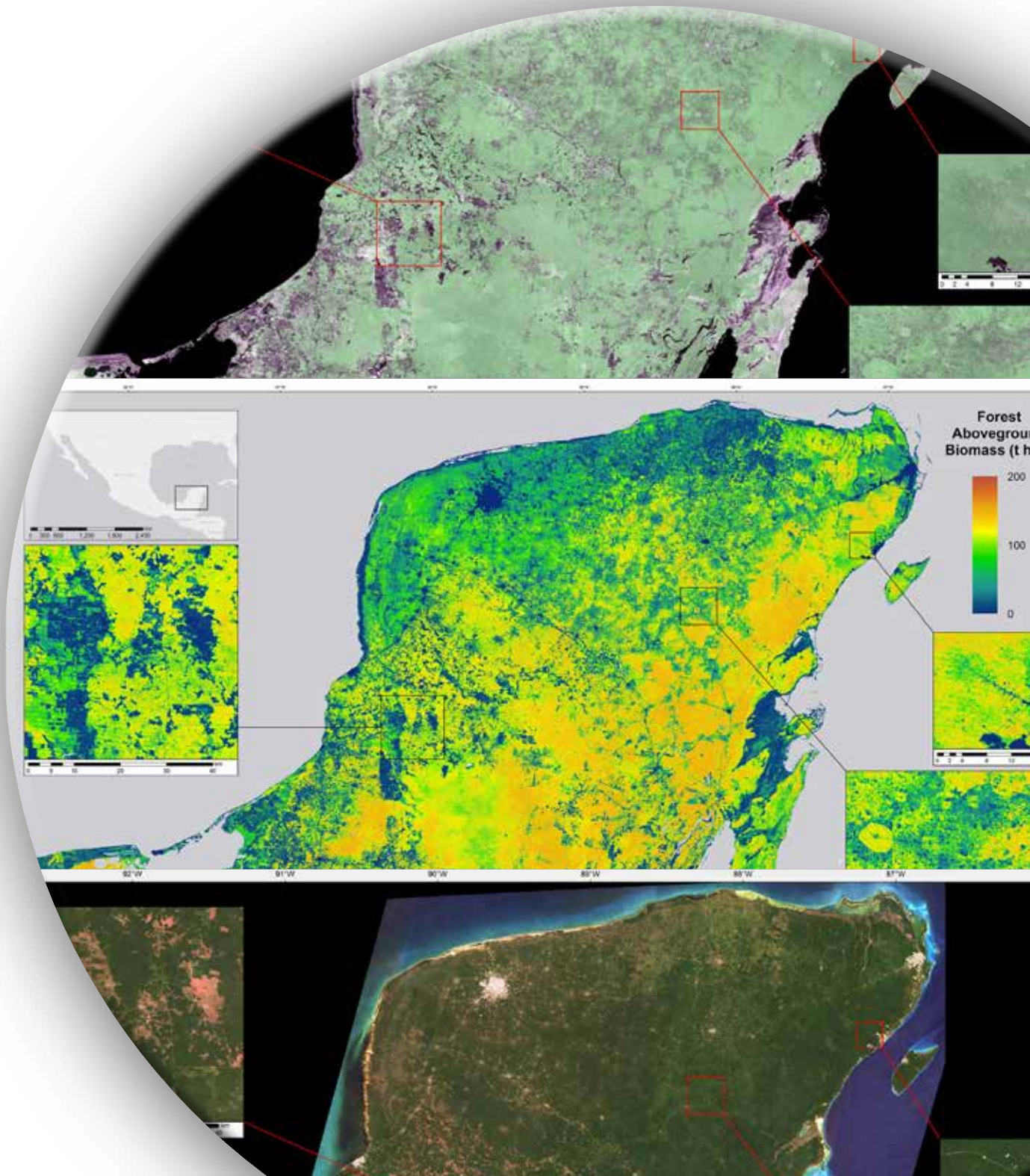
National Centre for Earth Observation

NATURAL ENVIRONMENT RESEARCH COUNCIL

The National Centre for Earth Observation

Impact Brochure



Foreword

National Centre for Earth Observation – the **Bigger** Picture

NCEO is a research centre funded by the UK's Natural Environment Research Council (NERC) with more than 100 scientists distributed across leading UK universities and research organisations. Our annual income is £11.5M, with £7M coming from NERC to carry out an ambitious programme of environmental research using satellite Earth Observations (EO), data assimilation and modelling techniques to answer fundamental science questions regarding the Earth system. This work results in about 200 peer reviewed journal articles every year and contributes to major environmental science reports nationally and internationally. The £4.5M of non-NERC income is derived from worldwide collaborations with industry, government and third sector organisations. NCEO links scientific expertise in environmental science with progress in the satellite technology sector and supports the exploitation of satellite data for societal and economic benefit. This brochure provides a brief summary of our impact beyond the academic research domain.

If you are considering a possible collaboration with us or would like to know more about how we might be able to work with you please contact me and I will put you in touch with the most relevant of our experts.

> “We are passionate about the importance of our research to society; EO science is increasingly beneficial for a range of applications.”

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Improved Monitoring of Crop Production

NCEO scientists are aiming to improve models for efficient and accurate monitoring of crop production, providing timely information for a range of agricultural activities.

Professor Mat Williams, NCEO-Edinburgh, is leading an industry partnership project with GSi (www.surfaceintelligence.com), an Edinburgh-based company, and Data Lab (www.thedatalab.com) aimed at developing satellite-based metrics related to crop yield and maps of crop cover type from machine learning with the intention to support yield forecasting for brokers.

Professor Phil Lewis, NCEO-UCL, working as principal investigator with Professor Chen from the Chinese Academy of Agricultural Sciences (CAAS), has been awarded a new three-year UK-China project grant focused on the use of remote sensing in regional crop monitoring employing 'big data' approaches and a data assimilation system. The project aims to improve the Chinese Ministry of Agriculture (MOA) operational system for crop modelling.

NCEO-Leicester and commercial partners have been involved in the High Value Crop Monitoring (HiVaCroM) project, funded by the European Space Agency and focused on delivering improved forecasting of potato yields through the use of satellite data, particularly from Copernicus Sentinel-1A and 1B radar instruments and Sentinel 2A optical imagery. The project has completed its proof-of-concept stage and has received great interest from the potato industry and supply chain community, and a demonstration service is being piloted during the 2017 growing season.

