Part of the conference series

Breakthrough science and technologies
Transforming our future

From satellite to soil: connecting environmental observation to agri-tech innovations

Conference report

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Introduction

On 17 June 2016, the Royal Society hosted a high-level meeting to discuss space and environmental observation technologies and their potential in agriculture. As our capability to observe the planet is rapidly improving, so is the opportunity to harness this 'big data', and the associated downstream technologies, to inform farming practices and bolster food security in the face of climate change. This conference brought together representatives from the space and earth observation communities, with 'end-users' such as farmers and agronomists, as well as governmental and commercial stakeholders.

This conference is the third in a series organised by the Royal Society, entitled Breakthrough Science and Technologies: Transforming our Future, which will address the major scientific and technical challenges of the next decade. Each conference will focus on one or more technologies and cover key issues including the current state of the UK industry sector, future direction of research and the wider social and economic implications. The conference series is being organised through the Royal Society's Science and Industry programme, which demonstrates our commitment to reintegrate science and industry at the Society and to promote science and its value, build relationships and foster translation.

This report is not a verbatim record, but summarises the discussions that took place during the day and the key points raised. Comments and recommendations reflect the views and opinions of the speakers and not necessarily that of the Royal Society.

Full versions of the presentations can be found on our website at: **royalsociety.org/science-events-and-lectures/2016/06/observation-and-agritech**

Executive summary

This conference connected three communities involved in the process of collecting, analysing and using the data from environmental observation. Participants included researchers in environmental observation technologies, including space-based Earth observation, end-users from the agriculture community and the intermediary companies who convert big data into formats that end-users can benefit from. It sought to highlight the potential of developments in this area, and to identify challenges and risks to future progress.

The UK, and the world, are facing unprecedented agricultural challenges in the coming decades as a consequence of climate change – the increased frequency of extreme weather events being experienced are already affecting crop harvests and making food security harder to ensure. To combat this threat advanced technologies that improve prediction, productivity and resilience in agriculture, for example EO data from satellites, offer the potential to revolutionise 21st century farming.

Exploiting this potential will provide an invaluable opportunity to mitigate against against problems such as poor harvests, starvation, economic turbulence and even political instability, which can lead to security issues of global concern. In particular, harnessing EO technologies will aid 'precision farming' by providing reliable monitoring and forecasting so that farmers can tailor their efforts accordingly, even within different areas of the same field.

Through its strong research base, burgeoning EO and satellite sectors and a growing willingness from the agricultural sector to adopt new solutions, the UK is well placed to become a world-leader in the adoption of these new technologies. In 2012, the Government recognised both satellites and agri-science as two of the 'eight-great' technologies, demonstrating its commitment to both.

In developed countries such as the UK, adoption of these new technologies should help farmers cope with variable weather affecting crop yields, avoid variations in productivity across a farm through better understanding of soil conditions, and avoid spoilage of produce by ensuring crops are harvested and sold at the right time.

However, reaping the benefits from technological advances in EO and agri-tech requires farmers and end-users to work closely with technology developers in industry and academia so that capabilities and needs are understood. Barriers to uptake in the UK include issues with internet connectivity, the interoperability between software and farm machinery, and a lack of transparent project funding. There is also uncertainty about the availability, usability and cost of data, including around how publicly collected EO data is opened up for product and service development to inform decision making.

In response to a perceived distance between the end-user and EO communities, this conference aimed to bridge this gap by bringing together stakeholders involved in satellites and agri-tech, as well as government and academia.

Although the term environmental observation encompasses a broad range of measurements from different sources, in the most part the conference focused on space-based EO.

Challenges to 21st Century agriculture

> "In the next 20 years we have to do the Green Revolution again in terms of the increase in production. We've got to do it again, we have got to do it in half the time and with less energy and inputs, and where all the easy stuff has already been achieved."
>
> **Professor John Crawford, Rothamsted Research**

The planet is facing unprecedented challenges. Climate change is leading to unpredictable growing seasons, alterations in pest and disease ranges, fluctuating weather patterns and extreme events, all of which mean that farmers' decisions of when and how they plant and treat their crops are vital.

The growing global population is also increasing our demand for land, such that farming will need to be ever more productive and efficient.

