SPACE-BASED EARTH OBSERVATIONS FOR CLIMATE SECURITY

KEY MESSAGES

- **Essential data source**. Earth Observation (EO) satellites are the principal source of global, timely data on the environmental health of the planet, and UK scientists are at the forefront in developing technologies to translate EO data into actionable information.
- **Critical monitoring and verification**. EO data are vital for monitoring the causes and effects of climate change, achieving rigour in the Paris Agreement global "stocktakes" and for emergency responses to environmental disasters.
- **Route to inform society**. EO data are used to engage and inform society about how climate is changing and the impacts of those changes on our lives, livelihoods and the natural world. It is essential that these EO data are open and freely available and made accessible in formats that do not require expert knowledge.
- **Human resource is a limiting factor**. To fully realise the benefits from EO in the above areas, expansion of the pool of people with advanced EO science skills and knowledge is needed. Advances in technology will also be required to exploit the potential of EO data.
- **The EU Copernicus EO programme**, in partnership with the European Space Agency (ESA) and other national space agencies, is the most ambitious EO initiative in the world and central to global climate monitoring. The UK science and technology community have made key contributions to Copernicus and should continue to do so to maximise its long-term impact alongside contributions to other complementary international space programmes.

INTRODUCTION

The need for accurate and precise data on the current state of the planet has never been more pressing. Given the rapidity of environmental change there is an urgent need for timely, reliable evidence to support climate action and to monitor the effectiveness of mitigation measures. Recent years have seen a proliferation of satellite sensing systems, both state and privately funded. Utilisation of this resource for monitoring planetary health is significant, but much greater potential can be unlocked if more skilled people, computational resources and international co-ordination can be brought to bear.

This briefing lays out the importance of EO data for achieving the goals of COP26, alongside opportunities to harness EO to improve climate security, achieve the UN Sustainability Development Goals and meet the need for actionable evidence for policy on climate change mitigation and adaptation.

Briefing authors:

- Jonathan Bamber, University of Bristol
- Paul Bates, University of Bristol
- Helen Brindley, Imperial College London and National Centre for Earth Observation
- Ben Evans, University of Cambridge
- Toby Jackson, University of Cambridge
- Chris Merchant, University of Reading and National Centre for Earth Observation
- Matthew Davey, Scottish Association for Marine Science
- Paul Palmer, University of Edinburgh and National Centre for Earth Observation
- Marian Scott, University of Glasgow
- Tom Spencer, University of Cambridge

WHAT IS EARTH OBSERVATION (EO)?

Earth Observation refers to observations of the Earth's surface, properties and atmosphere by satellites, airborne and ground-based sensors, which are all important elements of integrated observing networks. This briefing, however, focuses on satellite observations because of their global coverage and central importance to COP26 goals. EO data are being employed to develop global stocktake estimates and to assess the pace of climate change and its impacts and can provide near-instantaneous information over almost all parts of the Earth system.

Ocean variables include, for example, wind speed and direction, wave height, sea level change, surface temperature, and biological productivity. Key **land surfaces variables** include crop health and yields, forest carbon stocks, soil moisture, urbanisation, water quality and quantity, and mass movements such as landslides, flooding and other natural hazards. For the sensitive and delicately balanced **frozen parts of the planet** EO provides synoptic data on e.g. snowcover, permafrost thaw, sea ice, glaciers, ice sheets and icebergs. EO provides vital data on **atmospheric properties** such as vertical and horizontal profiles of temperature, water vapour, precipitation, trace and greenhouse gases associated with air quality and climate. In addition, EO is an important tool for **hazard detection** and monitoring, both natural and human-induced.

WHAT IS THE ROLE OF EO IN COP26 AND CLIMATE POLICY?

EO data are invaluable in a wide range of applications relevant to climate policy, assessing progress towards Paris goals and verification of national declarations on carbon budgets. The following two examples illustrate the central role EO data play in achieving the policy-related goals of COP26.

USE OF EO FOR POLICY AND DECISION MAKING: TWO EXAMPLES.