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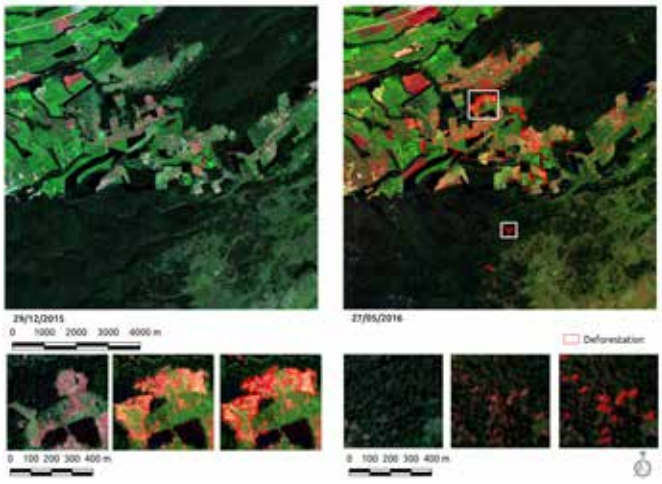
Global Forests: Contributions to UN Sustainable Development Goals

The role of forests is key to the Sustainable Development Goals (SDGs). Accounting for 30% of the Earth's surface, forests provide habitats for millions of species, are important sources of clean air and water, provide livelihoods for forest-dependent communities, and are a key part of the global carbon cycle. Intact forests absorb about 25% of global carbon emissions, whereas deforestation contributes between 10% and 15% of human-induced greenhouse gas (GHG) emissions. Protecting global carbon sinks and reducing deforestation and forest degradation are therefore essential to achieve the globally agreed target of limiting global warming to well below 2°C. UK government is investing approximately £1billion of UK official development assistance (ODA) in forestry over five years via the International Climate Fund (ICF).

NCEO scientists, led by Professors Heiko Balzter (Leicester) and Mat Williams (Edinburgh) are at the forefront of using satellite techniques to monitor carbon stocks in forests that support a range of climate change mitigation activities in the wider international community. Work with Ecometrica over a number of years has recently led to a breakthrough £14.2m UK Space Agency project, Forests 2020, funded under the International Partnership Programme. This is aimed at addressing inadequate monitoring systems which, despite frameworks to help developing countries protect and restore their forest resources, remain a barrier to effective implementation. EO is widely acknowledged as the only effective way to monitor forests at regional and national levels, however the accuracy, frequency, speed, and delivery of EO data products remain a



challenge. Forests 2020 is addressing these technical barriers in Indonesia, Brazil, Colombia, Mexico, Ghana and Kenya. The project focuses on the advancement of forest change-detection and measurement, particularly degradation and small scale deforestation in areas with persistent cloud cover; and identification of areas susceptible to fires or conversion pressures, or that are suitable for restoration, so that resources and interventions can be efficiently targeted. The project will improve the capacity of local partners and stakeholders to implement effective forest and ecosystem monitoring services covering more than 300 million hectares of tropical forests.

On a smaller scale, NCEO scientists have also demonstrated the processing of satellite radar images for UK forestry to the forestry Commission, under the "Earth Observation Data Integration Pilot – Innovative application of remote sensing to forestry management and monitoring", project funded by Defra.

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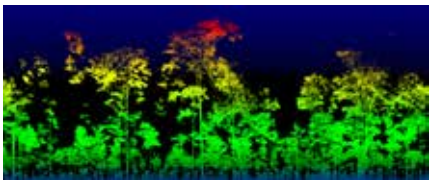
Terrestrial laser scanning



A team led by Dr Mat Disney (NCEO-UCL) is using terrestrial laser scanners (originally developed primarily for surveying and architectural use) to map forests in three dimensions, complementing our satellite-based observations that, by necessity, are limited to views from above. Terrestrial laser scanning builds 3D maps of forests, enabling accurate representations of carbon sources and sinks to support greenhouse gas measurement and management. The main users so far are climate and carbon cycle scientists, EO specialists from NASA and the European Space Agency (ESA), government funded projects in Brazil and Ghana, and media/public engagement events with the BBC, the V&A and others. The information provided is relevant to calculations of forest carbon stocks and fluxes in the tropics, potentially contributing to national-level valuations for those countries reporting under the UN Reducing Emissions from Deforestation and Forest Degradation (REDD+) initiative. In December 2016, a BBC story on the work attracted thousands of shares: reads/shares of the blog page are currently used to track interest in this work.

http://www.bbc.co.uk/news/science-environment-38335348

http://disneytls.blogspot.co.uk/

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Impact of Wildfires and Agricultural Residue Burning on Air Quality

In much of the developing world, poor air quality (AQ) is greatly contributed to by the open burning of hundreds of millions of tonnes of agricultural residues (surplus straw, stubble left after harvest etc) and by landscape burning across huge areas of forests and peatlands, often to clear or maintain land for agriculture. During dry spells levels of burning can increase dramatically as vegetation and peat normally too moist to burn can become involved in the fires. The UN World Health Organisation (WHO) reports the issue of outdoor air pollution from open burning to be of greatest significance in the developing countries of Asia, where it combines with emissions from other forms of air pollution to form regional 'haze'. Unlike the forecast for premature deaths from indoor air pollution, which are set to decrease over the coming two decades, those from outdoor air pollution are set to rise 50%. The ASEAN region is where open burning in peatlands, forests and agricultural areas has the most significant environmental and human health impacts worldwide. The effects are transboundary in nature, spreading far beyond national borders, though impacts vary greatly between nations.

Professor Martin Wooster, NCEO-King's College is working with international institutions and local bodies in Indonesia to investigate the specific characteristics of the peatland fire emissions that contribute to severe regional haze episodes, in order ultimately to develop better air quality forecasts. The 2015/16 El Niño brought a regional drought to the area, and Professor Wooster travelled to Indonesian Borneo at this time to help run a workshop for local scientists and environmental managers and to work with them to assess the extent of the problem close to one of the fires' main epicentres in Palangkaraya, the capital of Central Kalimantan and home to 250,000 people. The haze generated by the peat fires burning around Palangkaraya meant it had probably "the worst air pollution of anywhere worldwide", reaching levels unseen almost anywhere previously on Earth and with levels of fine particulates many times those considered 'extremely hazardous to heath'. Hospitals across the area, and more widely, reported thousands of new patients suffering from respiratory illness. A larger training workshop followed a year later in Jakarta, hosted by BMKG, the Government organisation responsible for air quality monitoring in Indonesia, and led in part by the World Meteorological Organisation which is considering ways to develop enhanced regional haze monitoring and forecasting systems for the region.

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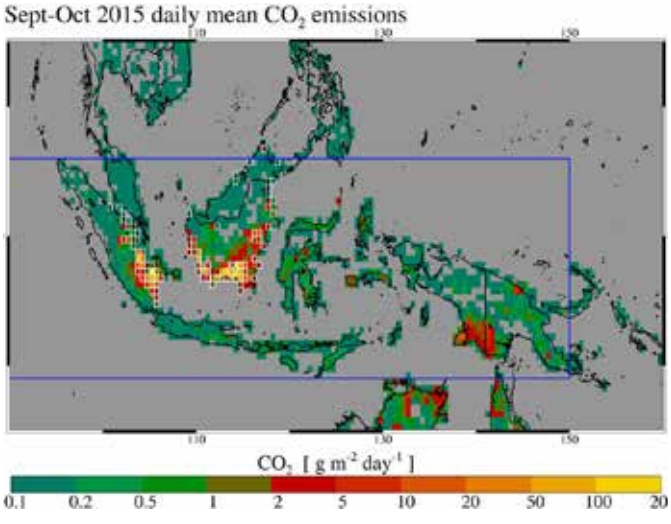

Sept-Oct 2015 daily mean CO_2 emissions
CO_2 [g m^{-2} day^{-1}]
0.1
0.2
0.5
1
2
5
10
20
50
100
20

