National Centre for Earth Observation

NATURAL ENVIRONMENT RESEARCH COUNCIL

The National Centre for Earth Observation

Earth Observation Science to Understand a Changing Planet

Our Mission

“Delivering transformational Earth Observation science capability to meet Earth System challenges.”

We are a **NERC research centre** with more than **80 scientists** distributed across leading UK universities and research organisations and led by Professor John Remedios at the University of Leicester. With an annual income of over **£8 million** we provide the UK with core expertise in Earth Observation science, data sets and merging techniques, and model evaluation to underpin Earth System research and the UK’s international contribution to environmental science.

Our scientists work strategically with **space agencies**, play significant roles in mission planning, and generate internationally-recognised data products from **20 different satellite instruments**. Our scientists publish more than **300 research articles** every year and contribute to major environmental science reports.

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

Professor John Remedios, Director of NCEO.

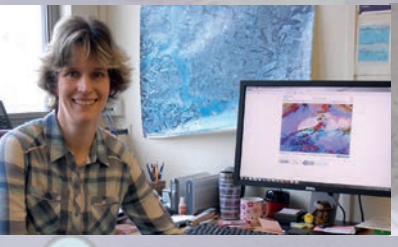
What we do

We have world-class capabilities in processing and analysing the vast quantities of data generated by satellites, aircraft and ground-based instruments to monitor and understand global and regional environmental change. Our research centre is unique in Europe in bringing together a wide base of Earth Observation (EO) data experts with scientists who model the Earth system to improve research into current and future environmental conditions.

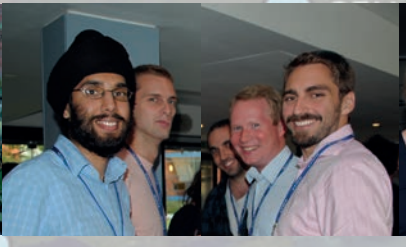
Our scientists have key expertise in transforming raw data into useful geophysical products for cutting-edge science, in confronting models of the Earth System with observations to improve models; and in combining datasets with models, to improve predictions. We host dedicated infrastructure for processing and storing data and performing model comparisons.

We act as a champion for the UK scientific community in its use of EO and have strong associations with other NERC centres. Our scientists provide training and access to remote sensing instruments on the ground and on aircraft. NCEO staff work with EO academics, engineers, industry and space agencies to plan new satellite missions.

We provide a range of services and facilities to UK scientists, acting as the NERC lead for various EO international programmes and for UK research access to observational data and new missions. We work closely with the UK Space Agency, the European Space Agency, EUMETSAT, meteorological agencies, government departments and businesses.








Earth observation for a changing planet

We live on a changing planet. As our population continues to expand we are placing ever greater demands on its resources and driving environmental change at an unprecedented rate. We need to understand these changes and the sensitivity of one part of the Earth System to evolution in another. As the dominant source of change we need to learn how to reduce our impact on the environment, using science to inform routes to sustainable living.

Earth observation (EO) satellites have a unique vantage point on the world, enabling us to identify, review and track global or regional changes and trends consistently, and to trace their influence across the planet. In a complex world, satellite instruments provide direct evidence of our planet's evolving state, both through their familiar imaging capability, but also via their unique ability to capture data which monitor simultaneously a host of key environmental markers at large scales - physical, chemical and biological. EO helps us understand disruptive events and hazards so protecting against loss of life and livelihood.

At NCEO we harness data from EO satellites, as well as aircraft and ground-based instruments, to study the Earth System and its continually changing nature ranging from variations in atmospheric composition to the carbon content of forests.

Over the next decade we will see a quantum leap in our ability to use EO data for environmental research. These data will increasingly help define government policy, as well as finding practical applications in business and education.

We work with a large number of industrial partners, national and international, and provide data support for a growing number of services. We undertake activities to enable the wider research community to link to market growth. We are strong drivers of new satellite missions, working with industry and space agencies to design next generation EO sensors.

Our vision is that we will lead in the UK and internationally in EO research and its applications, encouraging, collaborating with and building the EO community to serve science and society.

Understanding long-term changes in the Earth system

Access to continuous, well-calibrated long-term data records is increasingly important to understand and quantify environmental variations in the Earth system, especially in relation to climate science. These types of data enable scientists to identify, quantify and attribute changes to particular causes, for example to anthropogenic emissions of greenhouse gases or to large scale changes in land cover.

As new research instruments become operational on meteorological satellites and within Europe's Earth-monitoring 'Copernicus' system, our ability to observe changes to the environment will continue to grow and become fundamental for addressing environmental problems and plan for the future. The research techniques developed at NCEO are available for service providers and businesses to build into new information products for aiding society.

Contributing to climate research

By exploiting EO data and using models to examine the interaction between the atmosphere, biosphere and hydrosphere, as well as variability within each system, NCEO aims to improve the UK's capability for climate prediction over a wide range of climate-relevant timescales. This area of research will grow in significance in the future as the observational datasets further mature.

NCEO scientists are at the forefront of ESA's Climate Change Initiative (CCI) programme, set up in response to the UN Framework Convention on Climate Change's (UNFCCC) desire to support policymaking with accurate, quantifiable global evidence. NCEO researchers are merging datasets to produce data products for CCI that describe essential climate variables. These include aerosols, clouds, greenhouse gases, ocean-colour, ozone, sea-level height and sea-surface temperature. All of these, in their own way, provide information about the state of our climate. But they are even more powerful when combined to investigate key interactions within the Earth system. In future, NCEO will be using these mature datasets to evaluate models of future climate and constrain predictions.

For example, one of the largest sources of uncertainty in predicting future climate is related to the interplay between clouds and aerosols – tiny liquid droplets or particulates in the atmosphere that act as condensation nuclei for cloud-formation. As well as directly reflecting and absorbing radiation themselves, aerosols can affect the lifetime and reflectivity of clouds, hence strongly modifying the Earth's energy budget. But quantifying their precise impact is challenging due to the large variability in their composition, size and location, all of which can alter their influence on cloud properties and the energy budget.

NCEO researchers are using the emerging CCI records to evaluate the strength of observed aerosol-cloud interactions over a decade and more. These can be combined with observations from instruments such as the Geostationary Earth Radiation Budget Experiment (GERB), measuring the Earth's energy balance at the top of the atmosphere, with the ultimate aim of better constraining model predictions of future climate.

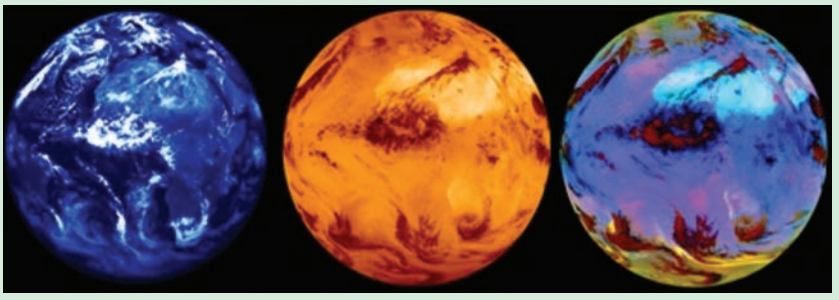
Similar initiatives link long-term records of variables such as sea-surface temperature, ocean heat content and sea-level and investigate how ocean-colour can provide information about the biological state and health of the ocean. NCEO researchers are working to exploit EO sea-surface temperature and sea-level data in conjunction with in-situ datasets to constrain and understand the variability of heat uptake by the oceans. Sea-surface temperature products are a key input for meteorological forecasting models and are crucial for understanding major events such El Niño, the warm phase of the El Niño Southern Oscillation that develops in the equatorial Pacific and is associated with extreme weather events.

The NCEO is committed to building on the success of the UK's climate record EO instruments, the Along Track Scanning Radiometers (ATSRs). These measure emitted thermal infrared radiation, from which highly accurate surface temperature datasets – such as sea-surface temperature - can be derived. Opportunities to extend the

> **"NCEO has provided the UK with a strong national capability for the exploitation of Earth observations. This capability has helped the Met Office by providing insights from the interpretation of EO data that reaches across many aspects of the natural environment. As we move to full environmental and Earth system models their expertise will be increasingly valuable."**
>
> Professor Dame Julia Slingo DBE FRS,
> Met Office Chief Scientist.

Sensors on the geostationary Meteosat satellite

The Geostationary Earth Radiation Budget (GERB) sensor is the first instrument designed to measure Earth Radiation Budget parameters on a geostationary satellite and provides radiation measurements over a disc of the Earth every 15 minutes. It operates alongside the SEVIRI infrared imager, which highlights dust and other atmospheric particles. These images were taken at 12pm on 8th June 2011, the left GERB image shows reflected shortwave radiation; the clouds strongly reflect shortwave solar radiation. The middle GERB image shows outgoing longwave radiation, so clouds appear dark as they trap heat radiated by the Earth. In the SEVIRI image on the right deep red indicates cloud systems, magenta shows a gathering dust storm in the Sahara desert and the yellow steaks are volcanic ash transported over the South Atlantic from the eruption of the Puyehue volcano in Chile. Credit: H. Brindley, NCEO-Imperial College London and J. Russell, Imperial College London.