Greenhouse Gas (GHG) emissions monitoring, verification and global stocktake

The Paris Agreement on Climate Change commits parties to develop progressive actions to reduce national GHG emissions towards a collective goal of mitigating the future rise in global mean temperature. GHG emission monitoring and verification plays a central role in the Paris Agreement, particularly as part of 5-yearly Global Stocktakes (GST), which will quantify the global sum of national emissions, but also as a way of ensuring individual countries act on their progressive pledges to reduce emissions as part of their Nationally Determined Contributions (NDCs). The first GST will be in 2023 and the measurements that will be used will be collected up until 2021. Earth observation data play an important role in this monitoring, providing a transparent and self-consistent assessment of GHG emissions[2]. This EO-based approach has, for example, been adopted by the Indian government to provide independent verification of their methane emissions[3].

Satellite observations, however, do not directly measure GHG fluxes (emissions minus uptake) and cannot unambiguously distinguish between anthropogenic and natural sources so that sophisticated numerical methods are necessary to translate the observed atmospheric CO_2 and CH_4 columns into geographical distributions of estimated fluxes, while auxiliary EO information is required to identify the source. Consequently, a GHG emission monitoring and verification system capability describes an integrated data and analysis framework that links the carbon cycle and atmospheric chemistry. The upcoming French-UK MicroCarb satellite, due for launch in 2022, will greatly improve the spatial resolution of CO_2 flux observations down to, for example, the scale of cities the size of Paris. These developments are particularly relevant to quantifying emissions from countries that are geographically small and/or cloudy. The UK science base includes world-leading groups in this field including, for example, as partners in the international Advanced Global Atmospheric Gases Experiment.

EO for weather extremes and environmental hazards

The IPCC have noted that climate change projections point to increased intensity and frequency of extreme weather events. Not only is the environment impacted by droughts, floods, wildfires, landslides, hurricanes of increasing strength and heatwaves, but these also have negative effects on public health and livelihoods, food security, biodiversity, infrastructure and economies and disproportionately impact the poorest and most marginalised communities. EO data support assessments of the scale of such impacts, thus assisting disaster management and adaptation. The spatial coverage of EO data is key to such assessments since extreme events may extend beyond a single region or national border and often occur in locations with sparse ground monitoring or that are difficult to reach. Existing and new EO platforms are increasingly being developed to provide real time services that benefit hazard monitoring and management such as polar shipping and oil spill hazards (e.g. https://polarview.org/).

INTERNATIONAL CONTEXT AND LANDSCAPE

The **Group on Earth Observations** (GEO), established in 2005, is an intergovernmental partnership aimed at improving the availability, access and use of EO data and promoting open data policies. It currently has 113 national members (including the UK) and 135 participating organizations such as the European Space Agency, the Belmont Forum (an international partnership funding environmental research), the major EO providers and several UN agencies. It recently established a Climate Change Working Group related to the Paris Agreement and another on disaster risk reduction, which are designed to develop a comprehensive EO strategy in these areas that will be important for future coordination. GEO also coordinates a work programme of over 60 activities, many of which are relevant to COP26. **Private companies** such as Planet Labs, MethaneSat and SPIRE have several hundred active satellites in orbit, providing near-daily coverage at a resolution of between 3.7m and 50cm. Access to the data is, in general, by subscription and is, therefore not equitably distributed and, in some cases, biased against nations that would benefit most from such data. Some of these commercial programmes are shown in Figure 1 alongside the dramatic improvement in spatial resolution and number of satellites over recent decades.

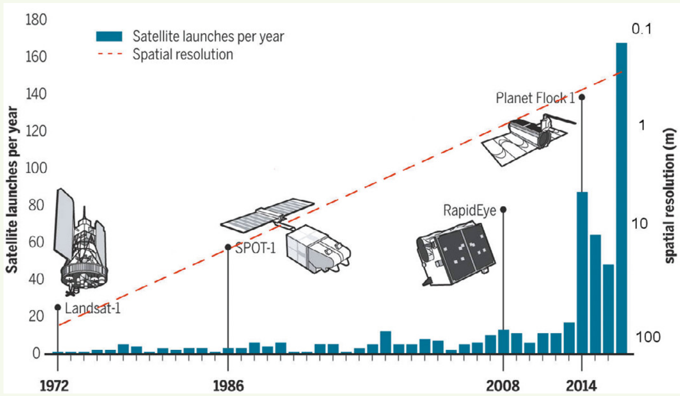

Figure 1: Number of visible imaging satellites and the approximate evolution in spatial resolution (right hand axis) over time since the launch of the first multispectral imaging satellite Landsat-1 in 1972[1].