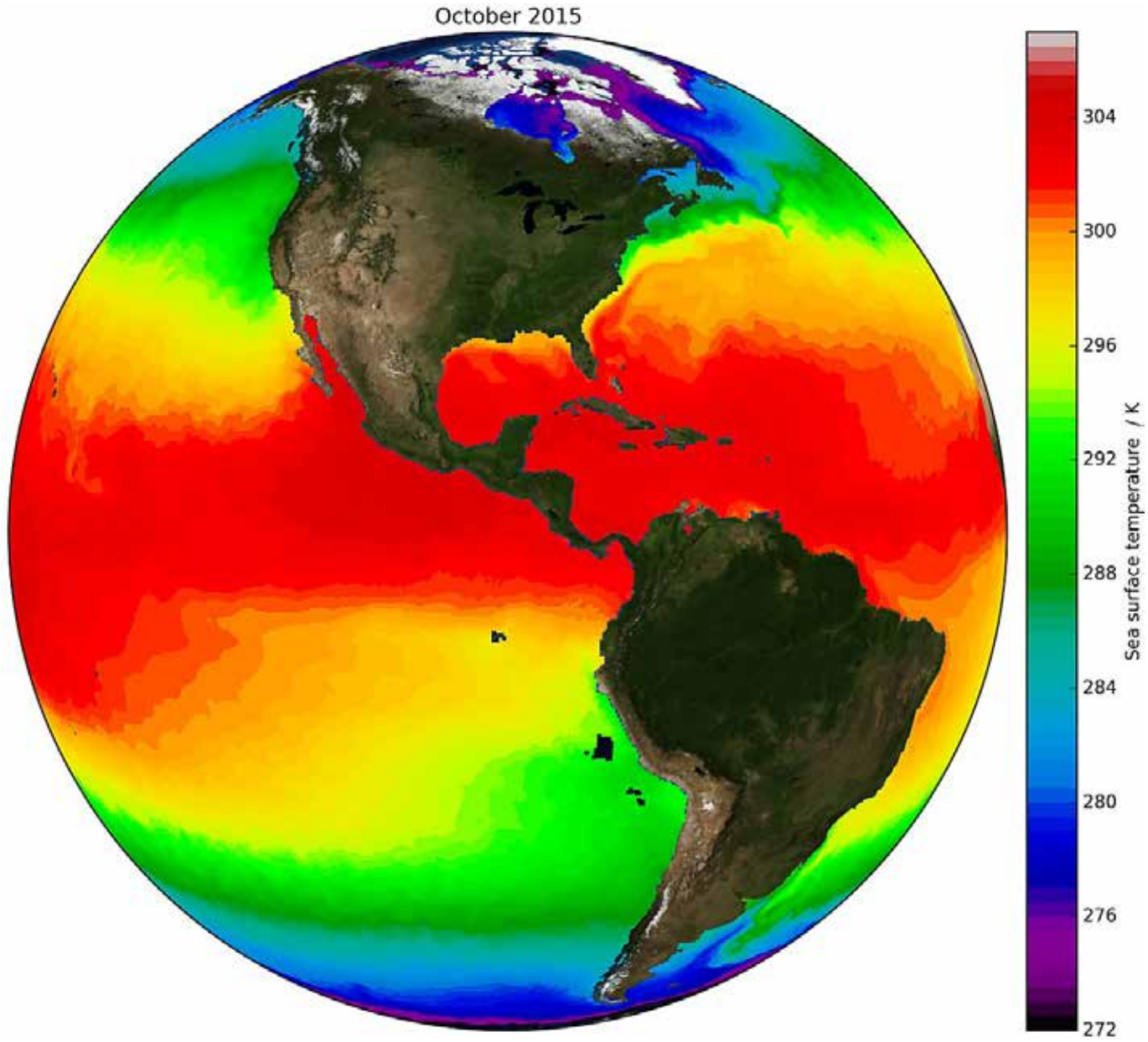
Monitoring Environmental Change on Decadal and Global Scales

Decisions about environmental change, including climate change are complex, costly and have long-term implications for governments, business and civil society. It is therefore vital that such decisions are based on the best available evidence. We need to understand the quality and provenance of that evidence, and whether any assumptions have been made in generating it. We need observations of weather, climate, water resources and from agriculture and other sectors. We also need to analyse the links between these and human and ecosystem development. We need to provide model projections of the future for all these elements. Finally specialists in different sectors need to work with scientists to interpret the information in a way that is relevant to them in order to make informed decisions.

The expertise of NCEO scientists is particularly valued because it allows the development of long-term consistent data sets from which to extract environmental change signals from natural variability, leading to collaborations with the European Space Agency, UK Met Office and the European Copernicus Programme as well as commercial organisations such as Telespazio Vega and CGI. The work of NCEO scientists is facilitated by data storage and computing facilities at the STFC Rutherford Appleton Laboratory, Harwell, CEDA and JASMIN respectively.

- **Marine biogeochemistry.** Work by NCEO-funded groups at Plymouth Marine Laboratory (PML) has resulted in decadal re-analysis of a shelf-sea biogeochemistry to support marine policy and climate studies, as well as the development of an operational forecasting system at the UK Met Office and for the wider community, such as the Copernicus Marine Environmental Monitoring Service and programmes for planning sustainable aquaculture in European seas.
- **Sea surface temperature.** NCEO-Reading is a world leading centre for studying sea surface temperature (SST), working internationally with the European Space Agency (ESA) and the European Centre for Medium-Range Weather Forecasts (ECMWF). SST provides fundamental information on the global climate system; it is an essential parameter in weather and climate prediction. EO data collected via satellites provides global observations of SST that are used in the running, validation, and interpretation of high resolution atmospheric and ocean models. The ESA Climate Change Initiative (CCI) programme (http://www.esa-sst-cci.org/) utilises around 180TB of raw EO data currently archived at CEDA and produces around 50TB of high level products. JASMIN allows scientists to generate 30+ years of datasets in just a few days, rather than months or years (see below for more information on CEDA and JASMIN). The SST section of the Copernicus Climate Change Service (C3S SST) is also making use of JASMIN to obtain near-real time satellite data and generate short delay products useable by ECMWF and others. Professor Chris Merchant (NCEO-Reading) who leads the work on SST is also a member of ESA's Earth Science Advisory Committee, UK Space Agency's Earth Observation Advisory Committee; the Working Group for Climate of the Committee on Earth Observation Satellites (CEOS) and the Coordination Group for Meteorological Satellites (which helps frame space agency responses to requirements for observing the climate system arising from the Global Climate Observing System and UN Framework Convention on Climate Change).