Stuart Martin, CEO of the Satellite Applications Catapult, noted that EO capabilities are particularly pertinent to two of the UN's Sustainable Development Goals: zero hunger and life on land (Figure 1).

FIGURE 1

UN-produced infographic showing Sustainable Development Goals (www.un.org/sustainabledevelopment)

Food security, sustainable agriculture, minimising environmental pollution, and economic security, together with their knock-on effects on political stability and even on global security, may all be contingent on making informed agricultural decisions.

In recent decades the world has seen volatility of wheat prices, fluctuating profits and yields (Figure 2). On the ground this has proved a challenging environment for farmers. Keith Norman, Technical Director at Velcourt, told those attending the conference that in the UK, the total income from farming is the lowest it has been since 1998.

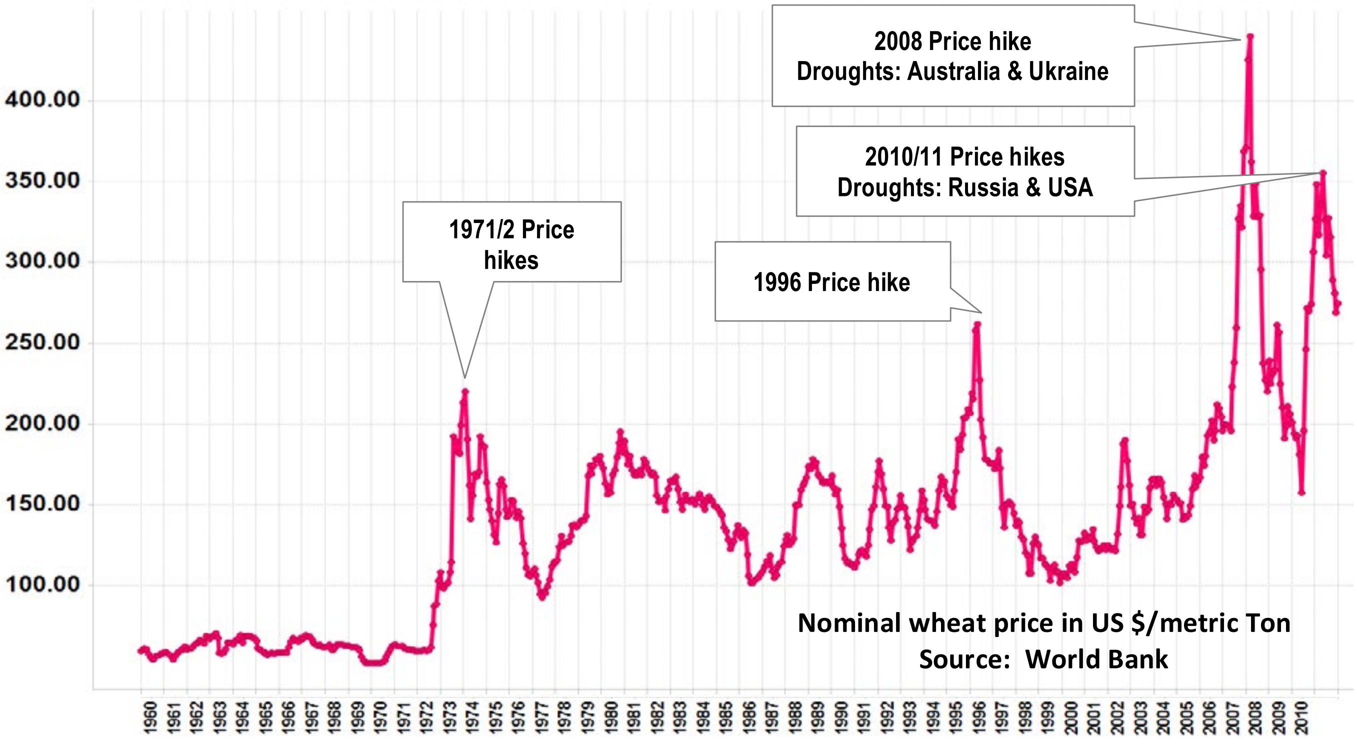
UK farmers have had to contend with increasing fluctuation in weather patterns and extreme events year-on-year, making their yields unpredictable, which has knock-on effects for storage, export and pricing. As an example, Norman reported that 2012 saw unusually heavy rains, and 2013 unusually cold temperatures, which meant that UK crops were negatively affected for two consecutive years.