The EU Copernicus Programme is the most ambitious, coordinated and comprehensive EO initiative to date. By 2030 it will comprise a fleet of more than 20 dedicated satellites in addition to a suite of third party contributing missions. The Copernicus programme is coordinated by the EU in partnership with several other agencies including the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the European Space Agency (ESA) and the European Centre for Medium Range Weather Forecasting (ECMWF). A key component of the programme is a comprehensive data processing and archival service with a core principle of providing timely data that are free to use. The data services comprise six themes: atmosphere, marine, land, security, emergency and climate change.

Using flooding as an illustrative hazard, EO data can be used to monitor the current status of a water body, identify the extent of past inundation events, as well as feeding into flood forecasts when combined with other information such as topography, elevation, soil moisture and precipitation. The integration of EO data with often sparse ground observations and models, via a process called data assimilation, can provide timely information on current and future flood risk and so inform hazard mapping, flood risk maps, mitigation measures and spatial planning of infrastructure. However, current uncertainties in inundation mapping from satellites can be large and key data sets required for accurate computer modelling of floods (such as topography, precipitation and soil moisture) are still difficult to observe to the required accuracy and resolution[4].

USE OF EO DATA FOR QUANTIFYING CLIMATE CHANGE

EO provides indispensable and unique measurements of changes in sea level, atmospheric composition, glaciers, ice sheets, groundwater, temperature and many other aspects of climate and habitability. These data enable scientists and policymakers to understand, diagnose and predict the rates, patterns and causes of climate change around the world. This section uses three examples to illustrate how EO data are utilised and their potential and is necessarily a selective sample. The examples cover a critically sensitive climate region with hemispheric teleconnections (the Arctic), a globally important ecosystem (the densely-populated coastal zone) and a key component of the carbon cycle (deforestation) with associated major impacts for international policy. While using these as exemplars, it is important to note that the global oceans cover 70% of the surface of the Earth, are important sinks for CO_2 and have been monitored from space for multiple decades including, for example, mean sea level, sea surface temperatures and ocean primary productivity[5].

The Arctic as an early warning system

The Arctic, home to 4 million people, is undergoing climate warming at about twice the global average rate. This is a result of amplification mechanisms in the Arctic climate system. What happens in the Arctic, however, does not stay there. Consequences of this warming for ecosystems, the physical environment, built environment and human activities are manifold[6].

Permafrost stores sufficient carbon in frozen soils to raise global temperatures by about 3ºC, if it were released during thaw. Meltwater from the Greenland ice sheet is raising global sea level and may influence ocean circulation[6].

EO data across the Arctic provide evidence of permafrost thaw and associated carbon release, sea ice and iceberg charts for shipping, and track the rapid demise of multi-year sea ice (Figure 2). Arctic sea ice has often been described as the paradigm of climate breakdown. Since reliable satellite records began in 1979, the perennial sea ice extent has declined by 13%/decade and has reached the lowest level since possibly 1500 years ago. Pan-Arctic observations of extent and concentration are only possible via EO[7]. However, EO services currently available for Arctic sea ice are fragmented, and often ill-suited for policy and/or climate applications[8]. As **the** region at the frontline of climate breakdown, there is an urgent need to provide an integrated, holistic, co-developed Arctic Observing System relevant to stakeholder needs.

