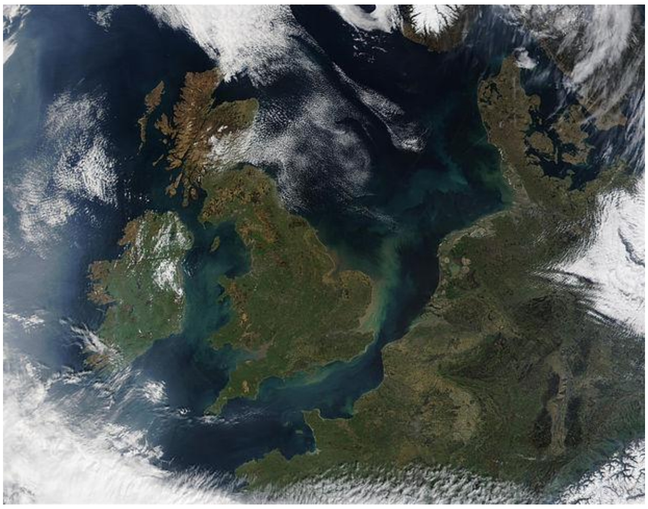
HOUSES OF PARLIAMENT
PARLIAMENTARY OFFICE OF SCIENCE & TECHNOLOGY

POSTNOTE

Number 566 November 2017

Environmental Earth Observation



Earth observation (EO) is the process of gathering information about the Earth from a range of sensors to provide monitoring data at a range of scales. This POSTnote outlines some of the environmental uses and benefits of EO data, the potential opportunities from advances in relevant technologies and challenges facing the effective use of EO data.

Overview

- Earth observation (EO) data is used for many environmental applications, including weather forecasting, climate change monitoring, disaster risk reduction and biodiversity monitoring.
- EO satellites and data are part of the UK's Space Innovation and Growth Strategy, which aims to increase the UK's share of the global space market to 10% by 2030.
- New technologies, such as small satellites and drones, are providing new ways to access EO data.
- Government departments and the private sector are seeking to develop better ways of using EO data and services to improve efficiency and value for money.
- Challenges facing the effective use of EO data include data access and lack of EO relevant digital skills. Brexit may affect the UK's interaction with EU EO programmes.

Background

Earth observation can refer to three main types:

- *In situ* surface or subsurface data collection, such as weather stations, sensors on marine buoys and other Internet of Things devices, which capture information from their immediate surroundings.
- Non-satellite remote-sensing, such as observations collected by sensors on aircraft or Unmanned Aerial Vehicles (UAVs, including drones).
- Remote-sensing from sensors on satellites.

Environmental EO from satellites is one aspect of the space economy. The UK Government has recognised the economic potential of the space industry and recently announced the Space Industry Bill to license and regulate space activities.[1,2] The Government aims to increase the UK's share of the global space economy to 10% by 2030 (projected to be £40bn).[3,4,5] Growth in the whole EO market is needed to meet this target, but the focus of this note is the growing applications environmental remote sensing.[6,7] Although the three types of EO are complementary, advantages of remote sensing over *in situ* observations include:

- Remoteness–Being able to collect data from difficult-to-access regions, such as the oceans or polar regions, and at scales too large for *in situ* monitoring, such as at the regional, national, continental and global scales. [8]
- Regular revisit times–Making repeated and consistent observations of the same features to monitor environmental changes.[9] For example, changes in the extent of Arctic sea ice, forests or urban areas.[10,11,12]

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.[13,14] Satellites collect data via a number of sensor types, including optical sensors, which derive information about the Earth from reflected sunlight, and radar sensors, which transmit and receive microwave pulses to assess, for example, the texture of the surface.[15] The capabilities of satellites can be understood with reference to resolution. There are two main types:

- **Spatial resolution** is the level of detail of each image, usually referred to as metres or centimetres per pixel. At 20m per pixel resolution large buildings can be identified and at 30cm per pixel small objects like cars.[16]

- **Temporal resolution** is the frequency with which the sensor passes over the same location. Satellites which remain over or frequently pass over a location can detect changes more rapidly. For example, weather satellites provide images of the same area roughly every 15 minutes, showing weather systems forming.