Andrew Richards from Agrii, reported that monitoring and understanding the implications of these more extreme climatic events is becoming more important for UK farming. The wheat yield plateau has been well documented over the last few years despite continuing genetic improvements, with the key drivers for yield being solar energy, water availability and nutrition.

However, 2011, 2014 and 2015 saw very high yields including a new record in 2015 where wheat was able to benefit from increased solar radiation and a long cool grain filling period. In the UK, where 40% of wheat is grown on drought prone soils and light levels can be limiting, monitoring and modelling accumulated radiation, moisture availability and temperature enables this information to be used to make better decisions on in-season yield potential and manage inputs more appropriately.

FIGURE 2

Nominal wheat prices in US$ per metric ton, by year.



Source: World Bank. Reproduced with permission from Barbara Ryan, Director, GEO (Group on Earth Observations) Secretariat.

What space and environmental observation capabilities do we have?

Environmental observation can be ground-based, including groundwater and geodetic sensors; airborne, on drones and light aircrafts; or space-based, on satellites.

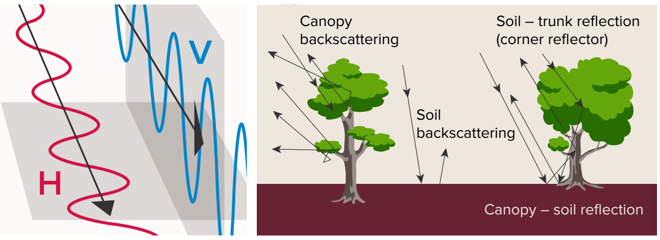
There have been a variety of satellites and EO technologies available for some decades, which are providing useful current and historical data for past comparison. New satellites are also planned for launch, including the second satellite of the European Space Agency's (ESA's) Sentinel 2 mission, scheduled for later this year, and its BIOMASS mission which will focus on the forest biomass with implications on biodiversity and carbon storage.[1]

Orbiting satellites observe the planet in two main ways. Firstly, optical satellites provide images using solar reflectance from the Earth, but this means they cannot see through cloud cover. A second key approach to observing the Earth, that overcomes issues associated with cloud cover, uses radar and microwave bounce-back to produce an image through backscatter. Synthetic Aperture Radar (SAR) instruments[2] aboard space satellites such as Sentinel 1 provide this (Figure 3).

"An optical satellite is like you walk into a field and look in with your eyes. And a SAR satellite – you walk in and shut your eyes and you sort of feel the crop – it looks at the structure," as Vince Gillingham of UK satellite imagery company, Ag Space, explained to the meeting. "It's showing us things we could never dream of, really, even three or four years ago."

FIGURE 3

Synthetic Aperture Radar can be used to determine the structure of an object on the ground. Sentinel 1 dual polarisation measures the horizontal and vertical backscatter (VV+VH)



Images taken with permission from Vince Gillingham's (AG Space) presentation.

Presentations at the meeting drew upon current EO programmes, including the US Landsat satellites and the European Space Agency's Copernicus programme, comprising the Sentinel 1 and 2 satellites and the UK's lidar.[3] These are publicly-funded governmental programmes, but many private EO companies are also involved in processing and disseminating data.

Our EO capabilities are constantly improving, with much of the Earth's surface being traversed frequently by an observation satellite. For example, Sentinel 1 produces radar maps once every 12 days, which will soon ramp up to once every 6 days, according to Dr Iain Cameron of Environment Systems. This equates to around 2,000 images a day currently being sent back from the Sentinel mission. EO satellites have also improved in their resolution. Most satellites have a resolution of 5 – 20 metres with some going down to a metre scale.

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1. http://www.esa.int/Our_Activities/Observing_the_Earth/The_Living_Planet_Programme/Earth_Explorers/Future_missions/Biomass (accessed September 2016).
2. http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/SAR_missions (accessed September 2016).
3. https://environmentagency.blog.gov.uk/2015/09/18/laser-surveys-light-up-open-data (accessed September 2016).