Driven by current observational limitations and the needs for policy-relevant, timely evidence for Arctic environmental change, the EU Copernicus programme has recently commissioned a new sensor, the Copernicus Imaging Microwave Radiometer (CIMR) that will operate on up to three satellites, providing daily coverage of Arctic sea ice and oceans. The earliest launch date, however, is 2028 with, potentially, a gap of several years in observing capacity. The China Meteorological Administration Feng Yun3 (FY3) satellites may be able to provide a bridge between now and CIMR highlighting the importance of international co-operation and coordination in providing continuous, validated global records of essential climate variables. These are physical, chemical or biological variables that critically contribute to the characterization of Earth's climate, as defined by the World Meteorological Organization, and are primarily measured and monitored from space (https://climatemonitoring.info/ecvinventory).

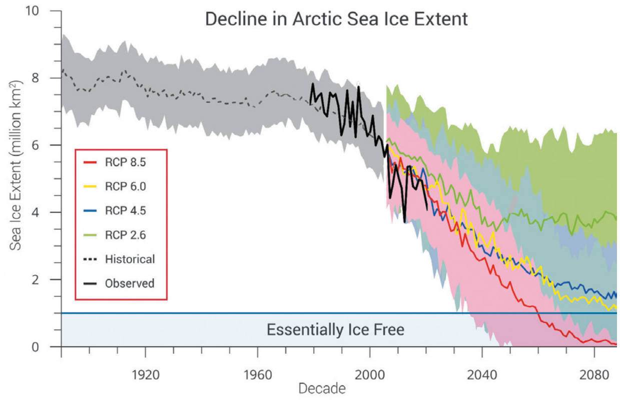

Figure 2: Record of end of summer (multi-year) sea ice covering historical ice charts from sparse shipborne and coastal observations (1900–1978), EO data (1979–present) and projections from climate model simulations for different GHG emission scenarios up to 2100. The accepted definition of an ice-free Arctic ocean is when the sea ice area is below 1 million km^2. Depending on the scenario this could happen by mid-century or earlier. (Adapted from US National Climate Assessment report, 2014[9]).

The critical coastal zone

Vegetated coastal ecosystems such as saltmarshes, mangroves and seagrasses are productive ecosystems that also trap sediments and the carbon that those sediments contain. Their per-hectare potential for sequestering carbon is substantially higher than most terrestrial ecosystems including tropical forests[10]. They are biodiversity hotspots and provide diverse regulating, provisioning and cultural services that include coastal protection. These environments are exceptionally vulnerable to expected environmental changes such as sea level rise and increased storminess and are being lost rapidly in many locations[10]. It is, however, becoming clear, in management and policy terms, that the coastal zone is a prime candidate for the implementation of **nature-based solutions** to climate change[11]. Coastal flood protection and erosion hazard reduction by ecosystem creation and restoration can, in some locations, provide a more sustainable, cost-effective and ecologically sound alternative to conventional coastal engineering.

Such ecosystems occupy a coastal domain that is challenging to access, leading to a paucity of environmental data. EO technologies are proving transformative for monitoring and understanding this fragile interface zone. For example, EO has been used to provide national and regional inventories of coastal ecosystems and for providing global inventories of saltmarshes, mangroves and seagrasses. These baselines demonstrate the efficacy of EO approaches in providing data within this shallow-water zone that is inaccessible to both land based and ship-borne survey.

Sophisticated EO analyses can provide diverse and detailed ecosystem insights at local or regional-scale. These approaches are, however, not widely available or implemented and investment in Knowledge Transfer and local training would greatly improve their uptake and contribution to decision making.

Global Plant Biomass

An increasing number of countries have a legal or policy commitment to reaching a net zero carbon economy. In order to achieve this, we need to measure how much carbon there is in biological communities and how this changes over time. EO is the most effective tool to measure the global terrestrial carbon cycle and how much carbon is potentially stored in vegetation. The power of this technique is that it can now be used to measure carbon budgets across multiple scales, from the largest tropical forests to the smallest algal blooms in Antarctica. It can also be used as a powerful conservation tool in these ecosystems and in global stocktake assessments.

An excellent example of the impact of EO in large scale forest conservation is the Global Forest Change data set which has been widely used to monitor annual deforestation and land-use change at 30 metre resolution[12]. In addition, global forest above-ground biomass has been mapped using a combination of EO and field data. The UK-led ESA BIOMASS mission due to be launched in 2023 and new laser ranging satellites will substantially improve our ability to monitor dense biomass forests and target areas for conservation and restoration. Combined with networks of field data and modelling work, these advances in EO enable us to accurately quantify the sources and sinks of forest carbon.