Understanding long-term changes in the Earth system

climate records are at the heart of NCEO support of the Copernicus Sentinel-3 mission. These datasets provide key markers of change in ocean climate but also capture local environmental factors.

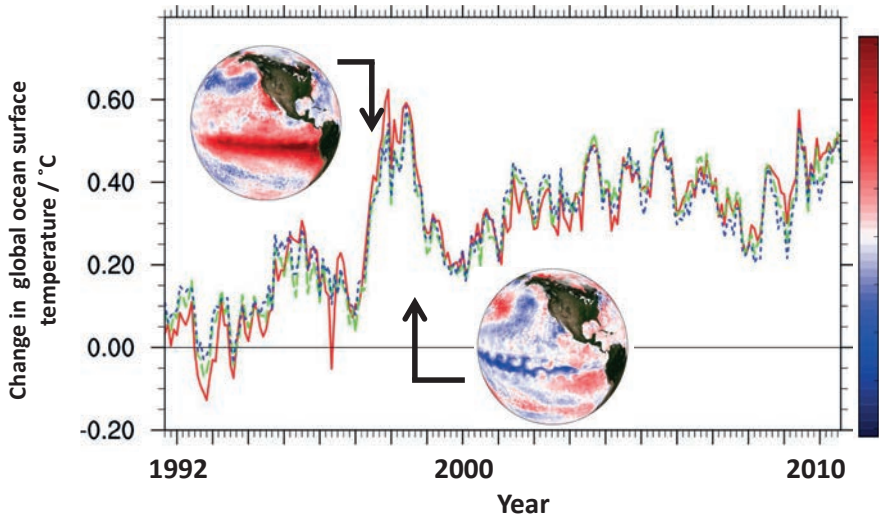
We are extending these approaches to the terrestrial surface, undertaking fundamental research into land-surface temperature, soil moisture and rainfall. In a world where heatwaves and droughts may become more common, coupled with the clear trends in urbanisation and intensification of agriculture, this work has potentially far-reaching impact. Our scientists are leading international efforts to build accurate satellite records of land-surface temperature.

Measurements made by the ground-breaking Cloud, Aerosol and Radiation mission (EarthCARE) will improve our understanding of the interactions of clouds, aerosols and radiation on a global scale. This will help improve climate predictions and weather forecasts. NCEO scientists are playing a key role in preparations for the mission, developing new data analysis techniques. EarthCARE is being developed as a joint venture between ESA and the Japan Aerospace Exploration Agency, JAXA, and is scheduled for launch in 2016.

Monitoring, diagnosing and predicting carbon flows

NCEO's research into feedbacks between the physical and biological processes involved in the carbon cycle feeds into our ability to diagnose and estimate future carbon dioxide levels and hence forcing of climate. The carbon cycle is closely coupled to greenhouse gas-induced climate change, since the ability of Earth's natural carbon sinks to store carbon – in oceans and forests, for example – affects how much of the greenhouse gas carbon dioxide there is in the atmosphere. The carbon cycle is also integral to the food chain on which we depend, as it includes how much carbon is fixed by vegetation as it grows, impacting the productivity of the whole planet.

We are using satellite observations combined with computer models of the land and ocean to quantify the movements of carbon around the planet – in particular the flows of carbon dioxide and methane – to understand the processes that drive them. These include the roles played by fire, open-ocean and shelf-sea biology, water-vegetation interactions and soil properties.

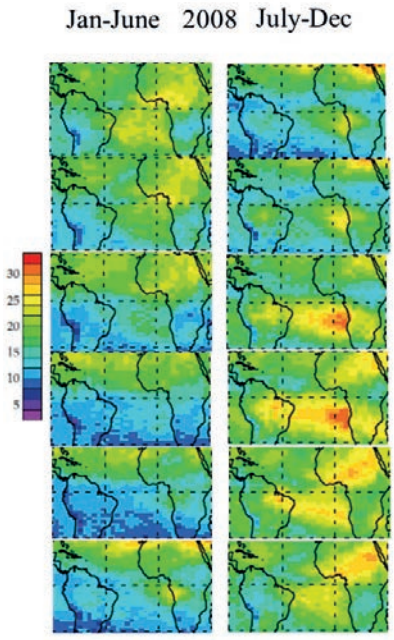


Satellite measurements of sea-surface temperature agree well with in-situ ocean thermometers. The plot shows a time series of the difference in measured global mean sea-surface temperature from the expected value for the time of year (assessed across many years). The dashed lines are from different combinations of in-situ ocean thermometers, and the red line is from three ATSR-sensors, with the data blended with other satellite missions. The globes show the sea-surface temperature anomalies during and after a major El Niño Southern Oscillation event, where red is warmer than usual and blue is colder. In an El Niño year (top), global temperatures are much higher on average than in a La Ninã year (bottom), with temperature patterns that drive global weather. Credit: C. Merchant, NCEO-University of Reading.

Providing new information about the atmosphere

The atmosphere is an important arena for understanding long-term change, from the greenhouse effect and ozone depletion within the upper atmosphere, to air quality and rainfall. Obtaining an accurate picture of the quantities of greenhouse gases being emitted into the atmosphere is important to monitor efforts to cut emissions under the UNFCCC and subsequent protocols, such as Kyoto. NCEO is part of international efforts to obtain accurate greenhouse gas concentrations from space. We are also bringing new instrumentation into service on aircraft.

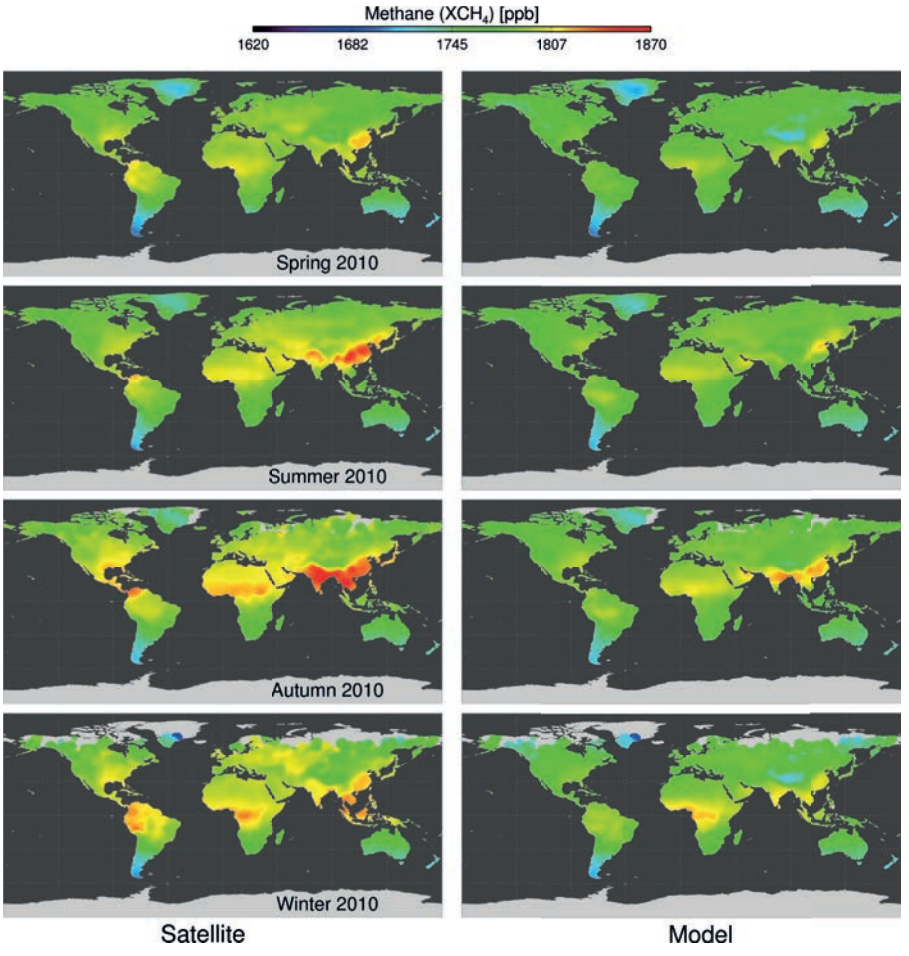
Climate change affects atmospheric composition, which could impact people's health if it results in increased air pollution near the ground. Of particular interest is tropospheric ozone, an important greenhouse gas and a toxic pollutant that can also damage vegetation and increase crop failure. But the processes that determine concentrations of tropospheric ozone and the global spread of this and other atmospheric trace gases are poorly understood, and have been identified as a high-priority research area by the Intergovernmental Panel on Climate Change. The long-term behaviour and lifetime of pollutants determines the atmosphere's sensitivity to climate, and vice versa.