How do these capabilities address global and local challenges?

The main way of harnessing satellite and environmental observation technologies for addressing global and local agricultural challenges lies in their ability to inform better decision-making.

Together, data from satellites, ground-based monitors and aerial drones could be used to help inform farmers which parts of a field are in need of fertiliser, water, pest or disease control, aiding in the management of the key variables: solar, rain and nutrients.

For instance, information from environmental observation, including space-based EO, could lead to an individual farmer selectively applying nitrogen more generously in one part of his or her field where soil nitrogen levels are lower – so-called 'precision farming'; or data-based predictions could help a commercial company decide whether or not to take out a ten-year contract on a crop in a region which in ten years may no longer be able to support that crop, perhaps due to climatic changes.

The conference heard from agronomists and agriculturalists involved in using environmental observation data to manage their crops on between-farm, between-field and within-field scales. In addition, environmental observation data was shown to be of use in depth cultivation variation, pest and insect detection, yield prediction, planning crop planting and calculating the survival of crops in different areas. This technology can also help distinguish different crops, developmental stages and rates of growth.

Furthermore, better weather-forecasting can help inform farmers when it is best to reap certain crops, critical for coffee growers in Africa, for example, who need to leave their crop outside for three days to dry.

It is not just in arable agriculture where environmental observation has the potential to benefit productivity. Livestock farming can also benefit from the precision management of grass for grazing, as highlighted by David Gardner, from Innovation for Agriculture.

It is the potential for more and more accurate yield forecasts that may be tantalising for agronomists looking to maximise yields while minimising inputs such as pesticides and fertilisers. Knowledge leading to better predictions for farming can therefore open up the potential for tailoring interventions to maximise benefits.

Furthermore, global EO projects can help monitor the way the Earth's landscape is changing and provide a valuable archive for the future. This historical data can be used to produce more accurate predictions for the future.

Environmental observation technology can also be used to minimise wastage. For example, in the UK 20-60% of certain crops may not be saleable because of supermarket and consumer preferences. With a more integrated approach farmers could use technology to harvest crops when they are at peak 'saleability'. For example, multispectral imagery can offer 'crop intelligence', revealing when the crop is the best size for one retailer as opposed to another. Such approaches, combined with other EOs, are being used by G's Growers in Murcia, Spain, as described by their Remote Sensing Technologist, Sergio Moreno Rojas.

BOX 1

Landsat: an economic case for freeing data

The US Landsat programme provides the longest-running civilian space-based observation of Earth. Its first satellite was launched in 1972.

The images captured by Landsat were sold privately for $500 a scene when the US government operated it. When private companies operated Landsats 4 and 5 in the mid-1980s this went up to $4-5,000 a scene.

At the peak of sales in 2001 – then by the US Geological Survey, 53 scenes a day were sold from Landsat, raking in a substantial $4.5-5 million a year.

At the time, Barbara Ryan, Director of the Group on Earth Observations Secretariat in Geneva, was working at the US Geological Survey (USGS). Despite facing some internal resistance, she advocated, along with colleagues, that this data should be made freely available as it was mainly being bought by other US government agencies, universities funded by the National Science Foundation and the contractors for the US Department of Defense.

"We were just recycling that $4.5 or 5 million of largely federal money, incurring transaction costs, to sell 53 scenes a day," Ryan noted.

After a change in data policy in 2007/2008 to make it free to the user, the use of Landsat data soared with 5,700 scenes a day being downloaded. Total downloads to date exceed 25 million scenes from the entire Landsat archive.

An economic analysis by Landsat's data advisory committee in 2011 estimated that in the US alone this stimulated $1.7 billion of economic return to the US, $400 million globally.

The total annual economic benefit of this was estimated at $2.1 billion. Ryan believes the experience with Landsat data heavily influenced Europe in its decision to make the Sentinel data freely available to the user.

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4. http://landsat.gsfc.nasa.gov/

Issues and potential barriers for EO in agriculture

Though the potential for EO is vast there are still barriers and considerations that need to be addressed in order to unleash the power that EO offers to agricultural decision-making.