Environmental Applications of EO Data

Use of EO data has been established for environmental applications such as weather forecasting, climate change, disaster risk reduction and ecosystem monitoring.

Weather Forecasting

Weather forecast models require a large amount of data to simulate changing weather patterns accurately. Many types of data cannot be measured from the ground, including atmospheric composition and cloud depth. Satellite EO provides global data on the state of the atmosphere. The Met Office incorporates satellite data into its high-resolution UK forecasting model on an hourly basis, to enable up-to-date forecasts.[17] The availability of EO from satellites and improvements in data processing and analysis have been major contributors to increased accuracy in weather forecasting, including for extreme weather events such as hurricanes.[18,19] For example, researchers found that predictions of the strength and location of Hurricane Sandy in 2012 lost accuracy when satellite data wasn't included.[20]

Climate Change

EO plays an important role in improving our understanding of the climate system and refining climate models. Models are tested on their ability to simulate past climatic conditions to give an indication of how likely future projections are. This requires a large amount of data on hundreds of climatic variables. EO satellites provide consistent sets of observations, made over sufficiently long periods of time to differentiate between natural variability and new trends. One aim of the European Space Agency's (ESA) Climate Change Initiative (part of ESA's EO Envelope Programme and based in Harwell) is to compile records of key climate variables.[21] Satellites are also needed to supply global data that are impossible to obtain from *in situ* measurements. For example, satellite altimeters are able to measure sea level height across the world's oceans to an accuracy of centimetres (POSTnote 555).[22] Sensors can also detect the presence and infer concentrations of moisture, greenhouse gases, dust and other particles in the atmosphere.[23] They can measure sea and land surface temperature and monitor ice thickness in polar regions, areas that have been a focus of UK research.[24,25,26]

Disaster Risk Reduction

EO data are routinely used to monitor, respond to and forecast natural hazards such as floods, storm surges and earthquakes.[27] EO data are used for near real-time monitoring of disasters, allowing resources to be directed to where they are needed most. For example, the extent of flood waters can be assessed from satellites, in conjunction with data from the ground such as river gauges.[22] When combined with land elevation data, water depth can be calculated.[28] EO data from satellites can also be used to monitor ground deformation, which can be used to assess the risks associated with an ongoing tectonic event.[22] For example, radar sensors on the Sentinel-1 satellite can detect changes in ground height as small as a millimetre, and such data was used to identify the regions of largest deformation during the 2015 Nepal earthquake.[29] Such EO data can be compared over time to monitor recovery after disasters.[30,31]The UK is a partner in the International Charter on Space and Major Disasters, which provides rapid access to EO data from member Space Agencies in emergencies.[32]

Ecosystems and Biodiversity Monitoring

EO data are used for ecosystem monitoring, habitat mapping and biodiversity assessments. Repeat satellite measurements allow for continuous monitoring of ecosystems and are used to detect changes in land cover distribution such as those caused by deforestation (POSTnote 466).[33,34] Advances in spatial and temporal resolution mean that research can now be conducted on smaller scales, which are often needed for ecological monitoring. For example, satellites have been used in combination with airborne and ground-based data, to count individual animals, such as whales and zebra, or to detect wildlife crime or illegal logging (POSTnote 547).[35,36,37,38]

Other applications

The intergovernmental Group on Earth Observations (GEO) has identified a range of benefits that the application of EO data provides, including some of the above.[39] In addition, EO is essential for energy and mineral resources management, food security and sustainable agriculture, infrastructure and transport management, sustainable urban development, and water resources management.

Advances in Remote-Sensing Technology

A range of satellites, including smaller and cheaper satellites, now allow for greater coverage of the Earth (Box 1). New forms of non-satellite remote-sensing, such as UAVs, have expanded the range of applications of EO data.