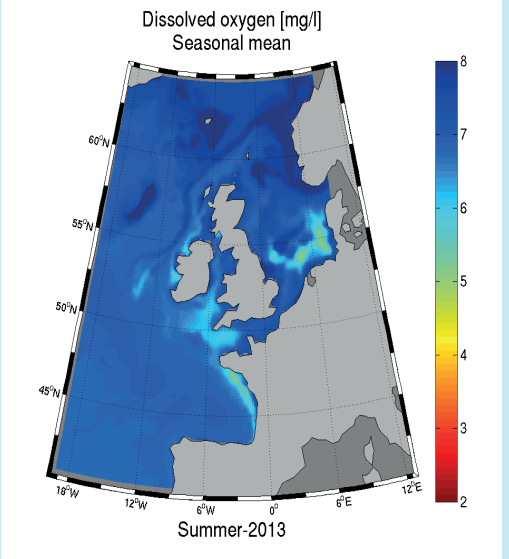
Monthly averages of ozone in the lower troposphere, processed from GOME-2 observations, an instrument on the MetOp-A platform. Ozone peaks in the Amazon and southern Africa are in response to seasonal biomass burning. NCEO researchers at STFC RAL Space create algorithms to generate ozone concentrations. Data assimilation experts at NCEO then use these products to drive models of the atmosphere. Credit: G.Miles, NCEO RAL.

NCEO researchers are discovering new ways to observe the critical chemicals, and are using satellite observations to conduct tests of climate-chemistry and chemistry-transport models.

While tropospheric ozone is a significant pollutant, stratospheric ozone protects us from harmful radiation from the sun. Our work contributes to the World Meteorological Organization's assessments of ozone depletion.



Methane is emitted from a variety of sources including wetlands, rice-paddies, cattle and fossil fuel burning. NCEO scientists use GOSAT measurements of methane and compare them to model simulations (right). By comparing the observations to the model predictions, we can see where the model is different and learn how to improve the model. Credit: R. Parker, NCEO-University of Leicester.



Dissolved oxygen is a crucial indicator of marine ecosystem health: excessively low levels can kill aquatic life. The map shows estimates of dissolved oxygen concentrations (mg/l) in summer 2013. Concentrations fell below the 6 mg/l threshold defined by the OSPAR commission in some areas. These estimates were obtained by assimilating EO data of ocean colour from ESA's CCI into an ecosystem model of the North East Atlantic. Credit: S. Ciavatta, NCEO-PML.

"NCEO provides the platform for creative, inter-disciplinary work, coupling expertise to tackle current 'big science questions' within the Earth System."

Dr Helen Brindley,
NCEO-Imperial College London.

Merging data for realistic predictions

Observations and computer models can give us interesting information about the Earth. But both of these sources of information are incomplete. There are always gaps in the measurements – a satellite might pass over a location just once a day for example - and models are never perfect representations of reality. Data assimilation helps us make the most of our observations and our models by combining the information each of them carries in optimised ways.

To combine data and models in the best way possible, we have to know how accurate each information source is to judge which to rely on most heavily at a particular location and time. We have to take account of the distortions that can affect our observations. These can range from noise in the electronics of the instrument, to the satellite's orbital characteristics. The accuracy of our model forecast depends on both the accuracy of the model itself – due to missing physics, for example – and the accuracy of the data that drive the model. Knowing the accuracy of both we can combine observations of multiple geophysical variables with model predictions to get the best possible description of what is going on.

expertise provides NCEO with an excellent capability for scientific assimilation and for applications to a wide range of data-model problems.

We also work closely with researchers at operational centres like the Met Office and the European Centre for Medium-range Weather Forecasts (ECMWF) to improve on the approximations in their data-assimilation systems that are essential for future weather and climate modelling.

> **"Over recent decades, satellite data has revolutionised our ability to monitor change on our planet. NCEO was set up to ensure that we get maximum value from that data for both the scientific community and society as a whole."**
>
> Professor Duncan Wingham,
> NERC Chief Executive.

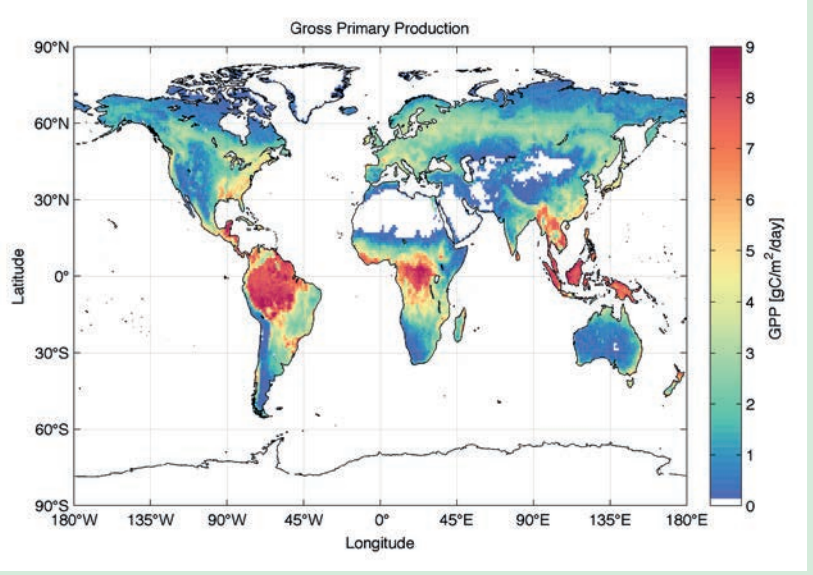
> **"As a computational task, data assimilation can quickly get out of hand, so we work with mathematicians to find better approximations to the problem."**
>
> Professor Peter Jan van Leeuwen,
> NCEO-University of Reading.

Data assimilation is a key ingredient for environmental model forecasting. For example, Met Office forecasters collect millions of observations and assimilate them into a highly complex numerical model every six hours to produce an estimate of the best state from which to make the next forecast.

At NCEO we are developing cutting-edge techniques in data assimilation and helping to strengthen scientific capacity in the UK for implementing next generation data assimilation algorithms. Data assimilation helps us identify how to improve models of the Earth System, by identifying mismatches between the data and the model predictions. Key challenges include how to treat uncertainty in the data and models of the Earth System, how to couple together systems with very different scales in both time and space, non-linear systems, and assessing the impact of novel observing systems.

At NCEO, staff involved in data assimilation work closely with others involved in satellite retrievals and in modelling. This integrated

Calculating the productivity of vegetation



NCEO researchers use global datasets of climate, leaf area, tropical carbon stocks and global soils maps to constrain a model of the carbon cycle. The image shows the estimated average daily rate of photosynthesis, globally, for the period 2000-2010. Values for photosynthesis, also known as 'gross primary production', are estimated here using novel data assimilation methods. The end result is a complete description of the stocks and flows of carbon through terrestrial ecosystems, and understanding of the processes that drive the flows, like photosynthesis. We can use our results to evaluate and improve more complex models of the Earth System that are used to predict the interactions of climate change with the carbon cycle. Our data assimilation scheme produces a full carbon budget and process parameter estimates with geographical resolution of 1 degree x 1 degree, calculated monthly, with error statistics, so this map represents only a small fraction of the output we have produced. Image credit: A. Bloom and M. Williams, NCEO-University of Edinburgh.

The Rt Hon Elizabeth Truss MP, UK Environment Secretary, visits CEDA in June 2015. Our data centre benefits UK scientists through open access to satellite data hosted on the JASMIN computing infrastructure, including Copernicus imagery for which CEDA is the UK academic hub. Credit: STFC.

Working with public sector agencies and government

NCEO links up the scientific supply chain, and in doing so gives the UK a unique advantage for accelerating progress in the satellite technology sector.

The public sector use of EO data is large and increasing. The meteorological agencies, Met Office and the European Centre for Medium-range Weather Forecasts (ECMWF) have major interests in using Earth Observation techniques to improve weather forecasting and broader environmental services including climate, ocean forecasting and analysis of atmospheric composition. The Met Office is a major NCEO partner for evaluating Earth System and climate models and driving forward improvements to these models using satellite data. The Joint Weather and Climate Research Programme (JWCRP) facilitates this partnership.

NCEO is playing a proactive role assisting policymakers and their agencies to use EO to achieve a range of outcomes:

- Evidence-based policymaking: creating and maintaining a strong evidence base for environmental decision making;
- Policy delivery and evaluation: developing monitoring and surveillance capability to deliver policy goals;
- International engagement: supporting, representing and promoting UK policy interests within international EO fora, such as the Intergovernmental Panel on Climate Change (IPCC), Group on Earth Observations (GEO), the Global Climate Observing System (GCOS) and the Global High Resolution Sea Surface Temperature (GHRSST) group.