Connectivity was an issue that was raised during the meeting by both speakers and delegates. In spite of many technological advances in recent years, farmers in the UK remain limited in many rural areas by their broadband connectivity. This seemingly simple issue may stymie their ability to benefit from sophisticated EO technologies and analyses. This contrasts with much of Africa, where mobile connectivity is good but phone technology less advanced. Therefore, different methods of getting the data to farmers need to be developed for different regions.

UK Government funding for the application of EO in agriculture was described to be sparse for some technological areas, while duplication of efforts was seen in others. This led to the conclusion that greater transparency is needed across funding bodies and government departments, ensuring money is used efficiently and avoiding unwanted gaps in funding efforts.

The quality and standardisation of the information farmers receive were also raised as issues. It was observed that there was variability in the uptake of new technologies by farmers - while some were resistant to change, others were early adopters. However, some users noted concerns around compatibility between software and farming machinery, while others argued that interoperability between software systems was hindered if companies were too protective of their intellectual property, thereby restricting progress in the uptake of new technologies.

> “Countries have borders, Earth observations don’t… if we do in fact want to unleash the power of Earth observations we need to advocate for broad open data policies. It’s absolutely needed for global monitoring and transparency so that not just the wealthiest of us have access to that information but we can in fact help create a more food secure world.”
>
> **Barbara Ryan, Group on Earth Observations.**

In particular, while EO technology measures crop performance at a certain time, in order to make the data more applied it is necessary to combine it with other phenotyping technologies (e.g. leaf area index and canopy cover) in order to both collect data where satellites fail and to calibrate processed satellite data.

Phenotyping, on the other hand, is only valuable if the measurement of actual crop performance is compared against potential crop performance. Analysing the performance gap against measured crop growth parameters will provide process knowledge that can be applied in decision support. Large datasets require collection and processing in models which are then compared with observed (actual) crop performance.

Handling big data

> “We are in a completely new realm of data volume. The question is what are we going to do with all this data?”
>
> **Dr Iain Cameron, Environment Systems.**

As our EO capabilities ramp up, we are receiving vast quantities of data that could potentially transform agriculture. However, the conference heard that the way in which this data is handled – in its dissemination, analysis and the way in which it is communicated to end-users – is crucial.

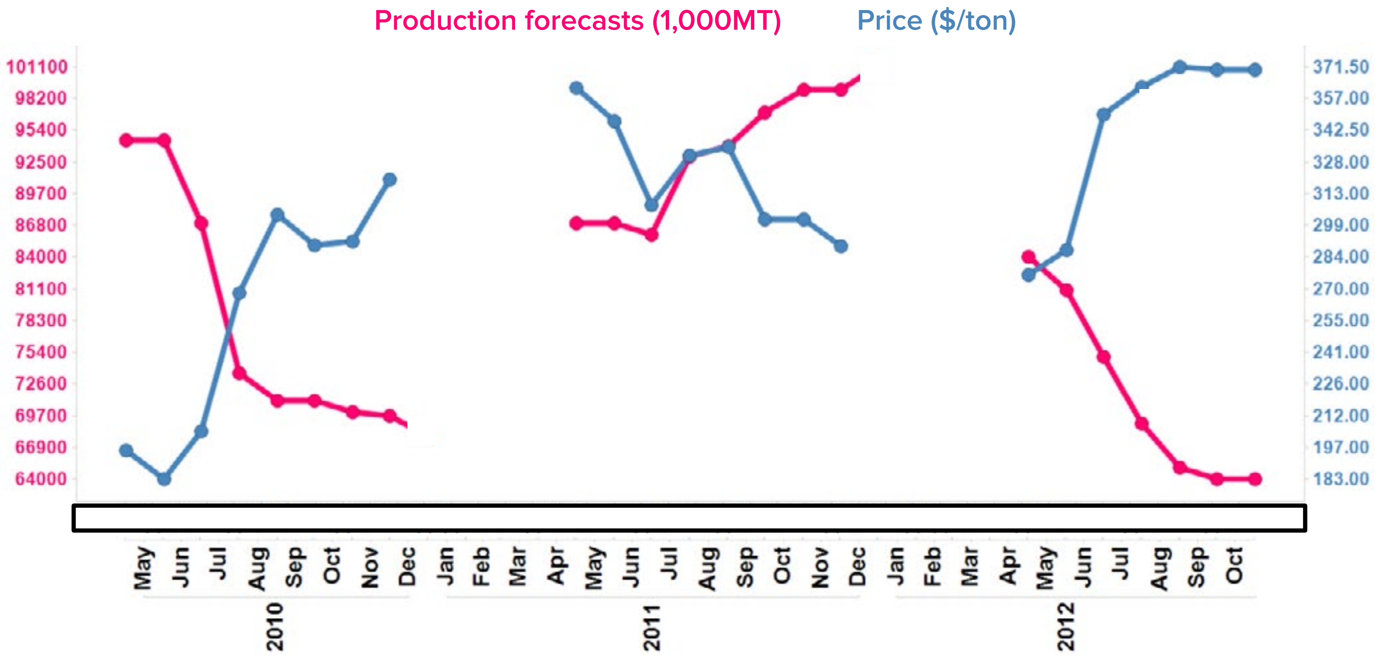
Barbara Ryan presented an international overview on the scope of how data can be used by describing the GEOGLAM (GEO’s Global Agricultural Monitoring) initiative. GEOGLAM was set up after the G20 meeting in Paris in 2011. With 103 member countries (drawn from United Nation Member States) it aims to provide more integrated EO data from satellite and ground-based sources to improve monitoring and crop yield forecasting around the globe.