  NCEO is also a patron/sponsor of the Group for High Resolution Sea Surface Temperature (GHRSST) (https://www.ghrsst.org/), an open international science group that promotes the application of satellites for monitoring SST.
- **Land surface temperature.** NCEO-Leicester has formed collaborations with UK Met Office for ESA DUE GlobTemperature (www.globtemperature.info) and H2020 EUSTACE (www.eustaceproject.eu), which are both at the frontier of land surface temperature (LST) science. GlobTemperature outputs are used as the first climate data record of LST from polar orbiting satellites and as the first global LST merged products to resolve the diurnal cycle. EUSTACE outputs provide a first multi-year global product of air temperatures derived from satellite skin temperatures over all surfaces of the Earth. The UK Met Office is assessing the GlobTemperature products for potential numerical weather prediction and climate service exploitation, while industry partners such as ARUP are assessing its use for urban planning, and Tullow Oil is exploring the product for potential mineral mapping.



Sea Surface Temperature product produced with support from JASMIN and CEDA at STFC. (Prof Chris Merchant and Dr Owen Embury, NCEO-Reading)

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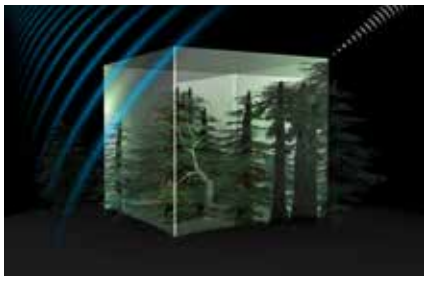
Leading Next-Generation Satellite Missions

NCEO scientists provide fundamental input to a range of international next-generation satellite missions focused on the Earth's most vital processes.

Forest Biomass

The BIOMASS mission, selected as ESA's 7th Earth Explorer in May 2013, will provide vital information on the state of our forests and how they are changing. The mission provides P-band synthetic aperture radar (SAR) measurements from space for the first time; these can be used to determine the amount of biomass and carbon stored in forests. This will be used to improve our understanding of the role of forests in the global carbon cycle, which underpins the implementation of the UN REDD+ initiative – an international effort to reduce carbon emissions from deforestation and land degradation in developing countries. Professor Shaun Quegan of the University of Sheffield and NCEO, conceived the concept for the mission over ten years ago and is one of the principal investigators.



Credit: ESA/AOES Medialab

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Carbon Dioxide

The Orbiting Carbon Observatory-2 (OCO-2) mission (https://oco.jpl.nasa.gov/) is NASA's first dedicated remote sensing satellite measuring atmospheric carbon dioxide (CO_2) from space. The data provides vital observations of carbon sources and sinks on regional scales and supports the quantification of CO_2 year-to-year variability over the seasonal cycles. The NCEO team involved in OCO-2, led by Professors Paul Palmer (NCEO-Edinburgh) and Hartmut Bösch (NCEO-Leicester), has engaged with policy makers in BEIS and Defra, and with commercial users (e.g. Lockheed Martin, Airbus DS, etc). The key innovation contributed to the OCO-2 initiative by the NCEO team is in the area of the scientific approach used to interpret the data. As a result of national activities, built from NCEO funding, both Professors Bösch and Palmer also sit on ESA and EU task forces that will help shape the European Copernicus service for CO_2, and they both are science team members on the upcoming French MicroCarb mission.

Credit: NASA

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Measuring the Earth's Energy Balance

The NASA-led Climate Absolute Radiance and Refractivity Observatory (CLARREO) mission (https://clarreo.larc.nasa.gov/) will provide accurate climate records for testing, validation, and improvement of climate prediction models. NCEO and NASA signed a letter of agreement in support of CLARREO. Studies in the UK involve the investigation of detectable signatures of climate change in the infrared spectrum of the Earth, based on the analysis of real atmospheric spectra, measured by past or current satellite instruments. The NCEO-Imperial College team involved in CLARREO, led by Dr Helen Brindley, is helping to formulate the mission definition and assessing what can be done now in terms of change detection and attribution from existing missions.

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Monitoring Fires from Space

A team at NCEO-King's College lead the algorithm development and product monitoring for the operational active fire products developed from data provided by the European Meteosat geostationary satellite. These products, funded by the satellite operator EUMETSAT, are delivered to users in almost real-time via the Land Surface Analysis Satellite Application Facility (LSA SAF), and are used to support the development of new emissions inventories for air quality applications, to provide real-

time air quality forecasts through the Copernicus Atmosphere Monitoring Service (CAMS), and to deliver improvement environmental management linked to fire impacts, particularly in Africa related to national parks and to surge suppression on high voltage power-lines that criss-cross African grasslands and which need to be temporarily turned off prior to fires coming close. The success of this work has led to the King's team helping specify the characteristics of a dedicated 'fire' measurement channel that will now be placed on the forthcoming Meteosat Third Generation series of satellites to provide enhanced data to support these applications, with improved temporal, spatial, spectral and dynamic range characteristics better focused on sensitive fire detection and on more precisely quantifying fire emissions.

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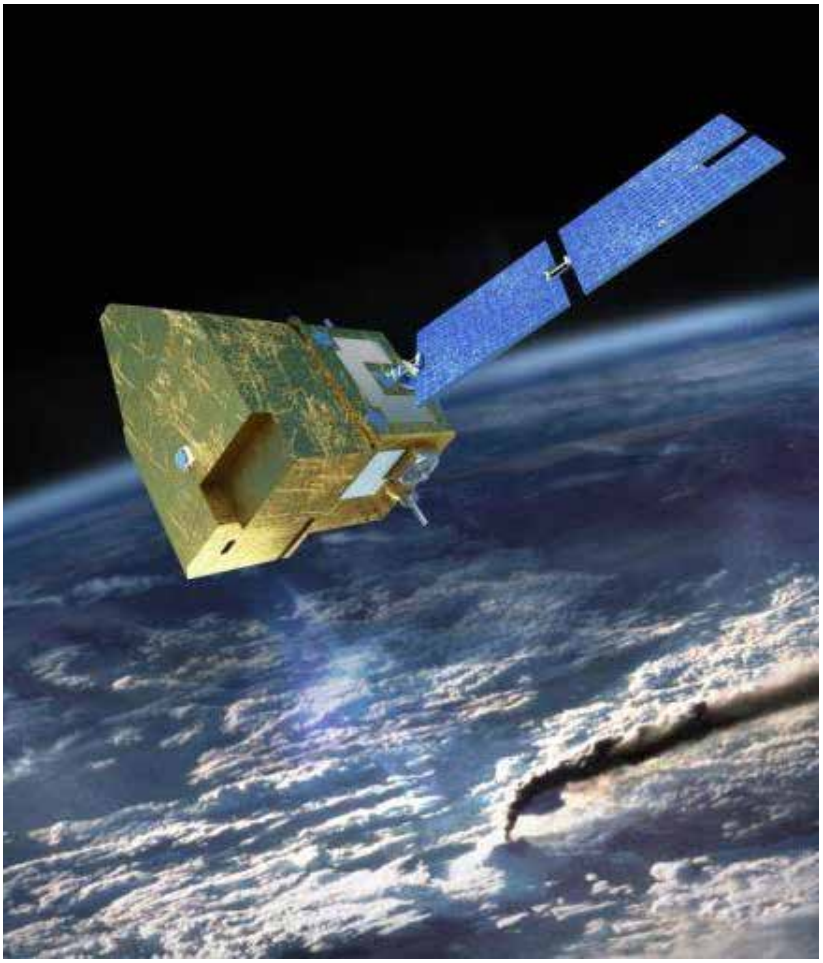
MicroCarb

MicroCarb is a joint French-UK satellite mission which will measure sources and sinks of carbon dioxide. It is the first European mission intended to characterise greenhouse gas fluxes on the Earth's surface. The mission, scheduled to launch in 2020, will enable the UK Space Agency and the French Space Agency, CNES to pave the way for a longer term operational system in response to the Paris Agreement.

