite imagery capture (Figure 10).

Figure 10: EO Using remote sensing technologies



The data from all sources will be analysed using techniques that identify correlations between the different data types. It is envisaged that this will allow the development of a system to provide predictions of crop yield and crop management requirements directly from remote sensing information.

The COMPASS system will collect data about crop performance, which collates data from yield records, EO data (from Sentinel 1 and 2) and ground truthing exercises. It uses this to map how actual crop performance varies against performance predicted by the crop model for different fields, to identify the impact of crop management decisions on crop output. Using this data in the Life Platform, Rezatec will develop management decision support tools to support specific user needs including:

- crop productivity (to improve smallholder and farmer crop management)
- environmental impact (to reduce negative impacts of crop production)
- supply chain optimisation (co-ordination of harvesting and logistics)
- crop monitoring at regional/national level (to improve market function)
- crop insurance (to enable insurers to target payments)
- research and development (to provide information to support basic and applied R&D programmes)
- investment (to help the equipment and agribusiness sectors target their investments)

### Sustainability model

International partners CIMMYT and COLPOS are leading the farmer support programme, communicating the benefits of using the Life Platform interface to farmers and running workshops to engage farmers throughout the project. The main focus of capacity building efforts will be introducing the interface to farmers, demonstrating the benefits of satellite for agriculture and supporting farmers to use the Life Platform.

Smallholders and their federations will receive basic crop information (data and knowledge) alerts free of charge and be able to access free information on crop growth in the long term, only paying if they want additional detailed crop management advisory services. However, once deployed successfully in Mexico, commercial companies, government agencies and crop insurance providers will pay through a fee-based subscription model for enhanced datasets, aggregated data and more detailed analysis than the basic free data which is made available to smallholders. Insurers will be able to target insurance cover more effectively, increase their market and reduce cost; processing sugar mills or cooperatives can optimise the sequence of harvesting based upon potential across thousands of fields; while agri-business and government support agencies can more accurately forecast crops and target their engagement with farmers.

Success in Mexico will also mean that the model will be extended to other developing countries growing wheat and sugar cane to increase the viability and returns from using EO data to support smallholder farmers.

# Rheatech: Drought and Flood Mitigation Service (DFMS)

## Project overview

- Target country: Uganda
- Project lead: Rheatech
- Project consortium: Environment Systems, Pixalytics, Databasix, AA International, AgriTechTalk International, HR Wallingford, UK Met Office, Mercy Corps, Oxford Policy Management
- International partners: Ministry of Water and Environment, Uganda; Kakira Sugar Company


## Project objectives and impact

This DFMS project aims to provide accurate flood and drought predictions to decision makers so that they can use that information to adjust their farming and livestock activities as well as various forecast indices supported by satellite and ground data. This would have the ultimate impact of reducing agricultural losses they would otherwise suffer from flood and drought impacts. It aims to:

- improve crop yields and livestock condition
- increase gross income of small-holder farmers/ pastoralists

In parallel, it also aims to build the capacity of the government agencies responsible for early warning systems to use flood and drought predictions to improve their ability to support farmers in case they were affected by flood or drought impacts.

## Solution

DFMS will be delivered on a new, open, easy-to-use and scalable Early Warning Platform (EWP) that will integrate multiple data sources, models and services. The platform is designed to assimilate heterogeneous data sources raging from satellite and meteorological data, as well as community/mobile sources which would be used for ground truthing. The platform would be able to support any other software development around it for other types of early warning systems to be integrated.

DFMS is an integrated chain of services and models implemented on the EWP. It will make use of agricultural information, meteorological data, ground water data, satellite data from Soil Moisture and Ocean Salinity (SMOS) satellite and Copernicus and Landsat Satellites, and information from existing climate forecast services to build environmental models of climate, ground and surface water in the target region. These models will be used to guide decision makers in drawing key conclusions, and assess the impact of any actions taken, in terms of advice to farmers to avoid disasters or how to maximise yields.

The resolution of DFMS combined weather and hydrological forecasts is significantly higher than other existing systems or services providing information at a parish level to impact on local farmers' crop yields and livestock performance. Building trust with users with reliable data and forecasts will encourage them to take action based on the DFMS.

By combining meteorological forecast, EO and ground observation data, DFMS provides greater analysis, analytics and insight tools for decision making at multiple levels for drought, flood and agriculture practices. Dissemination is improved by DFMS by providing users with web-based access which is tailored to specific user needs and with a high frequency of data updates. Additionally, historical and future climate analysis will enable long term infrastructure and agriculture planning by government or private sectors.