Satellites

Satellites have traditionally been large, expensive and mainly financed under military, national or intergovernmental programmes.[40] For example, Envisat, an ESA EO satellite launched in 2002, cost €2.3bn to develop and launch.[41] Technological advances are beginning to allow satellites to be made on a much smaller scale with off-the shelf components, which can reduce costs for some applications (Box 1). They are able to measure some of the same features as large satellites as a result of advances in miniaturisation of sensors.[42] These developments are increasing private sector involvement in the development and operation of satellites.[43,44]

Satellite spatial resolution is also improving. The 1972 Landsat-1 satellite provided images with a spatial resolution of 80m per pixel; the Copernicus Sentinel-2 mission provides resolutions of 10m per pixel.[45] Small satellites in low orbits, such as the DMC3 satellites, can provide images at a resolution of 1m or lower.[46] Temporal resolution is also increased by the use of 'constellations'; multiple satellites deployed in sequence for a single mission. The US company Planet recently launched a constellation (known

Box 1. Satellite Capabilities and Regulation
Satellites have been used for EO since the 1960s. Different types of satellites can provide information at different scales:

- Geostationary satellites are high altitude (~36,000km above the Earth).[47] They remain fixed above one geographical location and provide frequent data about that region (high temporal resolution). They are particularly useful for monitoring change over time, such as changing weather patterns.[48]
- Low earth orbit satellites are at a height of 200-2000km above the Earth.[47] Often these pass over the or near the poles on each orbit, imaging different sections of the Earth as they orbit. As these are closer to the Earth, the spatial resolution is generally higher (e.g. show more detail about the Earth's surface), but the temporal resolution is lower (e.g. every 1-2 weeks).

Satellites can be categorised by size. Small satellites are usually defined as satellites with a mass below 500kg, and include microsatellites (10-100kg); nanosatellites (1-10kg); and picosatellites (0.01-1kg).[49,50] Launch costs can sometimes be reduced, as several small satellites can be launched at once, or they can 'piggyback' on the launch of larger satellites (POSTnote 514, Box 2).[51] However, in the UK operators are required to obtain liability insurance (for pre-launch, launch and in-orbit stages) for each satellite, which can be prohibitively expensive for small satellite operators.[52,53] Liability is currently capped at €60 million; the draft Spaceflight Industry Bill currently does not retain this cap.[1] Plans for a spaceport in the UK could also reduce the cost of launching satellites for operators.[3,52]

as a 'Flock') of 88 small satellites (known as 'Doves') that can provide daily imagery of the entire Earth surface.[54] However there are concerns that the launch of large constellations could increase the amount of space debris, which can be a threat to satellites (POSTnote 355).[55]

Non-satellite Remote Sensing
Non-satellite remote sensing technologies can be used to complement satellite and *in situ* EO. Civilian UAVs can be an inexpensive method of collecting data at a higher spatial resolution (less than 20cm).[56] Miniaturisation of technology means an increasing array of sensors can be attached to UAVs.[57] They are particularly useful over defined areas that are expensive to survey from the ground, where disturbance should be avoided or where high-resolution data is required.[58] For example, UAVs have been used to monitor changes in the size of the breeding population of birds.[59] They are also beginning to be used to inspect and repair energy infrastructure, such as gas pipelines, which is currently labour intensive and expensive.[60,61] There are limitations to the use of UAVs, including regulatory issues and the requirement to operate within 'line of sight'.[62] New technologies and regulatory frameworks are being developed for 'beyond visual line of sight' operation, which would extend the uses of UAVs (POSTnote 479).