Professors Hartmut Bösch and Paul Palmer from NCEO at the Universities of Leicester and Edinburgh will represent the UK on the MicroCarb science team. By combining carbon dioxide data with state-of-the-art models, scientists are able to derive regional patterns of uptake by the surface and emissions of carbon dioxide to the atmosphere (fluxes). An improved knowledge of fluxes is key to providing much better predictions of the likely concentrations of carbon dioxide over the next decades and also the relative changes in natural and anthropogenic sources and sinks of carbon dioxide.



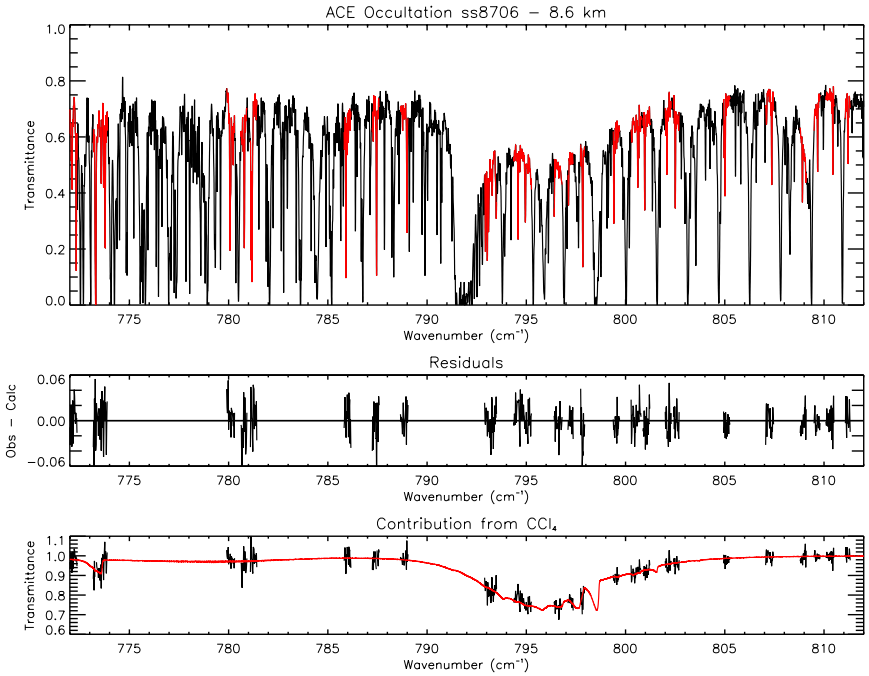
Spectroscopy Tools for the Earth Observation Community

NCEO scientists have been at the forefront of developing tools and methodological improvements for the wider community.

Spectroscopy

NCEO-Leicester has led developments in measuring atmospheric composition from satellite observations, based on an atmospheric radiative transfer model and high-quality spectroscopic data for molecules absorbing and emitting in the atmosphere. NCEO has provided a suite of tools (https://www.nceo.ac.uk/data-tools/atmospheric-tools/) for a number of important atmospheric gases. All the spectroscopic data produced from the project are provided to the international spectroscopic databases GEISA and HITRAN, serving the wider scientific community.

Recent work by Dr Jeremy Harrison has been related to improving the spectroscopy of halogenated species (Cl- and F-containing), which are linked to stratospheric ozone depletion; e.g. carbon tetrachloride, a molecule regulated by the Montreal Protocol. A recent international report (SPARC 2016, SPARC Report on the Mystery of Carbon Tetrachloride) included a preliminary retrieval of carbon tetrachloride from the spaceborne ACE-FTS instrument (using this new spectroscopic data). It was developed under the auspices of a Stratosphere-Troposphere Processes And their Role in Climate (SPARC) project, a core project of the World Climate Research Programme (WCRP), in response to continued questions about the discrepancy between estimated emissions related to atmospheric observations and those from reported production and consumption submitted to the United Nations Environment Programme (UNEP). This discrepancy has been highlighted in the Scientific Assessment Panel's report to the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer for both 2010 and 2014.



The figure provides a graphical representation of the new retrieval in the form of an observed ACE-FTS spectrum and the contribution from carbon tetrachloride. Top panel: an ACE-FTS transmittance spectrum over the 772 – 812 cm^{-1} region for occultation ss8706 (recorded on 25 March 2005, off the coast of northern Scotland) at a tangent height of 8.60 km. The features in red represent the microwindows used in the new CCl_4 retrieval. Middle panel: the total observed – calculated residuals for the CCl_4 retrieval. Bottom panel: Observed/calculated ratio (without the inclusion of CCl_4 in the forward model), with the calculated CCl_4 transmittance contribution to the measurement overlaid.

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Reference Forward Model.

NCEO-Oxford provides development, maintenance and publicity for the Reference Forward Model (RFM) (http://eodg.atm.ox.ac.uk), a general-purpose line-by-line radiative transfer model, for accurate spectral calculations in the infrared and microwave regions and specifically designed for use by remote sensing scientists, atmospheric radiation modellers, instrument developers, spectroscopists, and infrared astronomers. In the past year, this has included using the model to supply reference spectra for the UK Met Office and delivering the model to the European Space Agency

for simulations of the TROPOMI instrument on the Sentinel 5P satellite. The lead team has also performed simulations for a UK commercial company.

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Reducing the Impact of Pests on Agriculture

NCEO at Kings College London is working with the Centre for Agriculture and Bioscience International (CABI) and Assimila Limited on two projects related to the monitoring of threats to crop health, focusing on the need to maintain yields whilst avoiding inappropriate use of chemical pesticides. An estimated 40% of the world's crops are lost to pests and diseases (including insects, mites and plant pathogens), impacting on the ability of smallholder farmers to feed their families, and also affecting economic development, international trade, food supply chains and hampering pursuit of UN Sustainable Development Goals (SDGs). Pest outbreaks respect no political boundaries and climate change is making forecasts based on past experience increasingly unreliable. Innovation is essential to provide new solutions.

The first project PRISE (Pest Risk Information Service) is funded by the UK Space Agency's International Partnership Programme. PRISE aims to deliver both socio-economic and environmental benefits by enabling farmers to reduce unnecessary use of pesticides, providing information for more targeted and cost-effective spraying or other workable interventions. The PRISE project combines novel real-time EO technology, satellite positioning, plant health modelling and on-the-ground real-time observations of crop health to deliver a science-based pest and disease forecasting service to users.

The second project is funded by the STFC-NEWTON Agritech Programme in collaboration with China and focuses on two specific wide-scale issues: control of damage caused by locusts and by fungal wheat rust. Again the long term aim is to minimise impacts from inappropriate use of pesticides whilst safeguarding crops

and improving yields. This project is being conducted in collaboration with a number of co-funded Chinese organisations.