The advent of the European Copernicus programme provides a wealth of opportunities in support of the UK government's Department for Environment, Food and Rural Affairs (DEFRA) and its network of partners in areas such as biodiversity, agriculture, catchment management and water quality. NCEO is supporting DEFRA to realise open access to satellite data and make the most of EO-related capabilities.

> **"Access to NCEO's scientific knowledge and expertise is of key importance and we welcome NCEO's input to Defra's Earth Observation Centre of Excellence. We look forward to working closely to secure the benefits for the UK from the EU Copernicus Programme, building on our co-operation for the international Group on Earth Observations (GEO)."**
>
> Dr Ian Davidson,
> Deputy Chief Scientific Adviser, DEFRA.

Earth Observation for forests and vegetation

Our planet's biosphere is an important natural resource whose strength and vitality we need to understand and monitor. At NCEO we are investigating land-based resources, in particular the storage of carbon in forests, as well as ocean-atmosphere carbon exchange. The amount of carbon stored in forests depends on diverse factors, including forest health, the structure of vegetation, heat fluxes and evapotranspiration. We can track these factors using satellite instruments that measure aspects such as vegetation fluorescence and albedo.

Forests are a vital planetary resource and key to achieving global sustainable development. They help mitigate against climate change, prevent desertification and land degradation, and reduce poverty. Globally they cover 31 per cent of land area, contain over 80 per cent of terrestrial biodiversity and store more carbon than the atmosphere. [1] Nevertheless, deforestation remains high in many countries and in 2004-2013 it accounted for about 8 per cent of all greenhouse gas emissions from human activity. [2]

To combat deforestation, multilateral climate funds will increasingly incentivise preserving or re-growing forests. These include the UN's Reducing Emissions from Deforestation and forest Degradation plus conservation (REDD+) programme, and the Clean Development Mechanism.

Counting carbon in forests

EO has an increasingly important role to play in support of forest management. The Essential Climate Variables that relate to forest stocks are used by the Met Office and European Centre for Medium-range Weather Forecasts (ECMWF) for climate modelling, but also by the UN, national mapping agencies, and commercial companies providing services for the carbon market.

Whilst cloud frequently obstructs satellites' view of tropical forests, relatively new radar instruments can 'see through' mist and cloud, giving scientists an unrestricted view to spot where forest has been destroyed by illegal logging. NCEO researchers are working with the international partners such as the European Space Agency (ESA) to map global forest biomass stocks from optical and radar satellites.

NCEO work monitoring the impacts of fire, deforestation and degradation has been critical to plans for a new, purpose-built satellite to measure the carbon stocks contained in the Earth's forests with unprecedented sensitivity. Through a proposal led by Professor Quegan, BIOMASS was selected as the 7th ESA Explorer satellite and will be launched in 2020.

1 https://sustainabledevelopment.un.org/content/documents/2291Forest%20Issues%20Brief_FINAL.pdf
2 Global Carbon Project http://www.globalcarbonproject.org/carbonbudget/14/hl-compact.htm

Credit: Neil Palmer/CIAT for Center for International Forestry Research (CIFOR).

Developing new data products

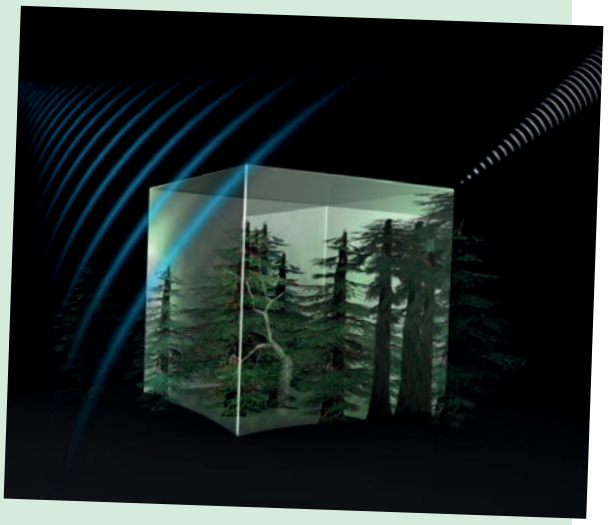
Researchers at NCEO have used satellite measurements of the Earth's reflectivity, known as 'surface albedo', to develop new data products for monitoring forest productivity and change on a regional and global scale. Bright snow and ice have a high albedo, meaning they reflect a larger proportion of incoming solar radiation back into space, while green areas like forests and fields have a much lower albedo. NCEO scientists have worked with their partners to create the first gap-free, 1 kilometre resolution maps of Earth's land surface with an uncertainty estimate for every pixel. The maps are useful for NERC scientists and a variety of agencies, including the UK Met Office, where they are used to update land surface information in weather models, resulting in more accurate weather predictions and climate forecasts.

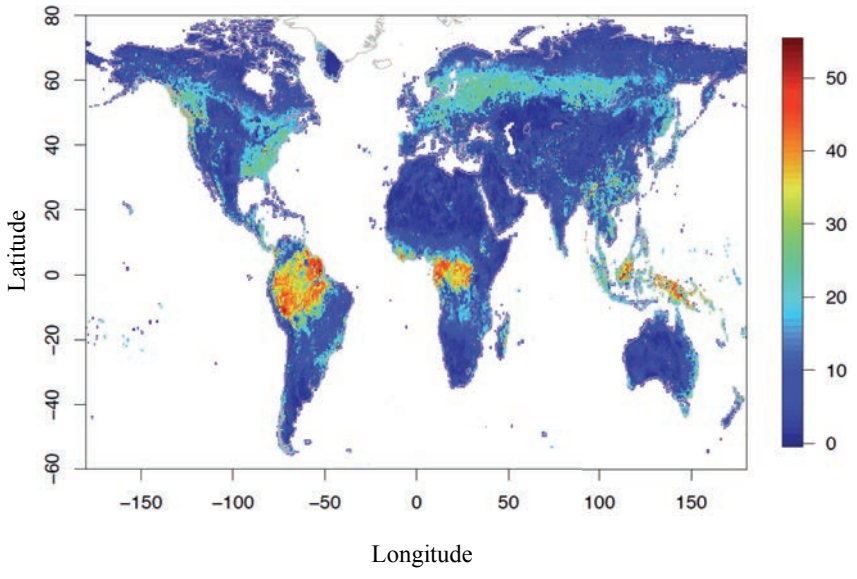
Products for albedo illustrate how we can build better data sets for vegetation behaviour, describing growth, greenness and cover, and account for the effects of fire disturbance. NCEO scientists are integrating soil moisture and land surface temperature with these forest data sets to derive further fundamental parameters to use in land surface models. This work gives scientists a better understanding of how the models capture vegetation change, and improves their predictive ability. We are also researching how our integrated data approaches can constrain land-surface interactions in climate models.

NCEO researchers collaborate directly with the UK Forestry Commission, using EO data to improve the UK National Forest Inventory. This has led to the first global map of vegetation height derived from the ICESat GLAS satellite. In Europe this dataset is used to forecast the risk that high winds pose for forests.

BIOMASS

The BIOMASS mission will provide unprecedented global measurements of biomass and height in the Earth's forests, at a scale of 200 meters, to support forest management and inform climate treaties and carbon trading. NCEO researchers are working with ESA to guide the project science. We are also measuring tropical forest plots using TLS techniques to validate data for the BIOMASS mission, due to launch in 2020.





Vegetation height from the ICESat GLAS satellite, showing major forests of the world. Low vegetation heights in coastal regions indicates land conversion, as well as the sharp edges at the southern borders of northern forests. Vegetation height data can be used to estimate the amount of carbon stored above ground. Credit: S. Los, Swansea University.

Ground-truth from laser scanning

Terrestrial laser scanning (TLS) involves taking millions of laser measurements of a tree and combining them to build up a 3D picture of the tree with millimetre accuracy, enabling researchers to estimate the tree's mass and thus its carbon storage.

TLS techniques feed into NCEO work on new satellite products, enabling our researchers to validate the satellite data and determine the carbon stocks of forests with unprecedented accuracy.

It also enables researchers to develop products to assess the impact of degradation and drought on forest carbon content.