Working with the Agricultural Market Information System (AMIS) and the Food and Agriculture Organization (FAO) in Rome, the crux of GEOGLAM is to use shared information to help Member States make informed decisions. Ryan calls it “the leveraging of EO for a more food secure world”.

Ryan illustrated in her talk how decades worth of satellite data can be analysed and used to mine information and therefore better inform forecasts and decision-making (Figure 4).

FIGURE 4

Aggregation of wheat production forecasts from main wheat export countries versus international market price 2010 – 2012.



Graph reproduced with permission from Barbara Ryan, Director, GEO (Group on Earth Observations) Secretariat

As Ryan put it: "In this day and age, with the technological advances that we do have, and the resources that exist, whether they are in space or on the ground, how come we can't do a better job, at the beginning of the season, of predicting where we will be at the end of the season..."

Another application of GEOGLAM's integrated approach is that the effects of governmental legislation or agricultural policy changes can actually be seen from space (Figure 5).

For example, the US government's push towards biofuels for ethanol in 2005 can be visualised using data from the US's Landsat satellites. In Waterloo, Iowa, land use changed from a regular rotation of corn and soy beans that year as farmers were incentivised by regulation to switch to corn. A preponderance of corn, until the legislation was removed in 2012, was revealed by Landsat.

Cost, access and availability are significant issues when discussing big data in the use of EO. Ryan stressed that much of the data used by GEOGLAM is free to the user from publicly-funded satellites, though it can also be used to view catalogues of high resolution data from private companies which users may have to pay for. She strongly advocates the case for free data,[5] citing her own personal experience with the US Landsat programme when she previously worked for the US Geological Survey (USGS) (see Box 1).

Whereas much of the data from government-funded satellites like the Landsats or ESA's Sentinels are currently free to the user, the private companies which provide information services to farmers are also reliant on these datasets.

FIGURE 5

Satellite images of Waterloo, Iowa showing distribution of corn and soybeans over a 12 year period (2000-2012)

Image reproduced with permission from Barbara Ryan, Director, GEO (Group on Earth Observations) Secretariat

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5. www.earthobservations.org/documents/dsp/20151130_the_value_of_open_data_sharing.pdf

Where there is increased access to free data, quality control and standards may be in question. GEOGLAM owns none of the data, acting rather like a “brokering institution” which Ryan compares with Uber not owning a single rental car, or Airbnb™ a single hotel room.

Discussions around data were not limited to availability and access, and additional considerations were raised when discussing the processing and use of EO outputs. Data of itself may be little help to end-users such as farmers or agronomists without appropriate analysis and communication to them.

Technologists from companies involved in processing data by integrating and combining multiple types from different sources, including satellites, remote sensing and on the ground observations, also spoke about issues associated with usability. It is through the linking of relevant data, adding value to it through data processing, modelling, simulations and algorithms, that the power of environmental observation is unlocked.