High Altitude Platform Stations (HAPS), such as airships, are also being used for EO. HAPS operate between 20 and 50km above the Earth, providing a 'bridge' between satellite information and UAV remote-sensing.[63,64] Some types of HAPS can remain in the atmosphere for periods of months to years.[65] HAPs could be used for many EO purposes, such as monitoring seismic events.[66]

Data Access
Open Data
Open data are generally free to access, use and share.[67] The Open Data Barometer ranks the UK number one in the world for data openness.[68] The Open Data Institute explains how open data makes public services more efficient, aids open policy-making, and drives innovation and economic growth.[69] It also substantially increases data use for research and commercial purposes.[70,71] For example, in 2008, the US Geological Survey released nearly 40 years of Landsat EO imagery into the public domain. The download of Landsat data has since increased two orders of magnitude (53 scenes per day to 5700 scenes per day), with an estimated annual economic benefit of $1.7bn in the US, and $400m elsewhere.[72] EO data from the Copernicus programme are free and open at the point of use (Box 2). However, there are costs associated with turning raw data into information that supports applications.

Commercial Applications of Data
Environmental EO data can be used for a variety of commercial applications. Access to open EO data has allowed businesses to develop value-added products, applications and services built on existing data, known as downstream services. Downstream services are a large component of the market potential of EO.[73] The downstream market potential of Copernicus was estimated at €0.7bn in 2012; this is expected to grow to around €1.8bn by 2030.[73] Both the UK Government and the EU have highlighted the importance of stimulating small and medium enterprises (SMEs) to build and deliver such services.[3,73] In the UK, the Satellite Applications Catapult has been set up to drive economic growth through the application of satellite data.[74] Examples of downstream services built on EO data include:

- Local authorities using combined EO and other geospatial data to aid urban planning
- Farmers monitoring crops using automatically prepared and interactive EO data.[75]

Public Sector Applications of Data
The UK Government is developing ways to make better use of EO data within the public sector. The UK Space Agency's Space for Smarter Government Programme (SSGP) aims to help departments access advice and expertise and improve public sector uptake of satellite data, information and services.[76] Defra is one of the first to have publically highlighted their intentions to use environmental EO data more effectively for policy. With SSGP support, it has established an EO Centre of Excellence to coordinate departmental expertise and improve data handling infrastructure.[77] There are also plans for a cross-cutting UK Government Earth Observation Service, to provide a public sector platform for accessing and developing EO services.[78] Such activities include land cover mapping and water monitoring.[79] ESA's Integrated Applications Programme helps to provide technical solutions using EO data in sectors such as health, energy and transport.

Current and Future Challenges
Data Volume and Skillset
There has been an exponential increase in the amount of EO data available as more satellites are launched and new methods are developed to collect EO data. For example, by Sentinel-1 currently produces over 10TB of EO data per day (equivalent to around 5 million digital camera photos).[80] This is collected on such a scale as to make analysis a challenge

Box 2. The Copernicus Programme
Copernicus is a European Commission funded EO programme, delivered in partnership with the European Space Agency (ESA) and other European agencies, including the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).[81] For the period 2014-2020, it will be Europe's primary EO system with a budget of €4.3bn.[82] Copernicus has three main components:

- **Space Component**: Copernicus will use satellite EO data from new satellites called Sentinels. Each Sentinel mission will collect different EO information and are deployed as two satellites, allowing for more frequent data collection over the same area.[83] UK users can access the data via the Sentinel Data Access Service (SEDAS). Copernicus will also use data from existing satellites, known as Contributing Missions, including weather data from EUMETSAT satellites.
- ***In situ* Component**: This includes ground, sea and airborne measurements. These provide data at smaller scales than satellites, and help validate satellite data. *In situ* networks (e.g. weather stations) are managed by member states.[84]
- **Services to Users**: Copernicus also delivers six managed services that support a range of applications: Atmospheric Monitoring; Marine Environmental Monitoring; Land Monitoring; Climate Change; Emergency Management; and Security. These use data from both the satellite and in situ components.

As a member of the EU and ESA, the UK has been involved in the establishment and development of Copernicus. The UK policy lead for Copernicus is Defra, with the UK Space Agency leading on the Copernicus Space Component. UK science agencies (e.g. STFC, RAL Space) and businesses (e.g. Airbus) have been involved in various aspects of the design and deployment of Sentinels.[85,86] A number of UK institutions have contracts to develop and deliver Copernicus Services. The European Centre for Medium Range Weather Forecasts, based in Reading, is responsible for delivering the Atmosphere and Climate Change services.[87] The UK is also a key member of other contributing agencies such as EUMETSAT, in which it is represented by the Met Office.