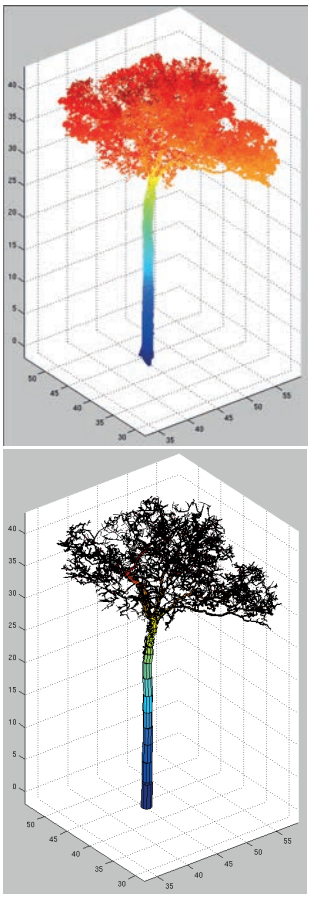
For example, NCEO is working with NASA on their forthcoming LiDAR instruments, which measure distance remotely by illuminating a target with a laser and analysing the reflected light. GEDI is due to go on the International Space Station in 2019, and ATLAS will be on the ICESat-2 mission to be launched in 2017 to improve estimates of forest height and carbon stocks.

> **"We can now turn highly-accurate laser measurements, comprising millions of 3D laser points, into estimates of tree mass."**
>
> Dr Mat Disney,
> NCEO-University College London.

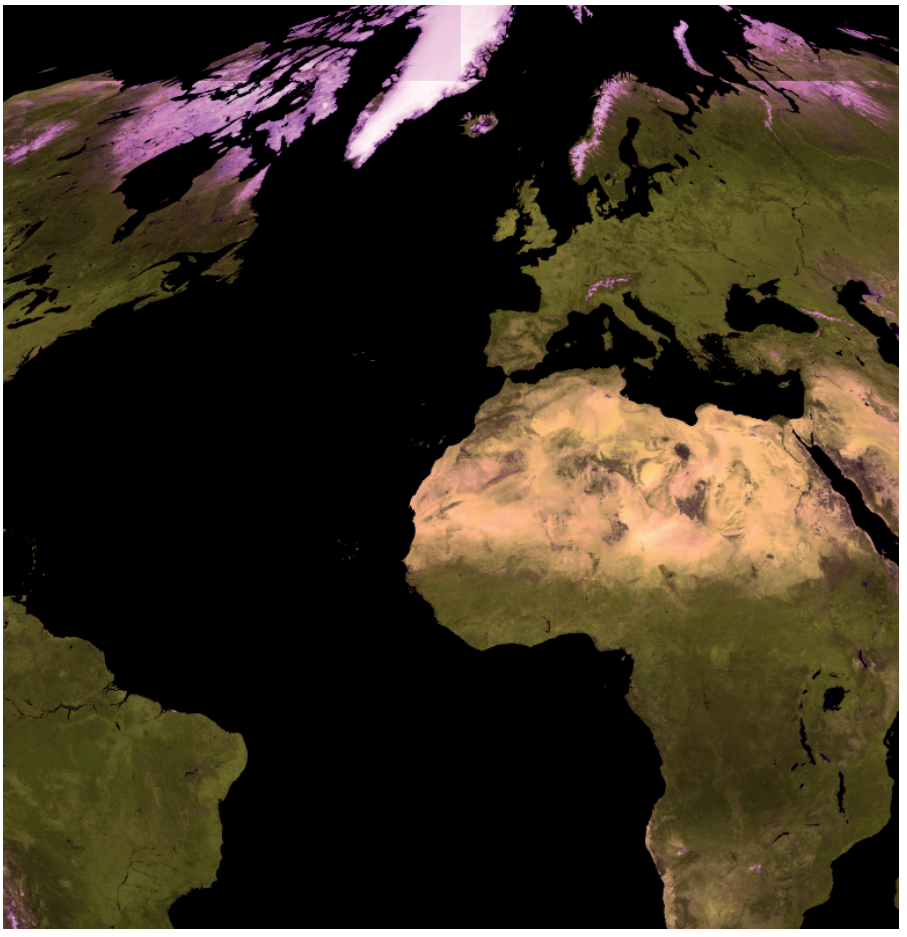
Earth Observation for forests and vegetation

Building 3D forest simulations

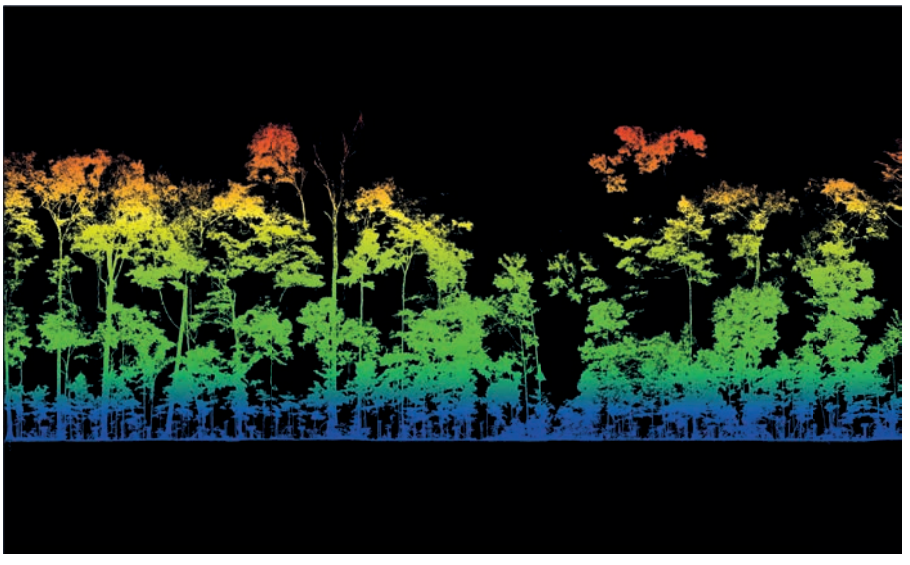
To understand how radiation interacts with vegetation and affects our satellite observations, NCEO researchers are building 3D models of forests, constructed from terrestrial LiDAR data. These highly-detailed 3D models are used to explore the physics of the LiDAR reflective process, probe tree canopy structure and function, model the impact of fire, and test and develop other, simpler radiative transfer models. We welcome collaborations and have developed an open toolbox of 3D models and simulation tools. These tools are made available to the NERC and international communities, and, as part of our NCEO remit, we offer training and expertise to help people make best use of them.



The top image is the LiDAR point cloud for a single, large tree from a tropical forest plot in the Brazilian Amazon; underneath shows the 3D model reconstruction derived from the point cloud, which allows researchers to calculate the volume of the tree, and hence its mass, very accurately. Credit: M. Disney, NCEO-University College London and A. Burt, University College London.



A 'mosaic' of the global shortwave albedo data from the GlobAlbedo dataset, June 2005. Credit: GlobAlbedo team, J.P. Muller, MSSL, S. Kharbouche and P. Lewis, NCEO-University College London.



A transect of LiDAR data, around 5m wide, 100m long, through a piece of tropical forest plot in the Brazilian Amazon. The plot is undergoing severe drought, imposed as part of an ongoing 12-year experiment to test the impact of drought on the rainforest. Credit: M. Disney, NCEO-University College London and A. Burt, University College London.

> "The Satellite Applications Catapult regularly looks to NCEO scientists to provide innovative solutions to real world business problems – from Chilean vineyard monitoring to air pollution measurements in London."
>
> Professor Nick Veck,
> Head of CEO Office, Satellite Applications Catapult.

Working with business

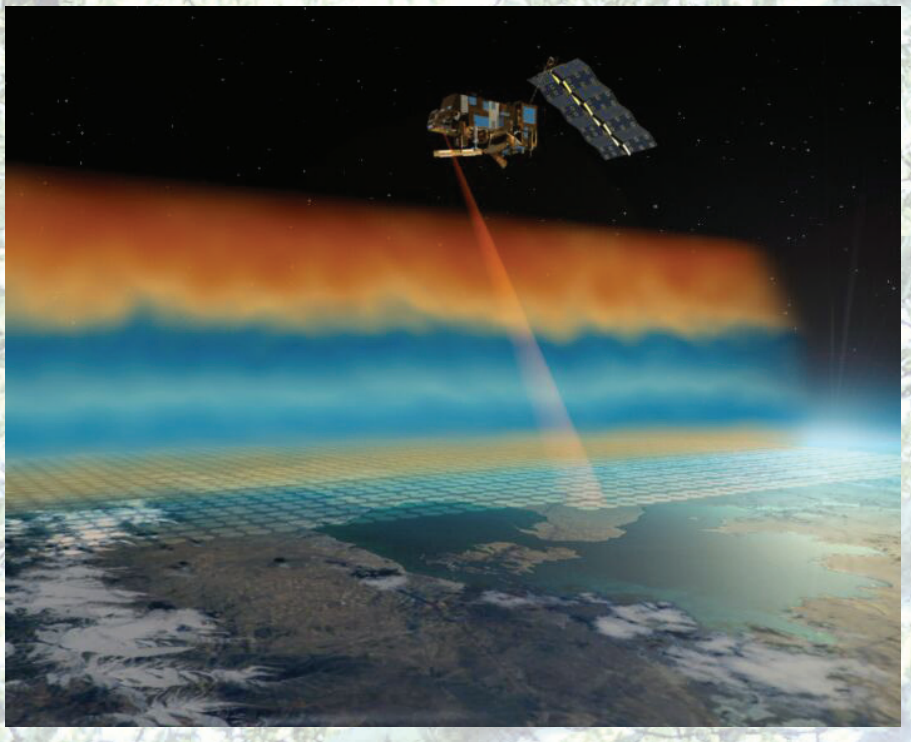
Satellite data are increasingly important in modern and emerging economies to support economic development and inform decision-making. The Space Innovation and Growth Strategy, an industrial study supported by NCEO, sets the UK the ambitious target of capturing ten per cent of the world market in satellite systems and services by 2030. This share of the market is worth £40 billion and equates to 100,000 new jobs. Services based on EO are key to this growth strategy. With its first-class scientific expertise, NCEO works with stakeholders nationally and internationally to support the UK's ambitions and meet the environmental challenges that face society.