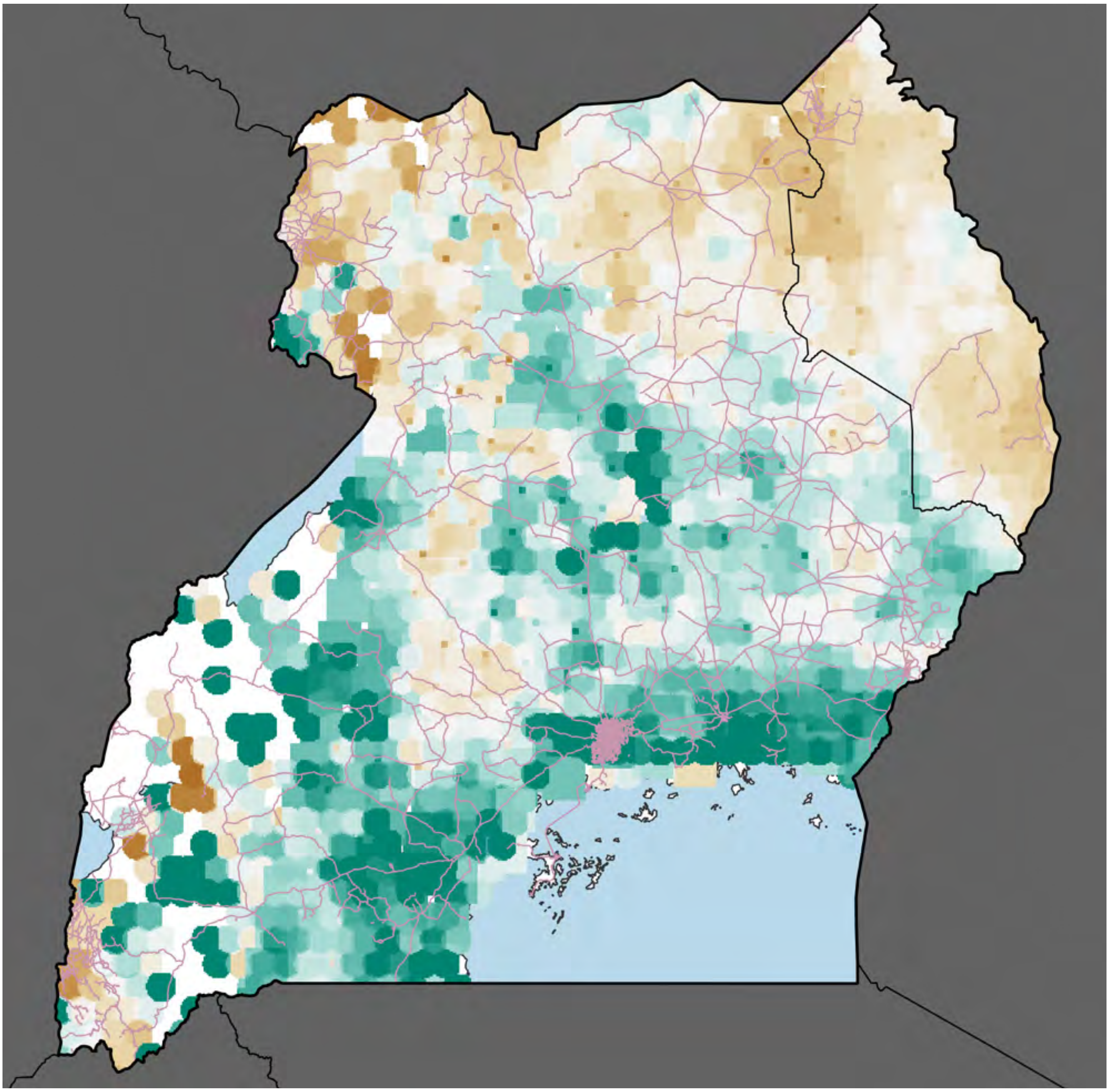
### Sustainability model

After deployment of the system, users will be trained on how to use weather forecasts, hydrological forecasts, flood and drought risk indexes, and EO derived indexes coming from the system. Government staff will also be trained on the use of early warning data/indices for decision and policy making.

The DFMS project consortium will seek commercial sustainability for the project via both government procurement and by providing the service commercially to industrial partners. The Ministry of Water and the Environment is intended to be the core anchor tenant (user) of DFMS, with further users, services and workflows embedded with Office of Prime Minister, Ugandan Meteorological Authority, Ministry of Agriculture Animal Industry and Fisheries and the National Agriculture Research Organisation. Local businesses, like Kakira Sugar, could subscribe to the service to provide their out-growers with much better and more comprehensive climate data.