(POSTnote 468).[88] However, a lack of relevant big data skills has been identified as a barrier, in particular for the effective use of EO data.[52,89]

Computing and Processing
Traditional computing infrastructures are inadequate for storing and processing increasingly large volumes of EO data.[40,90,91] However, cloud computing, the use of remote servers accessed via the internet to manage and process data, is being used to address this (POSTnote 510).[92] Cloud computing allows for on-demand, flexible and cheaper access to data and computing resources, and for the hosting and development of web-based EO services.[40,93] For example, the Satellite Applications Catapult and Centre for Environmental Data Analysis operate the Climate, Environment and Monitoring from Space (CEMS) service, processing, analysing and disseminating EO data.[94] New data preparation and analysis techniques, such as Analysis Ready Data (ARD; data that is pre-processed to a standard set of requirements) and machine learning (computer programs which improve with experience and use) will also be important (POSTnote 468).[40,95,96,97]

Validation and Quality Assurance
EO data is increasingly obtained from a wide range of sensors and platforms. All data needs to be appropriately validated to ensure it is an accurate representation of what is being measured and is fit for purpose.[98,99,100] In addition to validation using *in situ* measurements, novel citizen science approaches (POSTnote 476) present opportunities for data validation.[101,102] For example, in 2015 the COBWEB project used citizen surveys of Japanese Knotweed to help validate remote-sensing data on the risk of knotweed occurrence in Snowdonia National Park.[103] To ensure the quality of EO data users require information about where the data has come from and how it has been processed ('traceability').[104] Quality assurance also helps ensure data can be combined from different sources ('interoperability').[105,106]

Communication between Specialists and Users
Some have identified that poor communication between EO specialists and end-users can hinder the effective use of EO data.[107,108] There are concerns that there is a lack of awareness of what EO data can do in a range of sectors; programmes, such as SSGP, aim to address this for the public sector.[109] In academia there are calls for increased engagement with end-users throughout the research process, to ensure that users understand the capabilities and limitations of the data, and EO specialists understand the needs of users.[110,111] In the commercial and public sectors, there is a drive towards data and services which can be easily used by non-specialists, such as ARD.[112]

International Collaboration and Trends
Internationally, many countries are using EO data and launching EO satellites, including India, Brazil and Nigeria.[113,114,115] In the US, the Trump administration wants to reduce funding for NASA's Earth sciences programmes in the 2018 budget, including five EO missions, but these cuts are unlikely to all be approved by Congress.[116,117] In the UK the dominant concern is how Brexit may impact access to international EO programmes and collaboration. For example, the Copernicus programme provides free and open EO data at the point of use, which has been identified as a key benefit to the UK.[77] Copernicus is EU funded, delivered jointly with ESA and other European agencies (Box 2). There is a lack of clarity as to whether the UK will have access to Copernicus services after it leaves the EU. In July 2017, the UK Government announced it would like to continue its involvement in Copernicus. [118] Membership of ESA and EUMETSAT are not related to membership of the EU, but the UK may have to re-negotiate access to services that are EU funded, and may be less involved in the final implementation of satellites and services as the programme rolls out.[119,120] It is also unclear whether current contracts for service provision and satellite manufacture will be renewed.[121] There are also concerns that UK companies which currently manufacture satellites and instruments for Copernicus (e.g. Airbus and Surrey Satellite Technology Limited may not be able to bid for new contracts.[122]

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POST is an office of both Houses of Parliament, charged with providing independent and balanced analysis of policy issues that have a basis in science and technology. POST is grateful to Amy Creese for researching this briefing, to NERC for funding her parliamentary fellowship, and to all contributors and reviewers. For further information on this subject, please contact the co-author, Dr Jonathan Wentworth.

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