NCEO supports the exploitation of NERC EO research by industry, often through collaborative projects initiated by space agencies, EC and government departments, including:

- Advice on the expert use of NERC EO data by key industrial sectors: for example applications for climate services, forestry and agriculture, and cities;
- Supporting expert use of NERC EO techniques including improved algorithms, quality control, and data assimilation;
- Expertise on requirements for new EO satellites and sponsorship opportunities for missions;
- Co-sponsoring MPhil and PhD students for joint research projects with industry.

We work with strategic partners to build 'impact alliances', these include the Satellite Applications Catapult; Leicester Embrace; Reading Institute for Environmental Analytics; and the British Association of Remote Sensing Companies.

> "NCEO is a vital link between academia and commerce in developing new commercial services, and in co-operation with industry, a strong influencer in setting national and European policy."
>
> Derek Greer,
> Chief Operating Officer, Telespazio VEGA UK Ltd.



Profiles of atmospheric gases produced using the IASI instrument on Metop. NCEO is supporting the implementation of such data processing systems by service providers such as the Met Office, the Copernicus Atmosphere Monitoring Service, and industry. Credit: ESA - AOES Medialab.

Understanding and monitoring hazards in the Earth System

Each year hundreds of millions of people around the world are affected by severe environmental hazards and natural disasters. These include weather-related hazards such as cyclones, droughts, floods and poor air quality, as well as earthquakes, tsunamis and volcanoes.

According to the IPCC Fifth Assessment Report, climate change is already affecting the nature of natural weather-related hazards, leading to more frequent, extreme events, and will likely exacerbate natural hazards in the coming decades. Economic losses regularly exceed £65 billion annually and are projected to double by 2030.

Fires from space

Enhancements in the severity and frequency of drought can increase the frequency and severity of wildfires and other types of vegetation burning, but so can changes in human behaviour, such as increased logging or burning of post-harvest crop residues. Landscape fires burn, on average, about 3.5 per cent of the global vegetated land area each year, equivalent to twenty times the area of the UK. In doing so they release enormous quantities of gases and aerosols, many of which have significant impact on Earth's atmosphere and climate system, including the air we breathe. Some wildfires also increase soil erosion and water contamination, yet vegetation fires are also vital components of the functioning of many global ecosystems, and play an important role in the carbon cycle.

The widespread nature of biomass burning, coupled with its unpredictability, variability and dependence upon both climatic and human influence, make EO essential to its study at both regional and planetary scales. Fortunately, the infrared instruments carried by polar orbiting and geostationary satellites are extremely sensitive to the intense thermal radiation emitted by burning vegetation. Work by NCEO researchers has exploited this capability, and has had a transformative effect on how we quantify and monitor biomass burning from space. We have led the way in exploiting data from geostationary satellites to develop Fire Radiative Power (FRP) datasets, from which fires burning across whole continents can be mapped and their emissions to the atmosphere quantified in almost real-time.

Extremely hot, dry conditions in parts of the Mediterranean in August 2007 preceded the Greek 'megafire' event pictured, where smoke from huge wildfires affected millions of European citizens. Fire events like these can be studied in detail, and their impact on air quality assessed, using the satellite-derived Fire Radiative Power (FRP) measures and datasets developed by NCEO-King's College London, who are part of the international team that have developed the Global Fire Assimilation System (GFAS) now used within the Copernicus Atmosphere Service. This allows wildfire atmospheric impact assessments to be made in almost real time, along with forecasts of air quality impacts for the next few days. Credit: M. Wooster, NCEO-King's College London. MODIS data courtesy of NASA.

FRP data feed into air-quality forecasting operations run as part of the Copernicus Atmosphere Service, and geostationary satellite detections are also used for fire response operations, for example in South Africa where they allow operators to take appropriate action to temporarily turn off power transmission to avoid damage from "flashovers" when fires burn close to high voltage transmission cables. Recently NCEO researchers have developed the first fire product from the Sentinel-3 mission's SLSTR instrument, which is expected to start to deliver operational FRP data to the Copernicus Atmosphere Service and others in 2016/17.

Prescribed forest burn conducted by the Ontario Aviation Forest Fire and Emergency Service Division (AFFES) and attended by NCEO–King's College London and the Canadian Forest Service. These types of field campaign enable scientists make measurements from the air to compare to field-data taken on the ground, and in this case, help validate the Fire Radiative Power (FRP) approach to monitor wildfires globally. Credit: L. Johnston, Canadian Forest Service.

Mapping air quality

Urban growth can create its own problems, including an increased risk of air pollution. By 2050, seventy per cent of the world's population is expected to live in urban areas. The impact on air quality depends not only on direct emissions of pollutants but also on how these emissions interact with atmospheric circulation and chemistry.

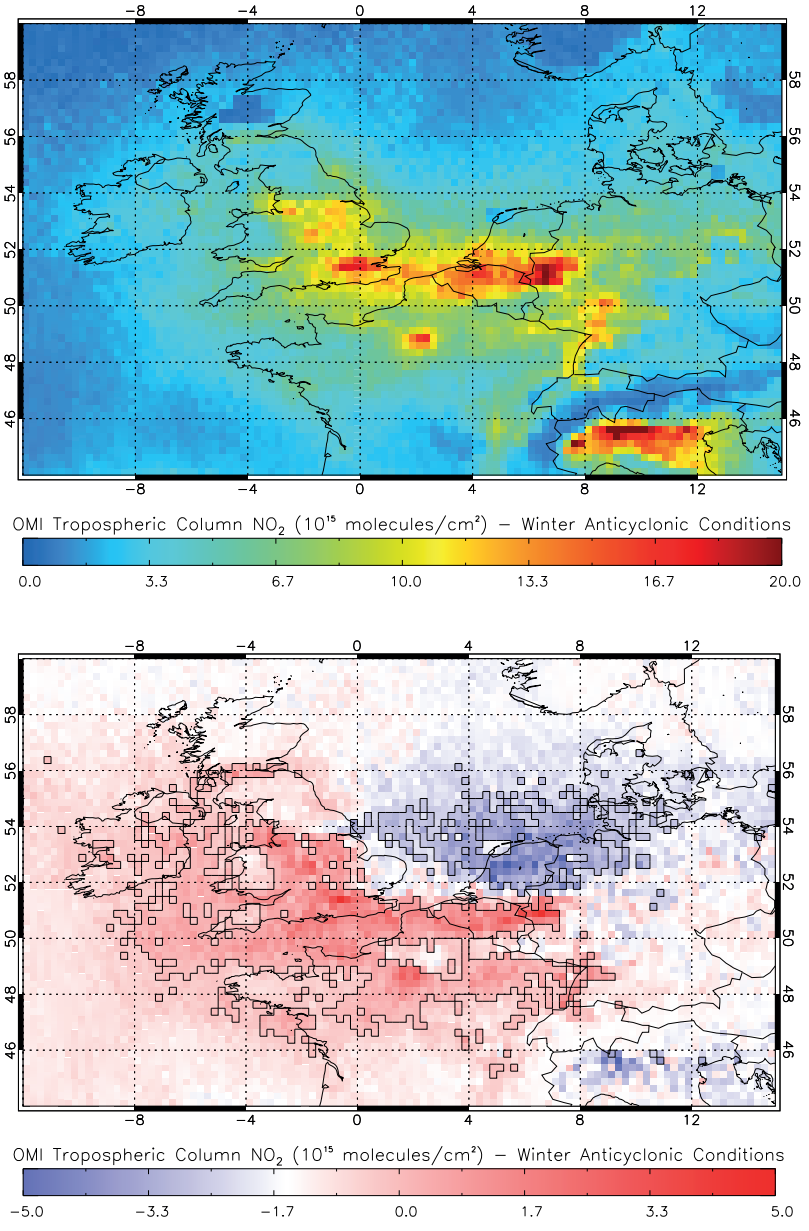
Improvements in EO of atmospheric composition mean that regional air quality can now be observed from space. NCEO, working in collaboration with the UK Met Office, are using measurements of the air pollutant nitrogen dioxide to examine how large-scale weather systems affect air quality. This work at NCEO has led to improvements in the Met Office model used to forecast daily air quality in the UK.