Furthermore, it can be readily seen that the approach for DFMS is easily extensible to all of Uganda and other countries at a future stage.

Figure 11: Soil moisture levels



# Annex B: Rapid review methodology

The rapid review sought to identify a cross section of existing research exploring the impacts and cost effectiveness of space-based solutions in agriculture in the section 'Impacts and cost-effectiveness of space solutions for agriculture'. It then sought to provide a narrative synthesis of the results with reference to the research questions and hypotheses.

## Search strategy

To that end, the research team first completed a search of both academic and official research. This included systematic searches of electronic databases and scanning relevant journals and articles.

Electronic database searches

Electronic databases were searched using the following key words:

agriculture OR farm OR forest OR fish

AND

earth observation OR remote sensing OR precision OR integrated land management

AND

cost-effective OR evaluation OR benefit OR public good OR supply chain optimisation OR decision support tool

Searches were conducted in March 2018, and included:

- Research in Agricultural and Applied Economics
- ScienceDirect
- AGRIS, FAO
- CGSpace
- NBER
- Science.gov
- SciELO
- Agricola (EBSCO Host)
- SpringerLink

## Hand searches

Additional hand searches of relevant article and journal bibliographies were completed, including Journal of Space Policy. This included manually searching relevant organisations publication lists and datasets including the OECD Space Forum and The Food and Agriculture Organisation of the United Nations.

## Reverse citation tracking

As part of the search, the authors also completed reverse citation tracking in order to identify more recent research that may be relevant to the study. This involves scanning citation lists of studies that have referenced identified studies in their work, potentially highlighting more recent relevant research.

## Limitations

This rapid review is subject to a number of limitations. The search is highly likely to have overlooked potentially relevant research. Due to time constraints, critical research appraisal assessments were limited to drawing on narrative discussion within a report accompanying a study. Judgements are therefore limited to the extent of the quality of conduct reporting of a study. Due to these apparent limitations, the conclusions that can be drawn from this review should be considered to provide an indicative, rather than a definitive, statement of the evidence concerning space based solutions in agriculture.

# Glossary

**N.B. This glossary references public domain definitions, including extensive use of Wikipedia, as the definitions are written in an accessible manner to the audiences of this report.**

**Algorithm** - In mathematics and computer science, an algorithm is an unambiguous specification of how to solve a class of problems. Algorithms can perform calculation, data processing and automated reasoning tasks.[78]

**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.

**Certification Schemes** – Market-based approaches to respond to customer demand for more evidence of sustainability and traceability in supply chains.

**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 Earth Observation and in situ (non-space) data. The Programme is coordinated 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.[79]

**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.[80]

**Electromagnetic Spectrum** - The range of frequencies (the spectrum) of electromagnetic radiation and their respective wavelengths and photon energies.[79]

**European Marine Observation and Data Network (EMODnet)** – EMODnet consists of more than 150 organisations assembling marine data, products and metadata to make these fragmented resources more available to public and private users relying on quality-assured, standardised and harmonised marine data which are interoperable and free of restrictions on use.[81]

**Famine Early Warning Systems Network (FEWS NET)** – A provider of early warning and analysis on food insecurity. Created by USAID in 1985 to help decision-makers plan for humanitarian crises, FEWS NET provides evidence-based analysis on some 34 countries.[82]

**Food Security** – The condition in which all people, at all times, have physical, social and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.[83]

---

78 Posted at: https://en.wikipedia.org/wiki/Algorithm. Accessed July 2018.

79 Website: http://www.copernicus.eu/main/overview. Accessed July 2018.

80 Posted at https://en.wikipedia.org/wiki/Earth_observation. Accessed July 2018.

81 Website: http://www.emodnet.eu. Accessed July 2018.

82 Website: http://fews.net. Accessed July 2018.

83 Food and Agriculture Organisation (FAO). 'An Introduction to the Basic Concepts of Food Security'. Posted at http://www.fao.org/docrep/013/al936e/al936e00.pdf. Accessed July 2018.

**GDP** – Gross Domestic Product is a monetary measure of the market value of all final goods and services produced in a period (quarterly or yearly) of time. Nominal GDP estimates are commonly used to determine the economic performance of a whole country or region, and to make international comparisons.[84]

**Georeferencing** - Aligning geographic data to a known coordinate system so it can be viewed, queried, and analysed with other geographic data.[85]

**GIS** – A geographic information system is a system designed to capture, store, manipulate, analyse, manage, and present spatial or geographic data.[86]

**GNSS** – Global Navigation Satellite System refers to a constellation of satellites providing signals from space that transmit positioning and timing data to GNSS receivers. The receivers then use this data to determine location.[87]

**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 or societal benefit to developing countries. Projects within IPP span a wide range of themes including: improving agriculture; reducing deforestation; improving disaster response; reducing maritime pollution and illegal fishing; optimising renewable energy; improving resilience to climate change.