In both projects NCEO at Kings College London is researching and advising the wider team on the appropriate use of satellite based EO methods, and assessing how such data can best contribute to the near real time assessment of environmental conditions contributing to the development and occurrence of key pests and plant diseases, so that appropriate warnings can be given and remedial measures enacted in time. The PRISE project also involves NCEO partner Centre for Environmental Data Analysis (CEDA), which advises on and implements cloud-based EO data storage, data processing and access.

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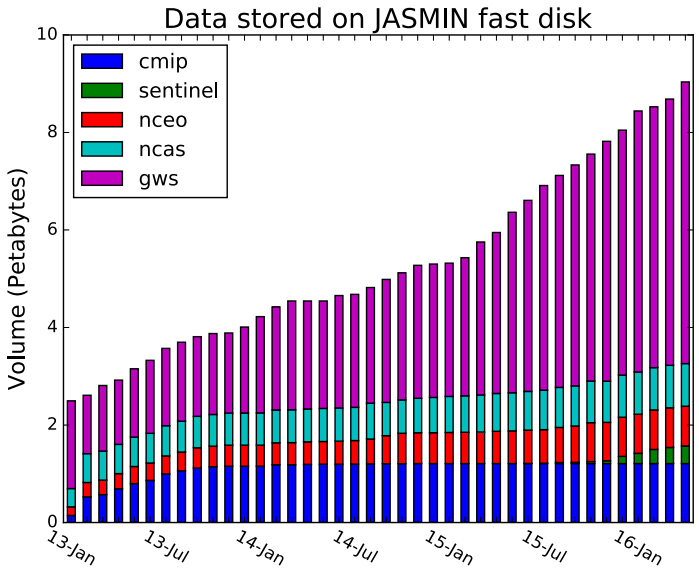
JASMIN and CEDA

In 2012, an initial 4.5 petabytes of high-performance storage was brought online, signalling the 'birth' of JASMIN and revolutionising access to environmental science data for NERC. JASMIN is half super-computer and half data-centre and provides a globally unique platform hosted by STFC, for computing and storing UK and European environmental science data. A bustling hub of scientific collaboration, JASMIN has nearly 150 NERC-related science projects using its group workspaces and the CEDA archive. These workspaces bring together researchers from across the domains of data-intensive environmental science.



Around 1000 virtual machines and 5000 cores of computing power are woven together with a fast internal network; which efficiently moves petabytes of data around, into, and out of JASMIN every month. Today, JASMIN's storage capacity has tripled to over 16 petabytes – as a comparison, 1 petabyte of average-length songs would equate to approximately 2000 years of continuous play!

Already, JASMIN has established its own 'data gravity' – the ability of data to attract additional applications and services. Research projects benefit (and in many cases have only become feasible) from locating their analysis activities alongside the CEDA archive and other resources, so that they can share their work efficiently with colleagues and other projects alike. JASMIN now has over 1200 users from a variety of backgrounds and levels of expertise. Over 100 (mostly doctoral) students register to use JASMIN every year; with around 2000 more registering each year to exploit data via the CEDA download services. The facility has enabled the UK scientific community to participate in major international programmes with the European Space Agency, European Commission and UK Space Agency.

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Bringing Earth Observation into the Classroom and Beyond: EO Detective

The Earth Observation Detective (EO Detective) project has been developed through UK Space Agency and NERC funding. To date, outputs from the project have been delivered to at least 21,000 school children and teachers across the UK. The initial aim was to use Tim Peake's Principia mission on board the International Space Station (ISS) to maximise the impact and engagement of the public with space and environment through EO-themed outreach activities, classroom resources for children aged 7-16 years, as well as career resources and extra-curricular material.

The EO Detective competition prize was the opportunity to have a photograph taken from the ISS. It was launched at the Royal Institution on 24 October 2015 and prizes were presented by Libby Jackson, the UK Space Agency's Astronaut Flight Education Programme Manager, at the National Space Centre on 1 October 2016. Entrants had to explain where on Earth they would like an astronaut to photograph and why. There were around a thousand interesting and varied entries, and an extra category had to be added for younger children. The EO Detective blog reported on winners and runners up.

The EO Detective team have run workshops at several events, including Launch Day celebrations in London and Leicester, the Big Bang Fair in Birmingham, and the public days of the Farnborough International Air Show. We interacted with thousands of children and adults – attendance over the four days of the Big Bang Fair alone was 80,000 – introducing them to space photography and satellite imagery. EO Detective project resources remain relevant, and are being promoted by our @EODetective Twitter account and on the Principia website, as well as being taken into a further 750 schools by phase 2 of the Tim Peake Primary Project. Additional funding from the UK Space Agency will help create materials for younger children, a careers resource, and activities that children will be able to take home or access independently, giving them the opportunity to engage parents, siblings, and their wider social network in exploring EO images.