New data from Sentinel-5P, and later from geostationary orbit, will allow NCEO scientists to demonstrate further characterisation of pollutant emissions, pollution transport and chemistry.

Sentinel-3A in the cleanroom at Thales Alenia Space in Cannes, France. UK scientists have made a huge contribution to the Sentinel-3 programme by designing, calibrating and developing algorithms for the Sea and Land Surface Temperature Radiometer (SLSTR) instrument, which will measure temperatures to an accuracy of better than 0.3 K. NCEO scientists have helped develop the SLSTR data products, and NCEO CEDA is the UK hub for archiving and distributing data from the Sentinel programme. Credit: ESA–A. Le Floc'h.

Monitoring harmful algal blooms

Harmful blooms of algae in the seas around the UK and Europe can cause significant economic losses to the aquaculture industry and present a threat to human health. The Scottish Executive estimated that 2.2 million salmon were killed by algal blooms between 1999 and 2002. Research algorithms developed at PML with NCEO support, and ocean colour images produced in near-real time by our NEODAAS facility contribute to research efforts into these blooms. This scientific supply chain is planned to be used in the BBSRC/NERC Sustainable Aquaculture programme in Global Food Security.



Urban hotspots of air pollution in London, Paris and Italy's Po Valley can be clearly seen during anticyclonic conditions, as these stable weather systems enhance the accumulation of nitrogen dioxide. The top image shows nitrogen dioxide under winter anticyclonic conditions for the years 2005 to 2011; the bottom image shows the difference of these results with respect to the wintertime average. A better understanding of the relationships between air quality and large-scale weather systems helps scientists improve regional air quality models to provide more accurate public forecasts, and so that the relevant authorities are aware of the potential impacts of these events. Credit: R. Pope, NCEO-University of Leeds.

Rapid response

The NERC Earth Observation Data Acquisition and Analysis Service (NEODAAS) facility offers a rapid-response capability as an EO data and information service, unique in the UK in its support of both the environmental research and wider decision-making communities. The facility can respond to disruptive events within a few hours. With a spatial resolution down to 250 metres, NEODAAS satellite imagery and datasets have helped scientists identify, understand and monitor rapid changes and advise governments, the public and other stakeholders about how to respond to disruptive events effectively and appropriately.

NEODAAS data and imagery regularly appear in the UK media, and support short-term observations and long-term trend analysis of, for example, weather-related events in the UK, Europe and worldwide, harmful algal blooms and volcanic eruptions.

NEODAAS image of a storm on 12th February 2014, used as a front cover for many UK newspapers.

Sentinel-1 A is the first Sentinel in orbit and is focussed on terrestrial and ice monitoring using synthetic aperture radar. NCEO scientists are supporting the community to access and utilise the data. The Sentinel satellites will be an important asset for UK environmental science. Credit: ESA/ATG medialab.

Working with Space Agencies

NCEO has the responsibility, on behalf of NERC, for interfacing day-to-day with the UK Space Agency to convey the needs and aspirations of the whole NERC community. NCEO ensures that the NERC community has supported access to satellite data, and acts as a champion for science in the arena of space technology development. NCEO supports joint activities coordinated by the UK Space Agency, such as the 'Climate Data from Space' stakeholder group.

The chief UK research satellite programme for EO is through UK Space Agency investment in the European Space Agency (ESA) Earth Observation Explorer Programme (EOEP). UK scientists from NCEO and other NERC centres and universities serve on the ESA Earth Sciences Advisory Committee. NCEO researchers have played leading roles in successful proposals for ESA missions (CryoSat currently, EarthCARE and Biomass to come) and are leading the scientific exploitation of data that these missions generate, for example through ESA's Climate Change Initiative, and the GLOB-series of projects to develop global datasets of different environmental parameters.

> **"I look to the NCEO not only as a focal point for the community doing first class academic research involving satellite data, but also for excellent examples of innovation and data management."**
>
> **Beth Greenaway,**
> Head of Earth Observation at the UK Space Agency.

Nearly all of the satellites that the UK government has invested in are run by European entities, including operational systems such as the European Commission's Copernicus Sentinel programme, and EUMETSAT's meteorological satellites. These are increasingly important for scientific research, including science campaigns and long-term observations. NCEO staff will provide science support to the Sentinel missions, particularly Sentinel-3 and Sentinel 5-P, and access to data through CEDA and CEMS. NCEO scientists are increasingly working in collaboration with EUMETSAT to apply and exploit the best scientific research algorithms.

NCEO's collaborations extend globally, for example NCEO scientists are involved in a number of NASA-led missions as co-investigators, including OCO-2, collecting data on atmospheric carbon dioxide, and GPM, to monitor global precipitation. We believe that UK science is best served by expert co-operation with the world's leading space agencies, scientists and missions.

Our dedicated infrastructure

Field Spectroscopy Facility (FSF)

www.fsf.nerc.ac.uk

NCEO provides governance and scientific oversight of NERC's Field Spectroscopy Facility based at the University of Edinburgh, which provides optical sensing expertise and equipment for assessing the detailed spectral reflectance properties of vegetation, rocks, soil and water under a host of different observing conditions. Ground-based spectral measurements are used to study critical environmental phenomena, such as the photosynthetic activity of vegetation and the changing albedo of snow and ice under different environmental conditions. They are also important for developing and validating the EO algorithms and data products stemming from satellite and aircraft missions. These types of remote sensing observations underpin a wide variety of studies in NERC's science programme.

Open path gas analysis of savannah grassland fire, South Africa. Credit: M. Wooster, NCEO-King's College London.

The FSF equipment is calibrated, high-resolution and quality-assured, and includes field spectroradiometers measuring from the visible to the shortwave infrared, sun photometers, an FTIR spectrometer and equipment for measuring underwater inherent and apparent optical properties. We also have a calibration and test laboratory that the community can use to characterise field instruments, which supports the development of new equipment. These ground-based instruments, calibration tools and measurement expertise are also used to ensure the quality and consistency of measurements made by the NERC Airborne Research and Survey Facility (ARSF), which conducts airborne remote sensing campaigns in the UK, Europe and worldwide.

Caption: FTIR spectrometer gas analysis of boreal forest fire smoke plume observed by sun occultation, Western Ontario, Canada. Credit: FSF, University of Edinburgh and NCEO.

NERC Earth Observation Data Acquisition and Analysis Service (NEODAAS)

www.neodaas.ac.uk

NEODAAS is a 24-hour / 7-day per week satellite data reception and processing facility based at the University of Dundee Satellite Receiving Station and Plymouth Marine Laboratory Remote Sensing Group. It provides near-real-time and archive data processing to support UK research scientists undertaking research anywhere worldwide. Notably, near-real time information derived from within minutes of satellite data reception are used to guide marine research cruises and aircraft campaigns to the most scientifically valuable locations, allowing NERC scientists to optimise their plans.

NEODAAS receives direct-broadcast data from a wide range of polar-orbiting missions, currently including AVHRR, MODIS and VIIIRS, and has collected long-term archives of AVHRR, CZCS, MODIS, SeaWiFS and VIIRS data. NEODAAS has global coverage for geostationary satellites, including GOES, MTSAT, SEVIRI and VISSR, and automatically archives all received data, making it available for view over the web. There are about 7,000 new user registrations and 4.5 million image downloads per year.

> **"The data was brilliant in helping us to validate our model and the help that accompanied it was sublime! This service has been seamless and you responded to all my queries extremely speedily which was extremely helpful."**
>
> Dr Ashley Brereton,
> National Oceanography Centre.

NEODAAS downloads global data directly from space agencies such as ESA, NASA and NOAA, producing both time-series of 'standard' environmental metrics such as ocean colour and sea-surface temperature, but also bespoke scientific products tailored to individual users, who need not be EO experts. The NEODAAS data portal provides options for data visualisation, and can give advice and guidance to such users on how best to interpret the EO datasets.

NEODAAS Dundee

Our dedicated infrastructure

Centre for Environmental Data Archival (CEDA)

www.ceda.ac.uk
www.jasmin.ac.uk

NCEO offers access to data, alongside massive storage, processing and analysis capabilities, through the Centre for Environmental Data Analysis (CEDA) on the JASMIN computing infrastructure. JASMIN hosts a range of activities, including the Climate and Environmental Monitoring from Space (CEMS) facility, to support the analysis requirements of the UK and European climate and environmental science community.

CEDA hosts and operates a number of NERC environmental data centres for atmospheric, EO, and solar system science. The EO data centre holds and provides online access to new datasets created by NERC scientists, but also maintains copies of large datasets produced by other agencies, including data from ESA, EUMETSAT, NASA and NOAA. It holds key climate data sets from the UK and the ESA CCI programme, opening up extended possibilities for model evaluation.