Analysis of the data into meaningful formats may be through indices, maps, historical comparisons and predictive forecasts. Some of the major tools are illustrated in Table 1.

TABLE 1

Tools used to process EO data and the applications to agriculture.

Tool	Type of data input	Description
Normalized Difference Vegetation Index (NDVI)[6]	Satellite data on solar reflectance	Produces a vegetation index which indicates the density of green vegetation and indicates plant health and growth.
Soil Moisture Maps	Satellite radar data	Used to inform farmers of within field differences in soil moisture to direct irrigation efforts. Maps can also be used for information about carbon storage.
Soil Brightness Maps	Satellite data processed by algorithms	Variation in soil quality reveals underlying soil physics affecting crops growing above.[7]
Lidar	Laser scanning by drones or satellites	Gives valuable information on the state of a crop. One parameter produced is crop height analysis – an indicator of plant health and yield. May also be used to discriminate between weeds and crops.
Biomass signatures	Remote sensing radar aboard satellites	Reveals insights into type, growth stage and seasonal trends of crops by the analysis of biomass. Different crops give different seasonal signatures, which can be used to produce land use maps. These can be used for regulatory crop compliance.
Soil nutrient maps	Soil sampling combined with GPS data[8]	Indicates nitrogen, leaf area indices, better weather forecasts and gap analyses to improve predictive modelling.

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6. http://earthobservatory.nasa.gov/Features/MeasuringVegetation/

7. Vince Gillingham of AgSpace told the meeting how his firm is the first to commercially produce these maps from Sentinel data, exporting this business to the Ukraine, China and Africa.

8. http://www.soyl.com/index.php/services/precision

Joining up emerging technologies

> “I can put my hand on my heart and say there will be agricultural robots – whether it will be in two years time or 30 years time – we will have to wait and see.”
>
> **Professor Simon Blackmore, Harper Adams University.**

Combining different technological approaches to agriculture also offers potential. EO technology could be used in conjunction with aerial drones and ultralight robots for farming in the future. Professor Simon Blackmore, Harper Adams University, highlighted such technological opportunities for precision farming, including laser-weeding; robotic seeding, spraying and mowing; robotic phenotyping and robotic strawberry harvesting. The UK Government is supporting the development of these complementary precision techniques through the establishment of the Agricultural Engineering Precision Innovation Centre (AGRI-EPI Centre), which aims to bring together academic and industrial research to help farmers and business owners become more profitable and sustainable.

One particular project of note is Blackmore’s challenge to achieve a “hands-free hectare” – to see if a hectare of commercial crop can be grown without human intervention for a year, using various new technologies.

“If we’ve got all this smart technology that can drive around itself, can we grow a commercial crop for one year without anybody ever going in there?” he asks, describing it as “a little like one of the grand challenges for agriculture”.

Blackmore highlighted weaknesses in the current farming system that might hinder future food production, including soil compaction by large, heavy machinery and the idea that we are coming to the end of the benefits of economies of scale. Economy of scale has benefited large fields and farms, but big machinery cannot be used in small fields.

“Where is this extra production going to come from if we are going to feed the planet?” asked Blackmore. “The big farms and the big fields I believe are very efficient with the big tractors and big equipment, but I now am starting to believe that the small to medium farms and fields have the greatest potential for increased production with appropriate technology.”

A more integrated approach, which applies EO and other emerging technologies to the whole of the food supply chain, beyond the farm-gate, was discussed, was discussed by Professor John Crawford, Rothamsted Research. Information could be connected from soil to consumer, for example, using food packaging which is increasingly containing devices that allow it to be tracked globally.

Joining up EO with other technologies such as tracking devices or even smartphone apps to monitor human health and lifestyle, could help optimise factors such as environmental sustainability, human health and food safety and quality.

Crawford asserted that better interconnectivity across the whole food chain, with strong leadership and a view to embracing complexity, would help the whole system and mitigate against risk in different parts of the supply chain.