NCEO team with Tim Peake

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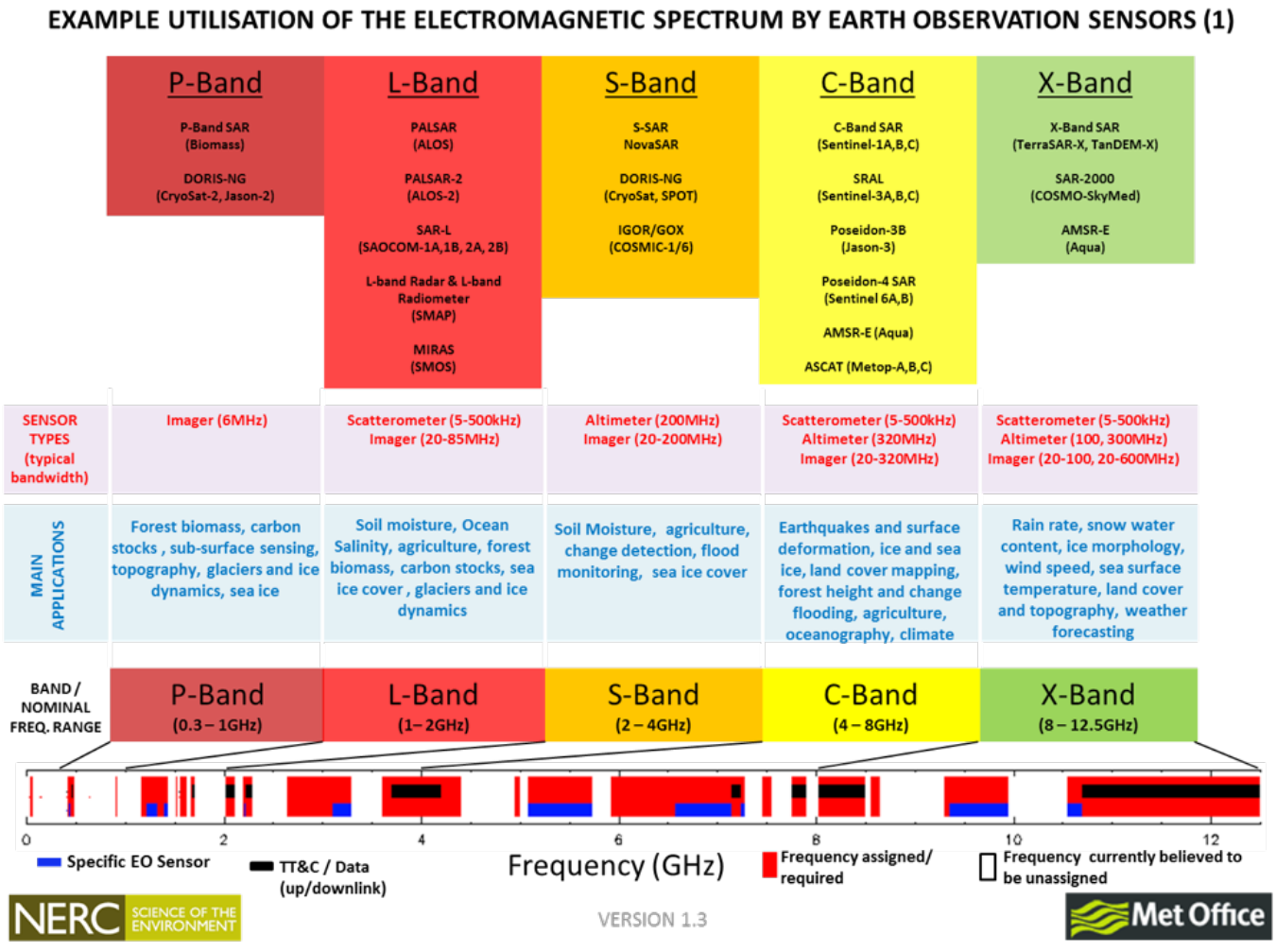
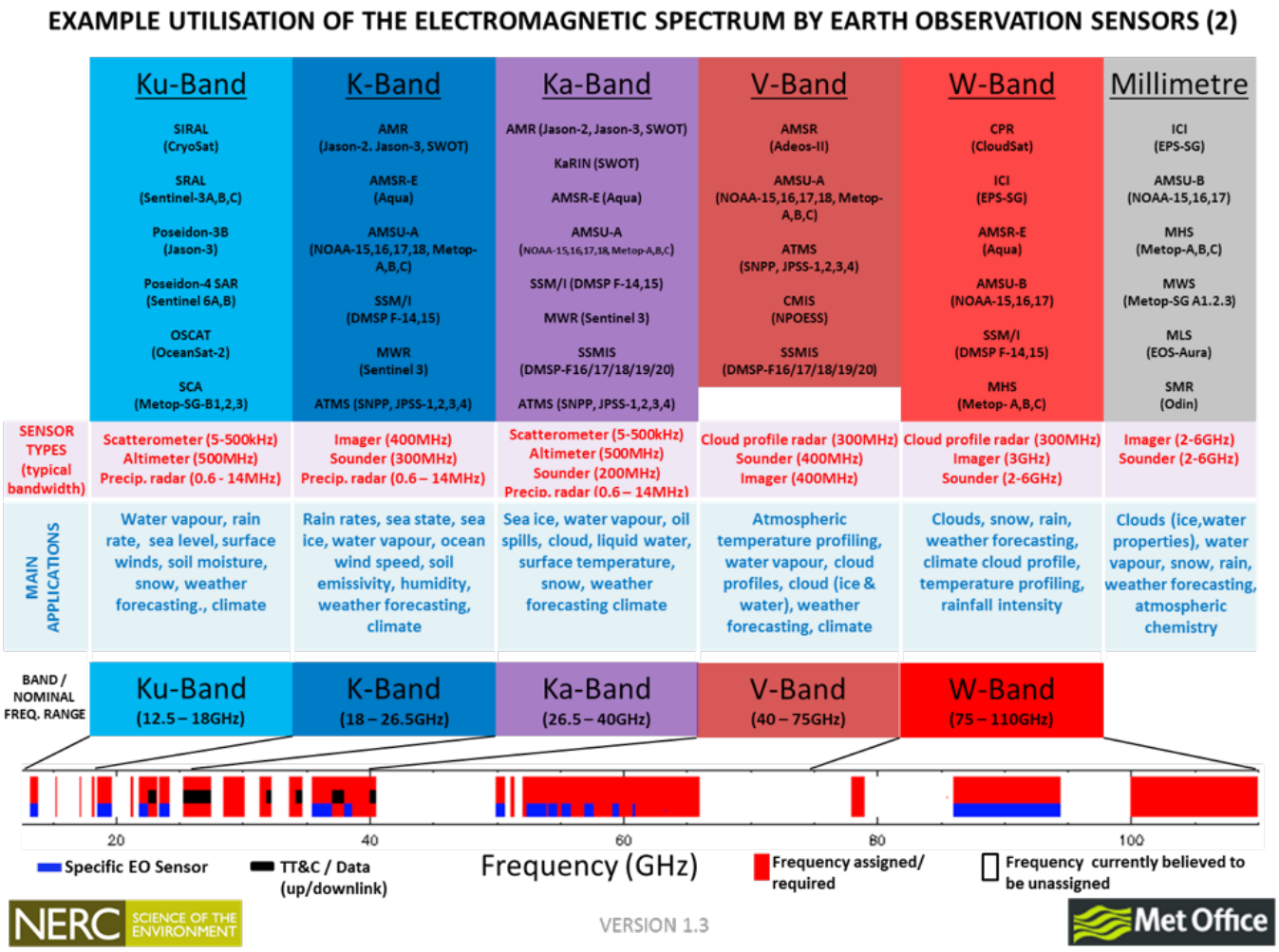
Impact of Proposed International Changes in Spectrum Allocation

Earth Observation is based on measurements of electromagnetic (EM) radiation made at multiple locations within the EM spectrum where information on the Earth's environment can be calculated or inferred. However, the EM spectrum is also exploited widely in many industries, such as mobile communications and broadcasting. Early in 2015, UK Space Agency invited NERC to join the Ofcom-UK Space Agency "Space Spectrum Advisory Committee" (SSAC) to ensure EO EM spectrum requirements were adequately represented in the discussion of sector spectrum needs. In the summer of 2015 Ofcom recognised that it needed to be better informed about the use of parts of the EM spectrum for both satellite EO and satellite "command and control". It initiated a strategic review of satellite and space science use of spectrum in the context of competing demands. In particular Ofcom recognised that requirements for wireless services are leading to growing competing demands for key spectrum resources, even with increasing efficiency of spectrum usage.

NCEO provided a comprehensive review of spectrum use by the EO community, together with an analysis of the science, societal impacts and commercial services which rely on particular spectrum regions. NCEO worked closely



Example utilisation of spectrum by EO sensors up to 12.5 GHz. EO sensor frequencies shown are illustrative but not comprehensive. Telemetry, tracking and control, and up/downlink of data are shown together as TT&C/Data



Example utilisation of spectrum by EO sensors from 12.5 GHz to 110 GHz. EO sensor frequencies shown are illustrative but not comprehensive. Telemetry, tracking and control, and up/downlink of data are shown together as TT&C/Data.

with the Met Office as a key stakeholder in spectrum allocation and with the UK Space Agency in presenting a government user view.