The CEDA EO data store on CEMS is the largest EO data archive in the UK, with over a Petabyte of satellite data and related data products. The archive contains over two decades' worth of satellite data from a range of satellite missions, whilst the data from the NERC ARSF aircraft campaigns extends back to 1982.

CEMS is run in collaboration with the Satellite Applications Catapult at Harwell to support scientists and industry working together to promote commercial exploitation of EO data. It offers access to collaborative workspaces, hosted processing, high performance computing, and a cloud computing environment that NERC scientists can access remotely.

CEDA is the UK academic data hub for ESA's Sentinel missions, with responsibility for storing data and providing access to it for the science community. Sentinel data volumes are significantly higher than previous satellite missions: up to 8 Terabytes per day significantly increases the archive volume by several Petabytes per year.

CEDA is located at the Science and Technology Facilities Council's Rutherford Appleton Laboratory in Oxfordshire.

Other NCEO capabilities

In addition to our coordinating role in the above facilities and data centres, NCEO is a member of the steering committee of the NERC Airborne Research and Survey Facility (ARSF), which provides a remote sensing capability targeted at the surface and lower atmosphere.

NCEO is implementing instrumentation to contribute to the network of ground-based Fourier Transform Spectrometers, called TCCON, which measures quantities of atmospheric carbon dioxide, methane and other gases at about 18 sites around the globe to validate satellite observations of these gases.

Similarly, the FSF Cimel sun photometer is part of the global AERONET sun photometer network that provides information on atmospheric aerosols around the globe. In addition to these publically available data, various other EO measurement capabilities within NCEO institutions are available to be used collaboratively with the wider research community, including Fourier Transform IR Spectroscopy, terrestrial laser scanning and IR imaging.

NCEO institutions have developed a range of retrieval algorithms, data assimilation models, analysis tools and underpinning data that can be used to either simulate or best exploit key EO datasets. The expertise in these and other widely used third-party tools are available to the research community in the UK and internationally.

NCEO researchers test GHOST: an aircraft-based instrument for observing atmospheric carbon dioxide and methane. The instrument can be flown near interesting emissions sources, such as power plants, city centres or wildfires, allowing researchers to measure their impact on the environment. Credit: D. Pearson, UK Astronomy Technology Ctr.

The scientists involved in the CAST-ATTREX flight campaign to track changes in the upper atmosphere. The NCEO-led GHOST instrument was flown on the NASA Global Hawk during the campaign in March 2015. Credit: D.Fratello, NASA Armstrong Flight Research Centre.

Keeping the UK at the forefront of world-class research

NCEO Training Support

We provide a range of tools and support to EO users across the globe, from ecologists and climate modellers to forestry researchers and policy-makers. Our training workshops include how to use our data, analysis tools, and modelling software, and we make our training materials freely available online on our website (www.nceo.ac.uk).

NCEO has trained over 50 PhD students to date, in projects ranging from mapping ice sheets to understanding climate variability. NCEO can host MPhil and PhD students either within its constituent research groups or as a CASE partner. We also provide short training courses in EO topics - recent examples include data assimilation and field/airborne spectroscopy and terrestrial radiative transfer - as well as teaching at summer schools, such as the EO summer schools run by the European Space Agency (ESA), and contributing to collaborative training courses. For example NCEO members made key contributions to the Massive Open Online Course ('MOOC') 'Climate Data from Space' MOOC, funded by ESA and developed by the company Imperative Space.

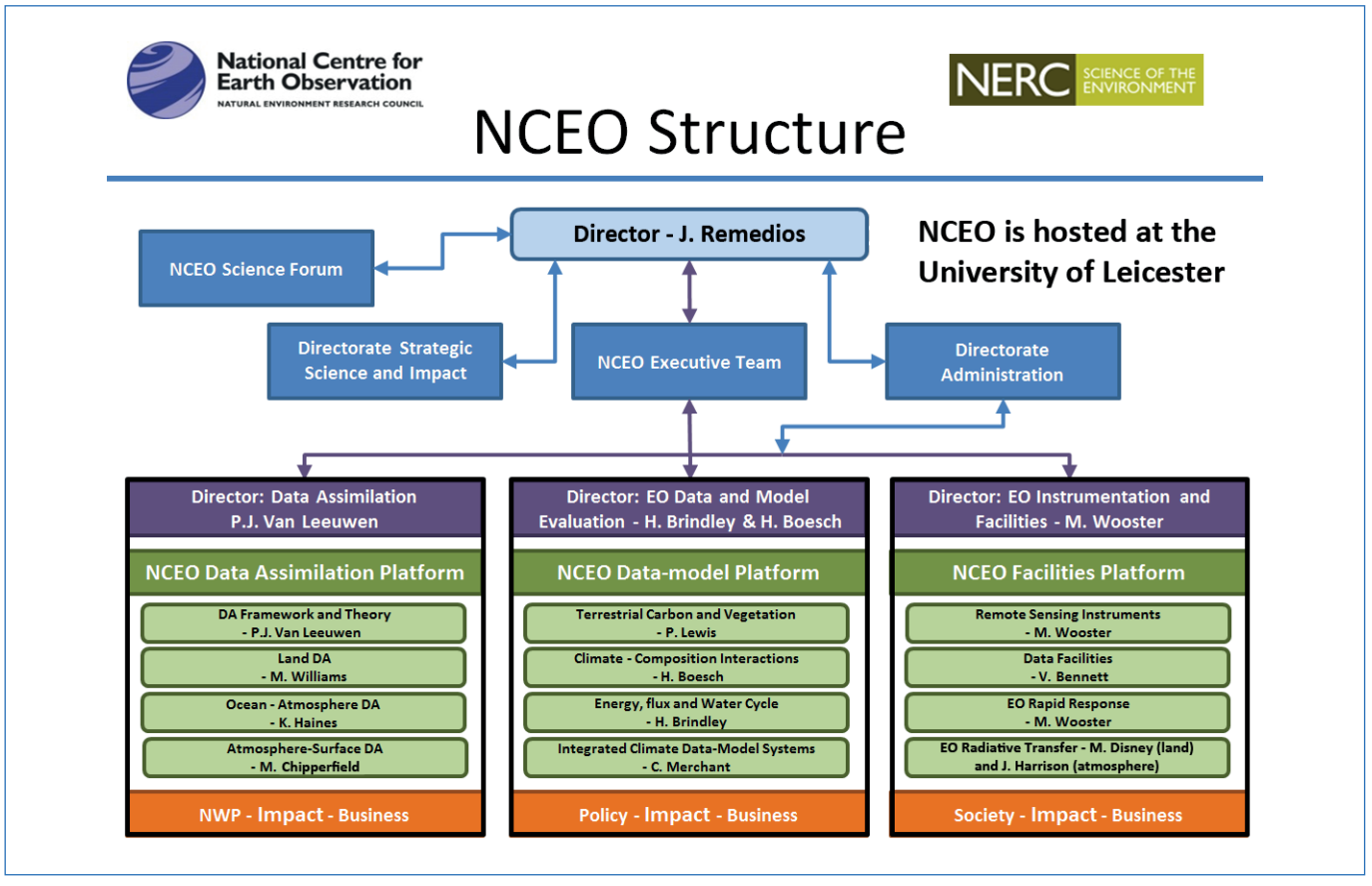
Our schools outreach programme introduces students and the general public to the work of NCEO through activities or demonstrations at open days, festivals and other events designed to showcase the work of scientists, such as the Leicester BBC Stargazing live event. A suite of teaching materials called 'EO Detective' guides teachers in the use of astronaut photography of the Earth, satellite images and EO data to deliver aspects of the National Curriculum for all key stages. Links to these are available on our website.

> **"The most rewarding aspect of working in EO is the opportunity to apply interesting physics and cutting-edge measurement technologies towards a better understanding of our environment and how it is changing as a result of human actions."**
>
> Dr Neil Humpage,
> University of Leicester.

In 2015 Britain's first ESA astronaut Tim Peake will start his six-month mission to the International Space Station. NCEO is developing Tim Peake learning materials to help teachers use space as an inspiring context for learning in the classroom.

NCEO structure

NCEO's chief capabilities are shared between five scientific units, additional core scientists located at specific research organisations, two scientific facilities, and one data centre. The NCEO Directorate is located with the Director, Professor John Remedios, at the University of Leicester, and at the University of Reading. We organise ourselves according to three broad scientific activities: Data Assimilation, EO Data-Model Evaluation, and EO Instrumentation and Facilities. These are shown as divisions shown below, each one having divisional directors and with key capabilities and infrastructure associated with each area (the 'platforms'): the platforms serve as vehicles for interactions within NCEO and with the wider NERC science community.



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