**LAI** – Leaf area index. LAI represents the amount of leaf material in an ecosystem and is geometrically defined as the total one-sided area of photosynthetic tissue per unit ground surface area.[88]

**Landsat-1 Satellite** - A commercial high-resolution optical imaging EO satellite system operating from space. Landsat is a joint effort of the United States Geological Survey (USGS) and NASA.[89]

**Light Detection and Ranging (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 3-D representations of the target.[90]

**Meteosat** - This series of satellites are geostationary meteorological satellites operated by EUMETSAT under the Meteosat Transition Programme (MTP) and the Meteosat Second Generation (MSG) program.[91]

**Meteosat SEVIRI** - SEVIRI is the scanner carried aboard the Meteosat Second Generation (MSG) satellite.[92]

**M&E** – Monitoring & Evaluation - Is an objective process of understanding how a project was implemented, what effects it had, for whom, how and why.[93]

---

84 Posted at: https://en.wikipedia.org/wiki/Gross_domestic_product. Accessed July 2018.

85 Website: https://support.esri.com/en/other-resources/gis-dictionary. Accessed July 2018.

86 Posted at: https://en.wikipedia.org/wiki/Geographic_information_systems. Accessed July 2018.

87 Website: https://www.gsa.europa.eu/european-gnss/what-gnss. Accessed July 2018.

88 FAO. Posted at http://www.fao.org/tempref/docrep/fao/011/i0197e/i0197e15.pdf. Accessed July 2018.

89 Website: https://landsat.usgs.gov/landsat-project-description. Accessed July 2018.

90 Posted at: https://en.wikipedia.org/wiki/Lidar. Accessed July 2018.

91 IPP brochure: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/732722/IPP_Brochure_online_final_copy_06-08-18.pdf

92 ibid

93 Caribou Space

**NDVI** – Normalised difference vegetation index quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs).[94]

**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.It is defined as: 'those flows to countries and territories on the DAC List of ODA Recipients and to multilateral institutions which are: i) provided by official agencies, including state and local governments, or by their executive agencies; and ii. each transaction of which: a) is administered with the promotion of the economic development and welfare of developing countries as its main objective; and b) is concessional in character and conveys a grant element of at least 25 per cent (calculated at a rate of discount of 10 per cent)."[95]

**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.[96]

**Orthorectification** - uses elevation data to correct terrain distortion in aerial or satellite imagery.[97]

**Radiometric Correction** - the process of removing the effects of the atmosphere on the reflectance values of images taken by satellite or airborne sensors.[98]

**Sentinel-3 SLSTR** - ESA's Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR) is primarily an ocean mission; however, the mission is also able to provide atmospheric and land applications. It provides data continuity for the European Remote Sensing (ERS), Envisat and SPOT satellites. Sentinel-3 makes use of multiple sensing instruments to accomplish its objectives.[99]

**Synthetic Aperture Radar (SAR)** - Synthetic Aperture Radar (SAR) satellites are a form of radar that is used to create two or three-dimensional images of objects, such as landscapes.[100]

**Terra/Aqua MODIS** - MODIS (or Moderate Resolution Imaging Spectroradiometer) is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning (EOS AM), while Aqua passes south to north over the equator in the afternoon (EOS PM). Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths.[101]

**UAV** – an Unmanned Aerial Vehicle, commonly known as a drone, is an aircraft without a human pilot aboard.[102]

94 GIS Geography. Posted at: http://gisgeography.com/ndvi-normalized-difference-vegetation-index/. Accessed July 2018.

95 Posted at: https://en.wikipedia.org/wiki/Official_development_assistance. Accessed July 2018.

96 Posted at: https://en.wikipedia.org/wiki/OECD. Accessed July 2018.

97 Website: https://support.esri.com/en/other-resources/gis-dictionary. Accessed July 2018.

98 Website: https://support.esri.com/en/other-resources/gis-dictionary. Accessed July 2018.

99 IPP brochure: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/732722/IPP_Brochure_online_final_copy_06-08-18.pdf

100 ibid

101 ibid

102 Posted at: https://en.wikipedia.org/wiki/Unmanned_aerial_vehicle. Accessed July 2018.

UK SPACE AGENCY