A response on behalf of NERC/NCEO was provided directly to Ofcom and to the UK Space Agency to support its analysis. Diagrams were developed as part of the analysis to provide a useful snapshot of the spectrum issues. NCEO was able to demonstrate the societal value of the EO use of spectrum and also to provide pointers to the growing EO service industry which was otherwise less represented in Ofcom's surveys. This work has been beneficial to the EO satellite industry (both upstream builders and downstream data), to EO research scientists, and to government EO services and agencies including the Met Office.

NCEO is now an acknowledged expert on EO and spectrum issues and continues to advise Ofcom, sitting on relevant committees at its invitation, liaising with the EO and with broader industry interested in spectrum and responding to requests for information from the UK Space Agency. Ultimately, NCEO is contributing towards the development of a well-informed government position with respect to the World Radio Congress (WRC), both WRC-15, which was successful from an EO industry perspective, and WRC-19.

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GEO and CEOS: Ensuring UK is plugged into the International Earth Observation Community

NCEO is working on behalf of the UK Earth Observation community to interface to two major international initiatives: the Group on Earth Observations (GEO) and the Committee on Earth Observation Satellites (CEOS).

GEO is a voluntary partnership of over 100 governments and the European Commission, plus a similar number of participating organisations, working to make EO data and resources freely available to help with better policy-making. GEO is leading a worldwide effort to create a data portal called the Global Earth Observation System of Systems (GEOSS) to link EO resources worldwide across multiple societal benefit areas. Defra is the UK policy lead for GEO.

CEOS is GEO's sister coordination body, and aims to coordinate civil space-based EO programmes across the globe. The UK Space Agency has responsibility for leading UK engagement with CEOS.

In 2016 NCEO set up a joint UK GEO/CEOS Office to coordinate UK activities relating to these two initiatives alongside Defra and the UK Space Agency. The Office is working to increase the visibility of GEO and CEOS to the UK EO community and facilitate and coordinate the UK's inputs to GEOSS.

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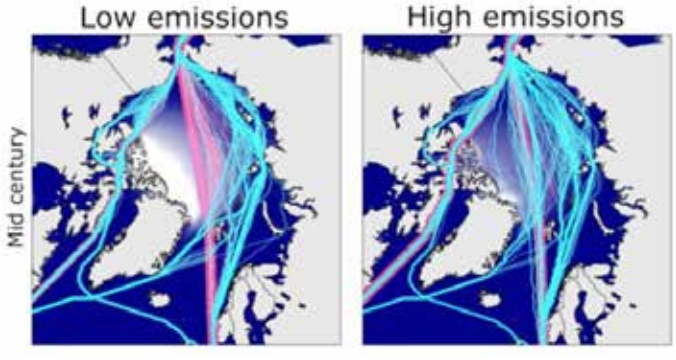
Policy Advice to UK Government

NCEO is regularly asked to advise UK Government on matters related to the use of space technology and on environmental issues.

- UK Space Agency asked NCEO for advice on the content of ESA EO programmes and levels of funding. UK is now lead funding nation on ESA EO programmes in a strong position to influence the programmes for UK benefit.
- NCEO provided two lead chapter authors, a chapter co-author and five other contributions to a Royal Society report, "Observing the Earth, expert views on environmental observation for the UK", commissioned by GO-Science. Covering climate, air, oceans and ice, land and freshwater, natural hazards and international dimensions, the report demonstrated the wide range of science and applications in the UK. Subsequently, NCEO also produced inputs to the Cabinet Office on agriculture and brought together government, industry and scientists in the UK EO Applications Workshop in 2015. These activities provide much information for the ongoing formulation of a cross-government EO service (UK-GEOS) which NCEO continues to support.
- Researchers from NCEO-Reading have investigated how the decline in sea-ice, driven by warmer temperatures, will make the region more accessible. They found that by 2050, opportunities to transit the Arctic will double for non-ice strengthened vessels. This work has been presented in Westminster and was also featured on the BBC science pages: http://www.bbc.co.uk/news/science-environment-37286750 . The figure shows possible shipping routes in September 2045-60, for a low and high emission scenarios. Pink routes are those taken by moderately ice strengthened ships and blue routes are those available to non-specialised shipping.



UK Achievements in GEO

UK is a member of the GEO Executive Committee and the Programme Board, helping to shape GEO.

The UK GEO/CEOS Office organised the GFOI (Global Forestry Observation Initiative) Policy Forum in London (6 September 2016), and the Space Data Coordination Group for GFOI - SDCG-10 in Reading (7-10 September 2016). The meetings were very successful but tinged with great sadness due to the death of Professor Jim Penman who chaired the Advisory Group for GFOI and led GFOI's work on developing a set of methods and guidelines to assist REDD+ countries in developing their national forest monitoring systems.

The office has also supported work to share metadata for UK EO datasets stored on data.gov.uk to the GEOSS data portal. In September 2016, 23,458 UK metadata records were harvested to the GEOSS data portal, including numerous NCEO datasets available on CEDA. These records are shared as open data by default and are available as part of the GEOSS Data Collection of Open Resources for Everyone (Data-CORE).

Skills Development and Training

NCEO offers and contributes to a wide range of training courses, workshops and summer schools in topics as varied as data assimilation, field spectroscopy and climate studies. Online training materials are available at https://www.nceo.ac.uk/skills/training/. We have also contributed significantly to a number of massive open online courses (MOOCs). If you have specific training needs or would like to join one of our activities contact Jan Fillingham, our Training Manager.

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Data Assimilation Training

A substantial part of the knowledge base in NCEO is in data assimilation. Data assimilation is the science of combining (satellite) observations of a system with complex numerical models of that system to obtain better model estimates to improve forecasts, and to improve the models themselves. It is used in every branch of the environmental sciences, from weather and ocean forecasting to land-surface forecasting and even crop yield forecasting. Because of its central role sufficient capability has to be developed and maintained in the UK and beyond. NCEO plays an important role in this, organising data-assimilation training courses for academia and industry, and training courses and summer schools abroad.

Examples include yearly data-assimilation training courses in collaboration with the ECMWF data-assimilation course. We provide participants in the latter with a solid basic understanding of data-assimilation methods before the ECMWF course starts, and thorough hands-on training days after the ECMWF course. The participants are typically employed at weather prediction centres all over the world. Complete self-contained courses are also organised by NCEO scientists in many countries. For instance, in 2016/2017 we organised or co-organised courses for young academics in the UK, Italy, Spain, and China.

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Sentinel 2: Credit ESA/ATG medialab

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Upper image: ALOS-2 PALSAR-2 dual pol. annual 2015 mosaic ©JAXA

Central image: Yucatan Peninsula Aboveground Biomass map 2010, © 2016 University of Leicester. GlobBiomass project is funded by ESA under ESA Contract No. 4000113100/14/I-NB. Authors: Pedro Rodriguez Veiga, Kevin Tansey, and Heiko Balzter

Lower image: Multi-temporal composite 2014-2016 generated using 1,029 USGS Landsat 8 Surface Reflectance scenes in Google Earth Engine