IMPLICATIONS FOR POLICY

Translating the vast (and growing) volumes of EO data into actionable information remains a technical and societal challenge which requires Big Data infrastructure and expertise, analytics, appropriate visualisations, international cooperation and stakeholder involvement. Co-design and co-production are essential for generating relevant, usable resources that are free to use.

Addressing this challenge requires action on skills and training to widen the pool of expertise providing informed brokerage between the science and policy needs. An exemplar approach to this is the £152m International Partnership Programme supported by the UK Space Agency, which aims to deliver sustainable economic, societal and environmental benefits to developing countries and which, for example, won the 2020 GEO Sustainable Development Goals Award.

Despite major progress in satellite technology and data analysis, in many areas we do not possess the robust operational monitoring and analysis systems that can produce quality-assessed EO products in a form that can be used by non-specialists. Greater investment in the development and long-term support for integrated observing systems, co-designed and created with stakeholders and end-users is essential to overcome the current limitations. In addition, scientists beyond the EO domain (such as those working in computer vision, Artificial Intelligence, Machine Learning and statistical inference), citizens, business and policy makers need to work together and between the traditional discipline-specific silos in which these communities have tended to operate.

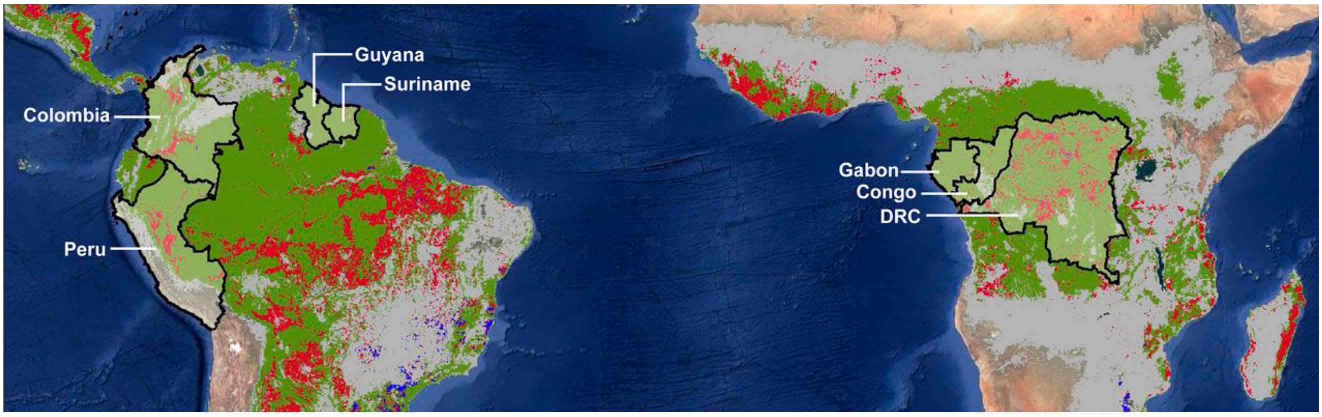

Figure 3: Map with high forest cover, low deforestation countries. Base map (green) is forest cover estimated in year 2000 applying a 30% forest cover threshold; red is measured tree cover loss, and blue is measured tree cover gain between 2001 and 2017 derived from the Global Forest Change dataset[13].

- **Capacity and capability building**. As an environmental science leader, the UK can, and should, contribute capacity-building in EO technology, methodologies and skills in support of nations not yet positioned to use EO effectively within the Paris Agreement process. This should include expanded provision of education and training in EO science and climate nationally but also through Official Development Assistance (ODA) programmes.
- **International cooperation** and coordination are needed between the space agencies, national funding bodies, NGOs and organisations such as the GEO and UNFCCC to ensure full and appropriate use of EO data is achieved, that the resources are free to use, and that they are tailored to stakeholder needs.
- **Trans-national funding**. A mechanism to fund such cooperation at an international level does not exist but will be critical to achieving the full potential of EO data and technology.