Summary

> “The rapid advances in satellite technology, coupled with terrestrial computing – the so-called ‘Big Data’ – is just beginning now to offer new and uncharted opportunities for exploitation of this data source. However, it is also very clear that we are not yet utilising the capabilities of space for maximum benefit.”
>
> **Sir Martin Sweeting, FRS and meeting chair.**

The use of satellite and environmental observations for agri-tech has rapidly increased in recent years, and as our technological capabilities improve further, this technology holds enormous potential for increasing crop yields while decreasing farmers’ inputs, such as fertilisers and disease control. Smart farming will be vital with global challenges such as climate change, increasing population and pressure on land.

Huge technological strides have been made in what we can observe on and around the Earth. Since the launch of Landsat 1 in 1972, a host of governmental and private sector satellites are giving us an ever-more detailed view of our planet. We can “see” down to a metre’s resolution of crop, peer into the Earth’s soil structure, and even see the radar signatures of crops damaged by pests from space.

With decades of archived images, we can compare datasets both globally and locally to produce ever more accurate crop maps and forecasts; vital in a time of fluctuating crop prices, food insecurity and plateauing yields.

Harnessing these datasets – in a form that is useful to the individual farmer in the field – is key. If properly analysed and communicated, EO offers precision farming, and the chance to intervene – be it with fertiliser, irrigation, or pesticide – before nature takes its predicted course.

While its potential is immense, issues on the usability of EO for end-users need to be addressed if the benefits are to be reaped. In the UK, the basic issue of internet broadband connectivity may limit the ability of some farmers to access useful information. Restrictions around intellectual property, which hamper the interoperability between software systems, may also need addressing in order for uptake to improve. Continued engagement of the scientific community with end-users will be key.

UK farmers have been early adopters of some technologies such as GPS, and EO data is already accessed by many farmers through private sector firms which provide EO information and analyses.

Globally, huge efforts are underway to maximise and improve how EO data informs agriculture and bolsters the economy. Key to this may also be the cost of EO data, with some arguing that keeping taxpayer-funded satellite datasets free is fundamental to innovation and economic success.

If harnessed well, satellite and EO data could help achieve the dream of global food security and help mitigate future climatic threats.

> “We have the ability – whether we have the will to create a more food secure world is yet to be seen.”
>
> **Barbara Ryan, Group on Earth Observations.**

Further information

General

www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Overview4

www.earthobservations.org/geoglam

UK lidar

https://environmentagency.blog.gov.uk/2015/09/18/laser-surveys-light-up-open-data/

SAR

www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/SAR_missions

DMC Constellation

www.dmcii.com

Royal Society Observing the Earth report

www.royalsociety.org/topics-policy/projects/environmental-observation

Agri-EPI Centre

www.agri-epicentre.com

BIOMASS mission

http://m.esa.int/Our_Activities/Observing_the_Earth/The_Living_Planet_Programme/Earth_Explorers/Future_missions/Biomass

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Organisers

Professor Sir Martin Sweeting OBE FREng FRS
Executive Chairman, Surrey Satellite Technologies Ltd.

Stuart Martin
Chief Executive Officer, Satellite Applications Catapult

Professor Melanie Welham
Interim Chief Executive, BBSRC

Chair

Mark Pope
Environment Forum Chair, National Farmers' Union

Speakers

Barbara Ryan
Director, GEO (Group on Earth Observations) Secretariat

Keith Norman
Technical Director, Velcourt

Andrew Richards
Business Development Manager, Agrii

Sergio Moreno Rojas
Remote Sensing Technologist, G's Growers

David Gardner
Chief Executive Officer, Innovation for Agriculture

Vince Gillingham
Director, AgSpace

Roelof Kramer
Head of Agriculture, Rezatec

Simon Griffin
Technical Manager, SOYL Precision Crop Production

Dr Iain Cameron
Senior Remote Sensing and GIS Consultant, Environment Systems

Professor Simon Blackmore
Head of Engineering Department, Harper Adams University

Dr Jim Godfrey OBE
Farmer and Chair of Innovate UK Sustainable Agriculture and Food Innovation Platform

Andy Shaw
Defra Earth Observation Advisor

Professor John Crawford
Associate Director of Research and Scientific Director, Sustainable Systems Programme, Rothamsted Research

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For further information
The Royal Society
6 – 9 Carlton House Terrace
London SW1Y 5AG

T +44 20 7451 2500
W royalsociety.org

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