Confidence in the underlying observations and in the validity of their interpretation is needed to support major policy decisions. The UK is well positioned to play a leading role in EO data quality assurance, as exemplified by the UK-proposed TRUTHS mission being developed by ESA. This expertise should be leveraged by, for example, expanding national and overseas aid programmes targeted at strengthening the integrity of the global stocktake process, national GHG verification and regional monitoring of carbon sources and sinks.

REFERENCES

1. Finer, M., et al. (2018), Combating deforestation: From satellite to intervention, *Science,* 360(6395), 1303-1305, doi:10.1126/science.aat1203.
2. Janssens-Maenhout, G., et al. (2020), Toward an Operational Anthropogenic CO_2 Emissions Monitoring and Verification Support Capacity, *Bulletin of the American Meteorological Society,* 101(8), E1439-E1451, doi:10.1175/bams-d-19-0017.1
3. Ganesan, A. L., et al. (2017), Atmospheric observations show accurate reporting and little growth in India's methane emissions, *Nature Communications,* 8(1), 836, doi:10.1038/s41467-017-00994-7
4. Beven, K., et al. (2020), Developing observational methods to drive future hydrological science: Can we make a start as a community?, *Hydrological Processes,* 34(3), 868-873, doi:https://doi.org/10.1002/hyp.13622
5. Kulk, et al., 2020. Primary Production, an Index of Climate Change in the Ocean: Satellite-Based Estimates over Two Decades. *Remote Sensing* 12, 826. https://doi.org/10.3390/rs12050826
6. Meredith, M., et al. (2019), Chapter 3: Polar Regions, in *IPCC Special Report on the Oceans and Cryosphere in a changing climate,* edited by H. O. Pörtner, et al., Intergovernmental Panel on Climate Change.
7. Stroeve, J., and D. Notz (2015), Insights on past and future sea-ice evolution from combining observations and models, *Global and Planetary Change,* 135, 119-132, doi:https://doi.org/10.1016/j.gloplacha.2015.10.011
8. Lee, C. M., et al. (2019), A Framework for the Development, Design and Implementation of a Sustained Arctic Ocean Observing System, *Frontiers in Marine Science,* 6(451), doi:10.3389/fmars.2019.00451
9. U.S. Global Change Research Program. (2014). *Climate change impacts in the United States: U.S. national climate assessment*. Available at: https://nca2014.globalchange.gov/
10. Mcleod, E., et al. (2011), A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2, *Frontiers in Ecology and the Environment,* 9(10), 552-560, doi:https://doi.org/10.1890/110004
11. Van Coppenolle, R. and S. Temmerman, 2020: Identifying global hotspots where coastal wetland conservation can contribute to nature-based mitigation of coastal flood risks. *Global Planet. Change,* 187, 103125, doi:10.1016/j.gloplacha.2020.103125
12. Hansen, M. C., et al. (2013), High-Resolution Global Maps of 21st-Century Forest Cover Change, *Science,* 342(6160), 850-853, doi:10.1126/science.1244693
13. Roopsind, A., B. Sohngen, and J. Brandt (2019), Evidence that a national REDD+ program reduces tree cover loss and carbon emissions in a high forest cover, low deforestation country, *Proceedings of the National Academy of Sciences,* 116(49), 24492-24499, doi:10.1073/pnas.1904027116

HOW TO CITE THIS PAPER

Bamber, J., Bates, P., Brindley, H., Evans, B., Jackson, T., Merchant, C. Davey, M., Palmer, P., Scott, M., and Spencer, T. (2021). Space-based Earth Observations for climate security. *COP26 Universities Network Briefing.*

Sponsored by UK Research and Innovation (UKRI)

THE COP26 UNIVERSITIES NETWORK

This briefing is produced in association with the COP26 Universities Network, a growing group of more than 60 UK-based universities working together to help deliver an ambitious outcome at the UN Climate Summit in Glasgow and beyond.

The briefing represents the views of its authors (listed on page one) and not necessarily that of every University or institution participating in the network. For more information about the COP26 Universities Network, please contact **cop26universities@imperial.ac.uk**